Athena Sustainable Materials Institute

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A Life Cycle Assessment of Ceramic and Porcelain Tiles and Ceramic Sanitarywares Manufactured by RAK Ceramics

This project report and its results are used to support the development of Environmental Product Declarations for Ceramic and Porcelain Tile, and Ceramic Sanitarywares.

Comissioner: RAK Ceramics P.J.S.C.

Construction Industry Consultant: Grey Matters Consultancy

EPD Program Operator: ASTM International

Prepared by: The Athena Sustainable Materials Institute

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Acronyms and Abbreviations

Btu	British thermal units
C2G	Cradle-to-Gate
CED	Cumulative Energy Demand
CF	Characterization Factor
CFCs	Chlorofluorocarbons
CFC-11	Trichlorofluoromethane
CO_2	Carbon Dioxide
EPDs	Environmental Product Declarations
eq	Equivalent
G2G	Gate-to-Gate
GWP	Global Warming Potential
HHV	Higher Heating Value
IC	Impact Categories
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
kg	Kilogram
kJ	Kilojoules
km	Kilometer
kWh	kilowatt hours
lbs	pounds
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
MJ	Mega joule
m^3	cubic meter
N	Nitrogen
NO_x	Nitrogen Oxides
O_3	Ozone
PCR	Product Category Rules
$PM_{2.5}$	Particulate Matter less than or equal to 2.5 micrometers in diameter
PM_{10}	Particulate Matter less than or equal to 10 micrometers in diameter
SO_2	Sulfur dioxide
VOCs	Volatile Organic Compounds
yd^3	cubic yard

1 General Study Aspects

Commissioner of the LCA project report and EPD	RAK CERAMICS P.O Box 4714 Ras Al Khaimah, UAE
External LCA Practioner	Athena Sustainable Materials Institute
Date/version	January 2021 Version 1.0

This study was conducted in accordance with ISO 14040:2006, ISO 14044:2006 and ISO 21930:2017. Also, this study is in line with the requirements of the following product category rules (PCR):

- IBU PCR Part A: Calculation Rules for the Life Cycle Assessment and Requirements on the Project report with reference to EN 15804+A2:2019 – Version 1.0.
- IBU PCR Part B: Requirements on the EPD for ceramic tiles and panels – Version 1.1
- IBU PCR Part B: Requirements on the EPD for Sanitary ceramics – Version 1.0

The Life Cycle Assessment was performed in agreement with the requirements of these Product Category Rules with reference to EN 15804 +A2:2019.

This project report has been commissioned with the intent to support the development of Environmental Product Declarations in accordance with ISO 14025 and the governing PCR.

This LCA project report was critically reviewed as per ISO 14040/44:2006 and the reference PCR requirements. The critical review report and responses to review comments is available from RAK Ceramics upon request.

This life cycle assessment was independently verified in accordance with ISO 14044 and the reference PCR by:	Name and affiliation for representative Thomas Gloria, Ph.D., Industrial Ecology Consultants LCACP ID: 2008-03

2 Study Goal

This project was initiated by RAK Ceramics P.J.S.C. to develop EPDs for ceramic and porcelain tiles and sanitaryware made vitreous ceramics and fine fired clay ceramics produced at their Ras Al Khaimah factory. The goal of this study is to provide information to support the development of these EPDs.

2.1 Intended Applications

The EPDs developed from this study is intended for use in Business to Business (B-to-B) communication. The EPDs reflect production weighted average products within the product lines as manufactured by RAK Ceramics P.J.S.C.

2.2 Intended Audience

The intended audience for this LCA project report is RAK Ceramics P.J.S.C. and the verifier of the subsequent EPDs. The intended audience for the EPD, for which this LCA project report serves as the reference document, include RAK Ceramics P.J.S.C.'s customers, architectural, engineering, and specifying professionals, LCA practitioners and tool developers, academia, governmental organizations, policy makers and other interested value chain parties who require reliable information on the environmental impacts of ceramic products.

The target market for the subsequent EPDs is worldwide.

2.3 Comparative Assertions

This LCA project report does not include comparative assertions; however, it and the subsequent EPDs may lead to future comparative studies intended to be disclosed to the public. LCAs and EPDs not covering *all* life cycle stages or based on a different PCR are examples of studies and EPDs offering limited comparability.

3 Study Scope

3.1 Product Description

This LCA project report includes results for four declared products, ceramic and porcelain tiles and vitreous and fine fired clay sanitary ceramics.

Table 1: Product Description			
Product category	**Declared Products**	**Application**	**Production**
Tiles	Ceramic Tiles	Floor and wall tiles for internal or external use.	Tile products are mixtures of predominantly clay and other natural occuring minerals that have been mixed with water and fired in a high temperature kiln. There are no hazardous or dangerous substances contained or released from the products.
	Porcelain Tiles	Floor and wall tiles for internal or external use.	
Sanitary ceramics	Vitreous China Ceramics	Water closets & tanks, Wash basins & pedestals, Urinals for internal use.	Sanitaryware products are made with white burning clays and finely-ground minerals that are mixed with water and burned at high temperatures. There are no hazardous or dangerous substances contained or released from the products.
	Fine Fire Clay Ceramics	Fire Clay Sinks for internal use.	

3.2 System Boundary

The system boundary for this study includes the following life cycle stages as per the governing PCRs (see Figure 1):

A1- Raw material supply (upstream processes): Extraction, handling, and processing of input materials.

A2- Transportation: Transportation of all input materials from the suppliers to the gate of the manufacturing facility.

A3- Manufacturing (core process): The preparation processes of ceramic products at RAK Ceramics P.J.S.C Ras Al Khaimah factory, P.O. Box 4714 Ras Al Khaimah, UAE. This phase also includes the operations of the manufacturing facility and all process emissions that occur at the production facility.

C1 Deconstruction/Demolition: Per the Part B PCR, the environmental impacts generated during the C1 phase are very low and therefore are neglected. C2 Transportation: The transportation of the product to the treatment plant is assumed to be 50 km total including the return trip as per the Part B PCR.

C3 Waste Processing: The waste processing includes the processing (crushing) for the 70% of the product that is assumed to be recycled.

C4 Disposal: The disposal module includes the landfilling processing for the 30% of the product that is assumed to be deposited in landfill at end of life.

D Recycling Potential: The substitution effect of the recycled material is assumed to avoid the production of crushed aggregate from conventional sources.

Description of the System Boundary (x : included in LCA; MND: module not declared; MNR: module not relevant)																		
Product			Construction Installation		Use							End-of-life				Benefits of Loads Beyond the System Boundary		
Raw Material supply	Transport	Manufacturing	Transport	Construction/Installatio	Use	Maintenance	Repair	Replacement	Refurbishment	Operational Energy Use	Operational Water Use	De-Construction/ Demolition	Transport	Waste processing	Disposal	Reuse	Recovery	Recycling
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D	D	D
x	x	x	MND	MND	MND	MND	MNR	MNR	MNR	MND	MND	x	x	x	x	x	x	x

Figure 1. Life cycle stage schematic – alpha-numeric designations as per IBU PCR (adapted from CEN 15978:2011)

3.3 Declared Unit

The declared unit for ceramic tiles and porcelain tiles is **one square meter of tile product** produced at RAK Ceramics' Ras Al Khaimah factory. The declared unit for sanitary ceramics is **one tonne of sanitaryware product** produced at RAK Ceramics' Ras Al Khaimah factory.

Table 2: Declared Unit			
Product	**Declared Unit**	**Weight Avg.**	**PCR**
Ceramic Tiles	1 m^2 of tile product	20 kg/m^2	IBU PCR Part B: Requirements on the EPD for ceramic tiles and panels – Version 1.1
Porcelain Tiles	1 m^2 of tile product	22 kg/m^2	
Vitreous China Ceramics	1 t of sanitaryware product	28 kg/pc	IBU PCR Part B: Requirements on the EPD for Sanitary ceramics – Version 1.0
Fine Fire Clay Ceramics	1 t of sanitaryware product	32 kg/pc	

3.4 Cut-off Criteria

The cut-off criteria for all activity stage flows considered within the system boundary conform with ISO 14044:2006, section 6 of the IBU PCR Part A:

- All inputs and outputs to a (unit) process were included in the calculation for which data is available. Data gaps were filled by conservative assumptions with average or generic data. Any assumptions for such choices were documented;
- In case of insufficient input data or data gaps for a unit process, the cut-off criteria were 1% of renewable and non-renewable primary energy usage and 1% of the total mass of that unit

process. The total neglected input flows, e.g. per module A1-A3 were a maximum of 5% of energy usage and mass. Conservative assumptions in combination with plausibility considerations and expert judgement were used to demonstrate compliance with these criteria;

- Particular care was taken to include material and energy flows known to have the potential to cause significant emissions into air and water or soil related to the environmental indicators of this standard. Conservative assumptions in combination with plausibility considerations and expert judgement were used to demonstrate compliance with these criteria.

3.5 Exclusions from product system

Except as noted in Section 3.1, all other life cycle stages as described in Figure 1 are excluded from the LCA study and EPDs (modules A4-A5, B1-7, and C1-4).

The following were excluded from the system boundary:

- Production, manufacture, and construction of manufacturing capital goods and infrastructure;
- Production and manufacture of production equipment, delivery vehicles, and laboratory equipment;
- Personnel-related activities (travel, furniture, and office supplies); and
- Energy and water use related to company management and sales activities that may be located either within the factory site or at another location.

3.6 Packaging

Biogenic carbon content is less than 5% of the product and packaging. The cardboard packaging is estimated to be 20-40 kg/t.

4 Life Cycle Inventory Analysis

The material and unit process data underlying this study and the resultant EPDs were derived from various sources. Secondary LCI data sources were generally used to compile material and energy flows (Module A1), while primary data were collected for foreground process inputs (A2 and A3). This section qualitatively and quantitatively describes the various data sources used to compile the life cycle inventory metrics and subsequent life cycle impact assessment (LCIA) indicator results for the six products.

4.1 Primary Data Sources

RAK Ceramics engaged the Athena Institute to develop life cycle inventory questionnaires for their production facility in Ras Al Khaimah, UAE. Data was gathered for the primary material inputs used in the production of the ceramic products for calendar year 2019. Data was also gathered for the distances to the material input suppliers.

Tables 3a-3d present the input and output flow data for each unit process that occurs at the production facility. The life cycle inventory was calculated by dividing the cumulative flows for a given unit process by the reference flow output for that process.

Table 3a: Cradle-to-gate LCI for 1 m^2 ceramic tile product		
A1: Raw Materials		
Inputs	**Units**	**Amount**
Qamar Clay	kg	13.4137
Limestone	kg	1.4787
Silica Red Sand	kg	2.1124
Shale Clay	kg	1.2674
Bentonite	kg	0.7393
Green Tiles Scrap Materials	kg	1.0562
Glaze & Pigments	kg	1.0562
A2: Transportation		
Inputs	**Units**	**Amount**
Raw Materials - Truck transport	tkm	1.1309
Raw Materials - Ocean transport	tkm	0
A3: Manufacturing		
Outputs - Product	**Units**	**Amount**
Ceramic Tile Product	kg	20.00
Outputs - Waste		
Tiles & SWD Scrap Waste Materials	kg	1.1247
Industrial Waste (Plastic, Wood, Cardboard)	kg	0.3593
Inputs - Energy		
Purchased Electricity	kWh	2.5149
Owned Power Plant & Co-Gen Production	kWh	2.3340
Diesel fuel	l	0.0539
Natural gas	m3	2.5591
Inputs - Water		
Fresh water	l	11.7153
Recycled water	l	15.8923

Table 3b: Cradle-to-gate LCI for 1 m^2 porcelain tile product		
A1: Raw Materials		
Inputs	**Units**	**Amount**
Soda Feldspar	kg	9.90
Potas Feldspar	kg	1.32
Ball Clay	kg	8.80
Bentonite 601	kg	0.44
Dolomite	kg	0.44
Glaze and Pigments	kg	1.10
A2: Transportation		
Inputs	**Units**	**Amount**
Raw Materials - Truck transport	tkm	6.4780
Raw Materials - Ocean transport	tkm	121.9879
A3: Manufacturing		
Outputs - Product	**Units**	**Amount**
Porcelain Tile Product	kg	22.00
Outputs - Waste		
Tiles & SWD Scrap Waste Materials	kg	1.2371
Industrial Waste (Plastic, Wood, Cardboard)	kg	0.3952
Inputs - Energy		
Purchased Electricity	kWh	2.7663
Owned Power Plant & Co-Gen Production	kWh	2.5674
Diesel fuel	l	0.0593
Natural gas	m3	2.8150
Inputs - Water		
Fresh water	l	12.8868
Recycled water	l	17.4816

Table 3c: Cradle-to-gate LCI for 1 t of Vitreous Ceramic		
A1: Raw Materials		
Inputs	**Units**	**Amount**
Potash Feldspar	kg	200.6780
Potash	kg	147.8680
Sand	kg	126.7440
Sand Mix FC Ball Clay	kg	126.7440
Hycast VC Ball Clay	kg	147.8680
DS Kaolin	kg	137.3060
TP Prosper Clay	kg	73.9340
SPK Kaolin	kg	52.8100
Ball Clay	kg	21.1240
Vitrous Pitchers	kg	21.1240
A2: Transportation		
Inputs	**Units**	**Amount**
Raw Materials - Truck transport	tkm	727.2260
Raw Materials - Ocean transport	tkm	4699.0338
A3: Manufacturing		
Outputs - Product	**Units**	**Amount**
Vitreous China Ceramics	kg	1000
Outputs - Waste		
Tiles & SWD Scrap Waste Materials	kg	56.2329
Industrial Waste (Plastic, Wood, Cardboard)	kg	17.9637
Inputs - Energy		
Purchased Electricity	kWh	125.7430
Owned Power Plant & Co-Gen Production	kWh	116.7009
Diesel fuel	l	2.6951
Natural gas	m3	127.9525
Inputs - Water		
Fresh water	l	585.7646
Recycled water	l	794.6163

Table 3d: Cradle-to-gate LCI for 1 t Fine Fire Clay Ceramics		
A1: Raw Materials		
Inputs	**Units**	**Amount**
AGS Ball Clay	kg	81.2462
RS 335 Ball Clay	kg	174.0989
VC Ball Clay	kg	150.8857
DS Kaolin	kg	116.0659
Wollastonite	kg	34.8198
Quartz Powder	kg	11.6066
Chamotee	kg	487.4769
A2: Transportation		
Inputs	**Units**	**Amount**
Raw Materials - Truck transport	tkm	349.4165
Raw Materials - Ocean transport	tkm	6638.9134
A3: Manufacturing		
Outputs - Product	**Units**	**Amount**
Fine Fire Clay Ceramics	kg	1000
Outputs - Waste		
Tiles & SWD Scrap Waste Materials	kg	56.2329
Industrial Waste (Plastic, Wood, Cardboard)	kg	17.9637
Inputs - Energy		
Purchased Electricity	kWh	125.7430
Owned Power Plant & Co-Gen Production	kWh	116.7009
Diesel fuel	l	2.6951
Natural gas	m3	127.9525
Inputs - Water		
Fresh water	l	585.7646
Recycled water	l	794.6163

4.2 Secondary Data Sources

All upstream material, resource and energy carrier inputs have been sourced from various industry-average datasets and literature.

Table 4 describe each LCI data source for raw materials (A1), transportation by mode (A2) and the core manufacture process (A3). Table 3 also includes a data quality assessment for all secondary data on the basis of the technological, temporal, and geographical representativeness as per the IBU PCR.

Table 4: Secondary Data Sources and Data Quality Assessment				
A1: Raw Material Inputs				
Inputs	**LCI Data Source**	**Geography**	**Year**	**Data Quality Assessment**
Qamar Clay **Shale Clay** **Ball Clay** **Sand Mix FC Ball Clay** **Hycast VC Ball Clay** **TP Prosper Clay** **Chamotee**	Clay {RoW}| market for clay | Cut-off, U	Global	2011	**Technology:** very good Process models average global technology **Time:** good Data is <10 years old **Geography:** very good Data is representative of global conditions.
Limestone	Limestone, crushed, washed {RoW}| market for limestone, crushed, washed | Cut-off, U	Global	2011	**Technology:** very good Process models average global technology **Time:** good Data is <10 years old **Geography:** very good Data is representative of global conditions.
Sililca Red Sand	Silica sand {GLO}| market for | Cut-off, U	Global	2011	**Technology:** very good Process models average global technology **Time:** good Data is <10 years old **Geography:** very good Data is representative of global conditions.
Soda Feldspar **Potash Feldspar** **Potash** **Quartz Powder**	Feldspar {GLO}| market for | Cut-off, U	Global	2011	**Technology:** very good Process models average global technology **Time:** good Data is <10 years old **Geography:** very good Data is representative of global conditions.
Bentonite	Bentonite {GLO}| market for | Cut-off, U	Global	2011	**Technology:** very good Process models average global technology **Time:** good Data is <10 years old **Geography:** very good Data is representative of global conditions.

Dolomite **Wollastonite**	Dolomite {RoW}| market for dolomite | Cut-off, U	Global	2011	**Technology:** very good Process models average global technology **Time:** good Data is <10 years old **Geography:** very good Data is representative of global conditions.
Sand	Sand {GLO}| market for | Cut-off, U	Global	2011	**Technology:** very good Process models average global technology **Time:** good Data is <10 years old **Geography:** very good Data is representative of global conditions.
Kaolin	Kaolin {GLO}| market for | Cut-off, U	Global	2011	**Technology:** very good Process models average global technology **Time:** good Data is <10 years old **Geography:** very good Data is representative of global conditions.
Glaze	Frit, for ceramic tile {GLO}| market for | Cut-off, U	Global	2014	**Technology:** very good Process models average global technology **Time:** good Data is <10 years old **Geography:** very good Data is representative of global conditions.
A2: Transportation				
Inputs	**LCI Data Source**	**Geography**	**Year**	**Data Quality Assessment**
Truck transport	Transport, freight, lorry 16-32 metric ton, EURO4 {RoW}| transport, freight, lorry 16-32 metric ton, EURO4 | Cut-off, U	Global	2014	**Technology:** very good Process models average global technology **Time:** good Data is <10 years old **Geography:** very good Data is representative of global conditions.
Ocean transport	Transport, freight, sea, transoceanic tanker {GLO}| market for | Cut-off, U	Global	2011	**Technology:** very good Process models average global technology **Time:** good Data is <10 years old **Geography:** very good Data is representative of global conditions.
A3: Manufacturing				
Energy	**LCI Data Source**	**Geography**	**Year**	**Data Quality Assessment**
Grid Electricity	Electricity, high voltage {AE}| market for electricity, high voltage | Cut-off, U	UAE	2014	**Technology**: very good Process models average UAE technology **Time:** good Data is <10 years old **Geography**: very good Data is representative of UAE electricity.

Diesel Electricity	Diesel, burned in diesel-electric generating set {GLO}| market for | Cut-off, U	Global	2011	**Technology:** very good Process models average global technology **Time:** good Data is <10 years old **Geography:** very good Data is representative of global conditions.
Natural Gas	Heat, district or industrial, natural gas {GLO}| market group for | Cut-off, U	Global	2015	**Technology:** very good Process models average global technology **Time:** very good Data is <5 years old **Geography:** very good Data is representative of global conditions.
Water	**LCI Data Source**	**Geography**	**Year**	**Data Quality Assessment**
Freshwater	Tap water {RoW}| market for | Alloc Rec, U	Global	2014	**Technology:** very good Process models average global technology **Time:** good Data is <10 years old **Geography:** very good Data is representative of global conditions.
Recycled water	Wastewater from ceramic production {RoW}| treatment of, capacity 5E9l/year | Cut-off, U	Global	2010	**Technology:** very good Process models average global technology **Time:** good Data is <10 years old **Geography:** very good Data is representative of global conditions.
Waste	**LCI Data Source**	**Geography**	**Year**	**Data Quality Assessment**
Tiles Scrap Waste	Inert waste, for final disposal {RoW}| treatment of inert waste, inert material landfill | Cut-off, U	Global	2010	**Technology:** very good Process models average global technology **Time:** good Data is <10 years old **Geography:** very good Data is representative of global conditions.
Industrial Waste (Plastic, Wood, Cardboard)	Municipal solid waste {RoW}| treatment of, sanitary landfill | Cut-off, U	Global	2010	**Technology:** very good Process models average global technology **Time:** good Data is <10 years old **Geography:** very good Data is representative of global conditions.
C1- C4 and D: End of Life				
Trucking	Transport, freight, lorry 16-32 metric ton, EURO4 {RoW}| transport, freight, lorry 16-32 metric ton, EURO4 | Cut-off, U	Global	2011	**Technology:** very good Process models average global technology **Time:** good Data is <10 years old **Geography:** very good Data is representative of global conditions.

Recycling process/Substituted	Gravel: Gravel, crushed {RoW}| production | Cut-off, U	Global	2011	**Technology:** very good Process models average global technology **Time:** good Data is <10 years old **Geography:** very good Data is representative of global conditions.
Landfill	Process-specific burdens, inert material landfill {RoW}| market for process-specific burdens, inert material landfill | Cut-off, U	Global	2011	**Technology:** very good Process models average global technology **Time:** good Data is <10 years old **Geography:** very good Data is representative of global conditions.

This LCA was created using industry average data for upstream materials. Data variation can result from differences in supplier locations, manufacturing processes, manufacturing efficiency and fuel types used. Data quality is judged on the basis of its representativeness (technological, temporal, and geographical), completeness (e.g., unreported emissions), consistency and reliability.

4.3 Data Quality

Technical representativeness: Technical representativeness is the degree to which the data reflects the actual technology(ies) used. Core manufacturing process technology is derived from the manufacturing facilities and is highly representative. The secondary data for inputs to the manufacturing process are deemed to be reflective of typical or average technologies used by RAK Ceramics in their production processes.

Temporal representativeness: Temporal representativeness is the degree to which the data reflects the actual time (e.g. year) or age of the activity. Core manufacturing process data is very recent (2019). All other key LCI data sources are less than 10 years old.

Geographical representativeness: Geographical representativeness is the degree to which the data reflects the actual geographic location of the activity (e.g. country or site). Geographical coverage of core manufacturing processes is the Emirate of Ras Al Khaimah. The electricity profile is specific to the United Arab Emirates production technology. Other data sources are global.

4.4 Calculation Method

For purposes of calculating the requsite resource metrics and life cycle impact indicators (see Section 5 below), LCI datasets are created for each energy/fuel type as well as raw material (kg) and transportation mode (tkm).

4.5 Allocation

At RAK Ceramics P.J.S.C.’s Ras Al Khaimah, UAE factory several ceramic and sanitaryware products are produced. Since the primary data for manufacturing was only available on a facility level, the environmental load among the products produced is allocated according to its mass.

For waste that is recycled, the ‘recycled content appraoch’ was chosen. The recycling of waste generated by the product system is cut off.

5 Life Cycle Impact Assessment

Life cycle impact assessment (LCIA) is the phase in which the set of results of the inventory analysis – the inventory flow table – is further processed and interpreted in terms of environmental impacts and resource use inventory metrics. As specified in the IBU PCR, Section 5, the CML impact categories shall be used for the mandatory category indicators to be included in the EPD. Additionally, the PCR requires a set of inventory metrics to be reported with the LCIA indicators (see Table 5).

Table 5. Life Cycle Category Indicators and Inventory Metrics (IBU PCR)

LCIA Indicators	**Abbreviations**	**Units**
Global Warming Potential (climate change)	**GWP**	kg CO2-eq
Global warming potential - fossil fuels	**GWP - fossil**	kg CO2-eq
Global warming potential - biogenic	**GWP - biogenic**	kg CO2-eq
GWP land use & land use change	**GWP - luluc**	kg CO2-eq
Ozone Depletion Potential	**ODP**	kg CFC-11-eq
Acidification Potential	**AP**	kg SO2-eq
Acidification potential, accumulated exceedance	**AP**	mol H+-eq
Eutrophication Potential	**EP**	kg PO4-eq
Eutrophication, Freshwater	**EP-Freshwater**	kg PO4-eq
Eutrophication, Marine	**EP-Marine**	kg N-eq
Eutrophication, Terrestrial	**EP-Terrestrial**	mol N-eq
Formation potential of tropospheric ozone photochemical oxidants	**POCP**	kg ethene-eq
Formation potential of tropospheric ozone photochemical oxidants	**POCP**	kg NMVOC-eq
Abiotic Depletion Potential for Non-Fossil Resources	**ADPE**	kg Sb eq
Abiotic Depletion Potential for Fossil Resources	**ADPF**	MJ Surplus
Water Deprivation Potential	**WDP**	m^3 world- Eq
Inventory Metrics – Resources*		
Use of renewable primary energy as energy	**PERE**	MJ
Use of renewable primary energy as a material	**PERM**	MJ
Total use of renewable primary energy	**PERT**	MJ
Use of non-renewable primary energy as energy	**PENRE**	MJ
Use of non-renewable primary energy as a material	**PENRM**	MJ
Total use of non-renewable primary energy	**PENRT**	MJ
Use of secondary materials	**SM**	kg
Use of renewable secondary fuels	**RSF**	MJ
Use of non-renewable secondary fuels	**NRSF**	MJ
Use of freshwater resources	**FW**	m3
Inventory Metrics – Waste and Outputs		
Disposed of Hazardous Waste	**HWD**	kg
Disposed of Non-Hazardous Waste	**NHWD**	kg
Disposed of Radioactive Waste	**RWD**	m3
Components for Reuse	**CRU**	kg
Materials for Recycling	**MFR**	kg
Materials for Energy Recovery	**MER**	kg
Exported Electrical Energy (Waste to Energy)	**EEE**	kg
Exported Thermal Energy (Waste to Energy)	**ETE**	kg

* *All energy demand inventory metrics were caluclated based on the lower heating value of the various energy resources. The lower heating value was calculated based on the Cumulative Energy Demand impact assessment method in SimaPro.*

Category indicators present possible or potential impacts and are based on environmental impacts that may be realized if the emitted chemical compound(s) actually follows the designated impact pathway and reacts accordingly in the receiving environment. Each potential impact pathway is calculated in isolation, and while a number of compounds may contribute to two or more pathways, no effort is made to partition individual chemical compound flows between impact pathways. As a result, LCIA results are only relative expressions of potentials and do not predict actual impacts, the exceeding of thresholds, safety margins or risks.

A short description of impact categories (IC) and characterization factors (CF) is provided below in Table 6. A characterization factor is a factor derived from a characterization model, which is applied to convert an assigned life cycle inventory analysis result to the common unit for the category indicator. The common unit allows calculation of the category indicator result.

Impact-estimate results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins, or risks.

Table 6: Impact Categories			
Impact Category	**Indicator**	**Unit**	**Model**
Climate change – total	Global Warming Potential total (GWP total)	kg CO2 eq.	Baseline model 100 years of the IPCC based on IPCC 2013
Climate change - fossil	Global Warming Potential fossil fuels (GWP-fossil)	kg CO2 eq.	Baseline model 100 years of the IPCC based on IPCC 2013
Climate change - biogenic	Global Warming Potential biogenic (GWP-biogenic)	kg CO2 eq.	Baseline model 100 years of the IPCC based on IPCC 2013
Climate change - land use and land use change b	Global Warming Potential land use and land use change (GWP-luluc)	kg CO2 eq.	Baseline model of 100 years of the IPCC based on IPCC 2013
Ozone Depletion	Depletion potential of the stratospheric ozone layer (ODP)	Kg CFC 11 eq.	Steady-state ODPs, WMO 2014
Acidification	Acidification potential, Accumulated Exceedance (AP)	mol H+ eq.	Accumulated Exceedance, Seppälä et al. 2006, Posch et al., 2008
Eutrophication aquatic freshwater	Eutrophication potential, fraction of nutrients reaching freshwater end compartment (EP-freshwater)	kg PO4 eq.	EUTREND model, Struijs et al., 2009b, as implemented in ReCiPe
Eutrophication aquatic marine	Eutrophication potential, fraction of nutrients reaching freshwater end compartment (EP-marine)	kg N eq.	EUTREND model, Struijs et al., 2009b, as implemented in ReCiPe
Eutrophication terrestrial	Eutrophication potential, Accumulated Exceedance (EP-terrestrial)	mol N eq.	Accumulated Exceedance, Seppälä et al. 2006, Posch et al.
Photochemical ozone formation	Formation potential of tropospheric ozone (POCP);	kg NMVOC eq.	LOTOS-EUROS ,Van Zelm et al., 2008, as applied in ReCiPe
Depletion of abiotic resources – minerals and metals	Abiotic depletion potential for non-fossil resources (ADP- minerals & metals)	kg Sb eq.	CML 2002, Guinée et al., 2002, and van Oers et al. 2002.
Depletion of abiotic resources - fossil fuels	Abiotic depletion potential for fossil resources (ADP-fossil)	MJ, NCV	CML 2002, Guinée et al., 2002, and van Oers et al. 2002.
Water use	Water (user) deprivation potential, deprivation-weighted water consumption (WDP)	m3 world eq. deprived	Available WAter REmaining (AWARE) Boulay et al., 2016

5.1 Life Cycle Impact Assessment Results

Table 7a-d summarizes the LCA results of the investigated ceramic products per the respective declared unit.

Table 7a. Life Cycle Impact Assessment
Results for 1 m^2 ceramic tile product

Environmental Indicator	Abbrev.	Units	Total	A1	A2	A3	C1	C2	C3	C4	D
Impact Categories											
Global warming potential	**GWP - total**	kg CO2-eq	5.61E+00	1.76E+00	1.95E-01	3.46E+00	0.00	1.72E-01	1.22E-01	1.61E-02	-1.22E-01
Global warming potential - fossil fuels	**GWP - fossil**	kg CO2-eq	5.28E+00	1.76E+00	1.95E-01	3.14E+00	0.00	1.72E-01	1.20E-01	1.61E-02	-1.20E-01
Global warming potential - biogenic	**GWP - biogenic**	kg CO2-eq	3.27E-01	2.50E-03	7.54E-05	3.24E-01	0.00	6.67E-05	1.56E-03	4.35E-05	-1.56E-03
GWP land use & land use change	**GWP - luluc**	kg CO2-eq	2.22E-03	1.80E-03	7.05E-05	2.87E-04	0.00	6.23E-05	1.59E-04	1.36E-06	-1.59E-04
Depletion potential of the stratospheric ozone layer	**ODP**	kg CFC-11-eq	1.09E-06	4.49E-07	3.43E-08	5.69E-07	0.00	3.76E-08	1.09E-08	3.23E-09	-1.09E-08
Acidification potential of land and water	**AP**	kg SO2-eq	2.27E-02	1.40E-02	7.00E-04	7.20E-03	0.00	6.70E-04	6.07E-04	1.16E-04	-6.07E-04
Acidification potential, accumulated exceedance	**AP**	mol H+-eq	2.70E-02	1.49E-02	9.97E-04	1.01E-02	0.00	8.81E-04	7.81E-04	1.61E-04	-7.81E-04
Eutrophication potential	**EP**	kg PO4-eq	7.99E-03	5.30E-03	2.00E-04	2.30E-03	0.00	1.59E-04	3.00E-04	2.72E-05	-3.00E-04
Eutrophication, fraction of nutrients reaching freshwater end compartment	**EP-Freshwater**	kg PO4-eq	6.73E-05	4.66E-05	8.24E-07	4.37E-06	0.00	1.46E-05	7.35E-05	9.10E-07	-7.35E-05
Eutrophication, fraction of nutrients reaching marine end compartment	**EP- Marine**	kg N-eq	6.58E-04	1.37E-04	1.68E-05	1.39E-04	0.00	2.96E-04	1.77E-04	6.91E-05	-1.77E-04
Eutrophication, accumulated exceedance	**EP- Terrestrial**	mol N-eq	6.83E-03	1.50E-03	1.83E-04	1.15E-03	0.00	3.24E-03	2.14E-03	7.57E-04	-2.14E-03
Formation potential of tropospheric ozone photochemical oxidants	**POCP**	kg ethene-eq	1.23E-03	6.00E-04	0.00E+00	6.00E-04	0.00	2.33E-05	3.97E-05	4.72E-06	-3.97E-05
Formation potential of tropospheric ozone photochemical oxidants	**POCP**	kg NMVOC-eq	1.97E-02	8.15E-03	1.04E-03	9.35E-03	0.00	9.23E-04	5.41E-04	2.12E-04	-5.41E-04
Abiotic Depletion Potential for Non-Fossil Resources	**ADPE**	kg Sb eq	2.96E-04	2.90E-04	5.58E-07	7.94E-07	0.00	4.56E-06	1.28E-05	2.35E-08	-1.28E-05
Abiotic Depletion Potential for Fossil Resources	**ADPF**	MJ Surplus	1.21E+02	2.32E+01	2.83E+00	9.27E+01	0.00	2.52E+00	1.34E+00	2.12E-01	-1.34E+00
Water user deprivation potential, deprivation weighted water consumption	**WDP**	m^3 world-Eq deprived	-6.09E-01	4.98E-02	4.68E-04	8.45E-04	0.00	8.28E-03	-4.64E-01	3.09E-04	-2.05E-01

Inventory Metrics - Resources											
Use of renewable primary energy as energy	**PERE**	MJ	2.39E+00	2.12E+00	2.83E-02	2.07E-01	0.00	2.86E-02	1.56E-01	1.65E-03	-1.56E-01
Use of renewable primary energy as a material	**PERM**	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total use of renewable primary energy	**PERT**	MJ	2.39E+00	2.12E+00	2.83E-02	2.07E-01	0.00	2.86E-02	1.56E-01	1.65E-03	-1.56E-01
Use of non-renewable primary energy as energy	**PENRE**	MJ	3.32E+01	2.72E+01	3.05E+00	0 102.9642	0.00	2.71E+00	1.86E+00	2.27E-01	-1.86E+00
Use of non-renewable primary energy as a material	**PENRM**	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total use of non-renewable primary energy	**PENRT**	MJ	3.32E+01	2.72E+01	3.05E+00	0.00E+00	0.00	2.71E+00	1.86E+00	2.27E-01	-1.86E+00
Use of secondary materials	**SM**	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Use of renewable secondary fuels	**RSF**	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Use of non-renewable secondary fuels	**NRSF**	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Use of freshwater resources	**FW**	m3	-5.91E-01	4.09E-02	5.00E-04	2.73E-02	0.00	8.28E-03	-4.64E-01	3.09E-04	-2.05E-01
Inventory Metrics – Waste and Outputs											
Disposed of Hazardous Waste	**HWD**	kg	1.48E+00	0.00E+00	0.00E+00	1.48E+00	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Disposed of Non-Hazardous Waste	**NHWD**	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Disposed of Radioactive Waste	**RWD**	m3	6.14E-08	3.50E-08	7.68E-09	1.87E-08	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Components for Reuse	**CRU**	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Materials for Recycling	**MFR**	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Materials for Energy Recovery	**MER**	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Exported Electrical Energy (Waste to Energy)	**EEE**	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Exported Thermal Energy (Waste to Energy)	**ETE**	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 7b. Life Cycle Impact Assessment Results for 1 m^2 poreclain tile product											
Environmental Indicator	**Abbrev.**	**Units**	**Total**	**A1**	**A2**	**A3**	**C1**	**C2**	**C3**	**C4**	**D**
Impact Categories											
Global warming potential	**GWP - total**	kg CO2-eq	kg CO2-eq	8.30E+00	2.07E+00	1.82E+00	4.19E+00	0	1.89E-01	1.34E-01	1.77E-02
Global warming potential - fossil fuels	**GWP - fossil**	kg CO2-eq	kg CO2-eq	7.90E+00	2.07E+00	1.82E+00	3.80E+00	0	1.89E-01	1.32E-01	1.77E-02
Global warming potential - biogenic	**GWP - biogenic**	kg CO2-eq	kg CO2-eq	3.97E-01	2.33E-03	1.67E-03	3.92E-01	0	7.34E-05	1.72E-03	4.79E-05
GWP land use & land use change	**GWP - luluc**	kg CO2-eq	kg CO2-eq	3.18E-03	2.03E-03	7.39E-04	3.47E-04	0	6.86E-05	1.75E-04	1.50E-06
Depletion potential of the stratospheric ozone layer	**ODP**	kg CFC-11-eq	kg CFC-11-eq	1.49E-06	5.11E-07	3.12E-07	6.26E-07	0	4.14E-08	1.20E-08	3.55E-09
Acidification potential of land and water	**AP**	kg SO2-eq	kg SO2-eq	4.55E-02	1.55E-02	2.12E-02	7.90E-03	0	7.37E-04	6.68E-04	1.28E-04
Acidification potential, accumulated exceedance	**AP**	mol H+-eq	mol H+-eq	5.46E-02	1.63E-02	2.50E-02	1.22E-02	0	9.70E-04	8.59E-04	1.77E-04
Eutrophication potential	**EP**	kg PO4-eq	kg PO4-eq	1.12E-02	5.70E-03	2.80E-03	2.50E-03	0	1.75E-04	3.30E-04	2.99E-05
Eutrophication, fraction of nutrients reaching freshwater end compartment	**EP-Freshwater**	kg PO4-eq	kg PO4-eq	7.56E-05	4.53E-05	8.47E-06	4.81E-06	0	1.60E-05	8.09E-05	1.00E-06
Eutrophication, fraction of nutrients reaching marine end compartment	**EP- Marine**	kg N-eq	kg N-eq	8.68E-04	1.43E-04	1.70E-04	1.53E-04	0	3.26E-04	1.95E-04	7.60E-05
Eutrophication, accumulated exceedance	**EP- Terrestrial**	mol N-eq	mol N-eq	9.11E-03	1.55E-03	1.89E-03	1.27E-03	0	3.56E-03	2.36E-03	8.32E-04
Formation potential of tropospheric ozone photochemical oxidants	**POCP**	kg ethene-eq	kg ethene-eq	2.23E-03	7.00E-04	8.00E-04	7.00E-04	0	2.56E-05	4.37E-05	5.19E-06
Formation potential of tropospheric ozone photochemical oxidants	**POCP**	kg NMVOC-eq	kg NMVOC-eq	3.40E-02	9.42E-03	1.20E-02	1.13E-02	0	1.01E-03	5.96E-04	2.33E-04
Abiotic Depletion Potential for Non-Fossil Resources	**ADPE**	kg Sb eq	kg Sb eq	3.12E-04	3.03E-04	3.39E-06	8.73E-07	0	5.02E-06	1.41E-05	2.58E-08
Abiotic Depletion Potential for Fossil Resources	**ADPF**	MJ Surplus	MJ Surplus	5.80E+01	2.87E+01	2.62E+01	0 101.9305	0	2.78E+00	1.48E+00	2.33E-01
Water user deprivation potential, deprivation weighted water consumption	**WDP**	m^3 world- Eq deprived	m^3 world- Eq deprived	-6.43E-01	7.87E-02	3.71E-03	9.29E-04	0	9.10E-03	-5.10E-01	3.40E-04

Inventory Metrics - Resources											
Use of renewable primary energy as energy	**PERE**	MJ	2.99E+00	2.31E+00	4.20E-01	2.28E-01	0	3.14E-02	1.72E-01	1.81E-03	-1.72E-01
Use of renewable primary energy as a material	**PERM**	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total use of renewable primary energy	**PERT**	MJ	2.99E+00	2.31E+00	4.20E-01	2.28E-01	0	3.14E-02	1.72E-01	1.81E-03	-1.72E-01
Use of non-renewable primary energy as energy	**PENRE**	MJ	6.55E+01	3.36E+01	2.86E+01	0 113.2606	0	2.99E+00	2.04E+00	2.49E-01	-2.04E+00
Use of non-renewable primary energy as a material	**PENRM**	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total use of non-renewable primary energy	**PENRT**	MJ	6.55E+01	3.36E+01	2.86E+01	0 113.2606	0	2.99E+00	2.04E+00	2.49E-01	-2.04E+00
Use of secondary materials	**SM**	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Use of renewable secondary fuels	**RSF**	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Use of non-renewable secondary fuels	**NRSF**	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Use of freshwater resources	**FW**	m3	-6.32E-01	5.89E-02	4.60E-03	3.01E-02	0	9.10E-03	-5.10E-01	3.40E-04	-2.25E-01
Inventory Metrics – Waste and Outputs											
Disposed of Hazardous Waste	**HWD**	kg	1.63E+00	0.00E+00	0.00E+00	1.63E+00	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Disposed of Non-Hazardous Waste	**NHWD**	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Disposed of Radioactive Waste	**RWD**	m3	1.35E-07	4.35E-08	7.08E-08	2.05E-08	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Components for Reuse	**CRU**	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Materials for Recycling	**MFR**	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Materials for Energy Recovery	**MER**	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Exported Electrical Energy (Waste to Energy)	**EEE**	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Exported Thermal Energy (Waste to Energy)	**ETE**	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 7c. Life Cycle Impact Assessment Results for 1 m² vitreous ceramicc product											
Environmental Indicator	**Abbrev.**	**Units**	**Total**	**A1**	**A2**	**A3**	**C1**	**C2**	**C3**	**C4**	**D**
Impact Categories											
Global warming potential	**GWP - total**	kg CO2-eq	5.16E+02	5.98E+01	1.53E+02	2.94E+02	0	8.61E+00	6.09E+00	8.06E-01	-6.09E+00
Global warming potential - fossil fuels	**GWP - fossil**	kg CO2-eq	4.99E+02	5.94E+01	1.52E+02	2.78E+02	0	8.61E+00	6.00E+00	8.03E-01	-6.00E+00
Global warming potential - biogenic	**GWP - biogenic**	kg CO2-eq	1.66E+01	3.45E-01	9.61E-02	1.62E+01	0	3.34E-03	7.80E-02	2.18E-03	-7.80E-02
GWP land use & land use change	**GWP - luluc**	kg CO2-eq	1.36E-01	6.09E-02	5.82E-02	1.35E-02	0	3.12E-03	7.94E-03	6.82E-05	-7.94E-03
Depletion potential of the stratospheric ozone layer	**ODP**	kg CFC-11-eq	6.41E-05	7.11E-06	2.65E-05	2.84E-05	0	1.88E-06	5.44E-07	1.62E-07	-5.44E-07
Acidification potential of land and water	**AP**	kg SO2-eq	1.83E+00	3.08E-01	1.12E+00	3.60E-01	0	3.35E-02	3.04E-02	5.80E-03	-3.04E-02
Acidification potential, accumulated exceedance	**AP**	mol H+-eq	2.27E+00	3.57E-01	1.38E+00	4.78E-01	0	4.41E-02	3.91E-02	8.06E-03	-3.91E-02
Eutrophication potential	**EP**	kg PO4-eq	4.05E-01	1.04E-01	1.78E-01	1.13E-01	0	7.96E-03	1.50E-02	1.36E-03	-1.50E-02
Eutrophication, fraction of nutrients reaching freshwater end compartment	**EP-Freshwater**	kg PO4-eq	4.02E-02	2.09E-02	1.41E-02	4.47E-03	0	7.29E-04	3.68E-03	4.55E-05	-3.68E-03
Eutrophication, fraction of nutrients reaching marine end compartment	**EP- Marine**	kg N-eq	5.58E-01	7.38E-02	2.86E-01	1.80E-01	ND	1.48E-02	8.86E-03	3.45E-03	-8.86E-03
Eutrophication, accumulated exceedance	**EP- Terrestrial**	mol N-eq	5.77E+00	7.98E-01	3.15E+00	1.62E+00	ND	1.62E-01	1.07E-01	3.78E-02	-1.07E-01
Formation potential of tropospheric ozone photochemical oxidants	**POCP**	kg ethene-eq	8.99E-02	1.37E-02	4.44E-02	3.04E-02	0	1.16E-03	1.99E-03	2.36E-04	-1.99E-03
Formation potential of tropospheric ozone photochemical oxidants	**POCP**	kg NMVOC-eq	1.70E+00	2.22E-01	9.05E-01	5.13E-01	ND	4.61E-02	2.71E-02	1.06E-02	-2.71E-02
Abiotic Depletion Potential for Non-Fossil Resources	**ADPE**	kg Sb eq	8.66E-04	2.31E-04	3.66E-04	3.97E-05	0	2.28E-04	6.41E-04	1.17E-06	-6.41E-04
Abiotic Depletion Potential for Fossil Resources	**ADPF**	MJ Surplus	7.75E+03	7.73E+02	2.21E+03	4.63E+03	0	1.26E+02	6.72E+01	1.06E+01	-6.72E+01
Water user deprivation potential, deprivation weighted water consumption	**WDP**	m^3 world- Eq deprived	3.35E+01	5.39E+01	7.10E+00	5.52E+00	0	4.14E-01	-2.32E+01	1.54E-02	-1.02E+01

Inventory Metrics - Resources											
Use of renewable primary energy as energy	**PERE**	MJ	1.00E+02	6.03E+01	2.81E+01	1.04E+01	0	1.43E+00	7.82E+00	8.24E-02	-7.82E+00
Use of renewable primary energy as a material	**PERM**	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total use of renewable primary energy	**PERT**	MJ	1.00E+02	6.03E+01	2.81E+01	1.04E+01	0	1.43E+00	7.82E+00	8.24E-02	-7.82E+00
Use of non-renewable primary energy as energy	**PENRE**	MJ	8.62E+03	9.37E+02	2.39E+03	5.15E+03	0	1.36E+02	9.29E+01	1.13E+01	-9.29E+01
Use of non-renewable primary energy as a material	**PENRM**	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total use of non-renewable primary energy	**PENRT**	MJ	8.62E+03	9.37E+02	2.39E+03	5.15E+03	0	1.36E+02	9.29E+01	1.13E+01	-9.29E+01
Use of secondary materials	**SM**	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Use of renewable secondary fuels	**RSF**	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	ND	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Use of non-renewable secondary fuels	**NRSF**	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Use of freshwater resources	**FW**	m3	-2.88E+01	2.45E+00	4.03E-01	1.37E+00	0	4.14E-01	-2.32E+01	1.54E-02	-1.02E+01
Inventory Metrics – Waste and Outputs											
Disposed of Hazardous Waste	**HWD**	kg	7.42E+01	0.00E+00	0.00E+00	7.42E+01	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Disposed of Non-Hazardous Waste	**NHWD**	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Disposed of Radioactive Waste	**RWD**	m3	8.07E-06	1.17E-06	5.97E-06	9.34E-07	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Components for Reuse	**CRU**	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Materials for Recycling	**MFR**	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Materials for Energy Recovery	**MER**	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Exported Electrical Energy (Waste to Energy)	**EEE**	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Exported Thermal Energy (Waste to Energy)	**ETE**	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 7d. Life Cycle Impact Assessment Results for 1 m^2 fine fire clay product											
Environmental Indicator	**Abbrev.**	**Units**	**Total**	**A1**	**A2**	**A3**	**C1**	**C2**	**C3**	**C4**	**D**
Impact Categories											
Global warming potential	**GWP - total**	kg CO2-eq	4.38E+02	3.60E+01	9.87E+01	2.94E+02	0	8.61E+00	6.09E+00	8.06E-01	-6.09E+00
Global warming potential - fossil fuels	**GWP - fossil**	kg CO2-eq	4.22E+02	3.58E+01	9.86E+01	2.78E+02	0	8.61E+00	6.00E+00	8.03E-01	-6.00E+00
Global warming potential - biogenic	**GWP - biogenic**	kg CO2-eq	1.65E+01	1.62E-01	9.06E-02	1.62E+01	0	3.34E-03	7.80E-02	2.18E-03	-7.80E-02
GWP land use & land use change	**GWP - luluc**	kg CO2-eq	9.64E-02	3.96E-02	4.00E-02	1.35E-02	0	3.12E-03	7.94E-03	6.82E-05	-7.94E-03
Depletion potential of the stratospheric ozone layer	**ODP**	kg CFC-11-eq	5.14E-05	4.04E-06	1.69E-05	2.84E-05	0	1.88E-06	5.44E-07	1.62E-07	-5.44E-07
Acidification potential of land and water	**AP**	kg SO2-eq	1.75E+00	1.97E-01	1.15E+00	3.60E-01	0	3.35E-02	3.04E-02	5.80E-03	-3.04E-02
Acidification potential, accumulated exceedance	**AP**	mol H+-eq	2.12E+00	2.39E-01	1.36E+00	4.78E-01	0	4.41E-02	3.91E-02	8.06E-03	-3.91E-02
Eutrophication potential	**EP**	kg PO4-eq	3.44E-01	7.16E-02	1.50E-01	1.13E-01	0	7.96E-03	1.50E-02	1.36E-03	-1.50E-02
Eutrophication, fraction of nutrients reaching freshwater end compartment	**EP-Freshwater**	kg PO4-eq	2.97E-02	1.44E-02	1.01E-02	4.47E-03	0	7.29E-04	3.68E-03	4.55E-05	-3.68E-03
Eutrophication, fraction of nutrients reaching marine end compartment	**EP- Marine**	kg N-eq	4.50E-01	4.89E-02	2.03E-01	1.80E-01	0	1.48E-02	8.86E-03	3.45E-03	-8.86E-03
Eutrophication, accumulated exceedance	**EP- Terrestrial**	mol N-eq	4.63E+00	5.52E-01	2.26E+00	1.62E+00	0	1.62E-01	1.07E-01	3.78E-02	-1.07E-01
Formation potential of tropospheric ozone photochemical oxidants	**POCP**	kg ethene-eq	8.48E-02	8.70E-03	4.43E-02	3.04E-02	0	1.16E-03	1.99E-03	2.36E-04	-1.99E-03
Formation potential of tropospheric ozone photochemical oxidants	**POCP**	kg NMVOC-eq	1.37E+00	1.48E-01	6.53E-01	5.13E-01	0	4.61E-02	2.71E-02	1.06E-02	-2.71E-02
Abiotic Depletion Potential for Non-Fossil Resources	**ADPE**	kg Sb eq	7.10E-04	2.58E-04	1.83E-04	3.97E-05	0	2.28E-04	6.41E-04	1.17E-06	-6.41E-04
Abiotic Depletion Potential for Fossil Resources	**ADPF**	MJ Surplus	6.63E+03	4.40E+02	1.42E+03	4.63E+03	0	1.26E+02	6.72E+01	1.06E+01	-6.72E+01
Water user deprivation potential, deprivation weighted water consumption	**WDP**	m^3 world- Eq deprived	-6.33E+00	1.67E+01	4.42E+00	5.52E+00	0	4.14E-01	-2.32E+01	1.54E-02	-1.02E+01

Inventory Metrics - Resources											
Use of renewable primary energy as energy	**PERE**	MJ	7.25E+01	3.78E+01	2.28E+01	1.04E+01	0	1.43E+00	7.82E+00	8.24E-02	-7.82E+00
Use of renewable primary energy as a material	**PERM**	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total use of renewable primary energy	**PERT**	MJ	7.25E+01	3.78E+01	2.28E+01	1.04E+01	0	1.43E+00	7.82E+00	8.24E-02	-7.82E+00
Use of non-renewable primary energy as energy	**PENRE**	MJ	7.38E+03	5.33E+02	1.55E+03	5.15E+03	0	1.36E+02	9.29E+01	1.13E+01	-9.29E+01
Use of non-renewable primary energy as a material	**PENRM**	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total use of non-renewable primary energy	**PENRT**	MJ	7.38E+03	5.33E+02	1.55E+03	5.15E+03	0	1.36E+02	9.29E+01	1.13E+01	-9.29E+01
Use of secondary materials	**SM**	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Use of renewable secondary fuels	**RSF**	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Use of non-renewable secondary fuels	**NRSF**	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Use of freshwater resources	**FW**	m3	-3.03E+01	1.04E+00	2.48E-01	1.37E+00	0	4.14E-01	-2.32E+01	1.54E-02	-1.02E+01
Inventory Metrics – Waste and Outputs											
Disposed of Hazardous Waste	**HWD**	kg	7.42E+01	0.00E+00	0.00E+00	7.42E+01	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Disposed of Non-Hazardous Waste	**NHWD**	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Disposed of Radioactive Waste	**RWD**	m3	5.45E-06	6.84E-07	3.83E-06	9.34E-07	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Components for Reuse	**CRU**	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Materials for Recycling	**MFR**	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Materials for Energy Recovery	**MER**	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Exported Electrical Energy (Waste to Energy)	**EEE**	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Exported Thermal Energy (Waste to Energy)	**ETE**	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00

5.2 Interpretation

Figure 2a-d shows the relative contribution to the cumulative impacts of the A1 through A3 phases of the life cycle. The C1 through C4 phases and Module D are all relatively insignificant in terms of the overall results and are thus excluded from this contribution analysis. In the cradle-to-gate portion for ceramic tiles, the manufacturing (A3) is the major contributor to GWP, ODP, POCP and ADPf. Major A3 impacts came from the combustion of natural gas for heat during the drying process. For the indicators AP, EP and ADPe, the major impacts occurred during the raw material supply (A1). Transportation (A2) impacts are insignificant for ceramic tiles.

For the porcelain tiles production, the impact of transportation is much higher and accounts for around 20% of the overall impact. This is due to longer transportation distances.

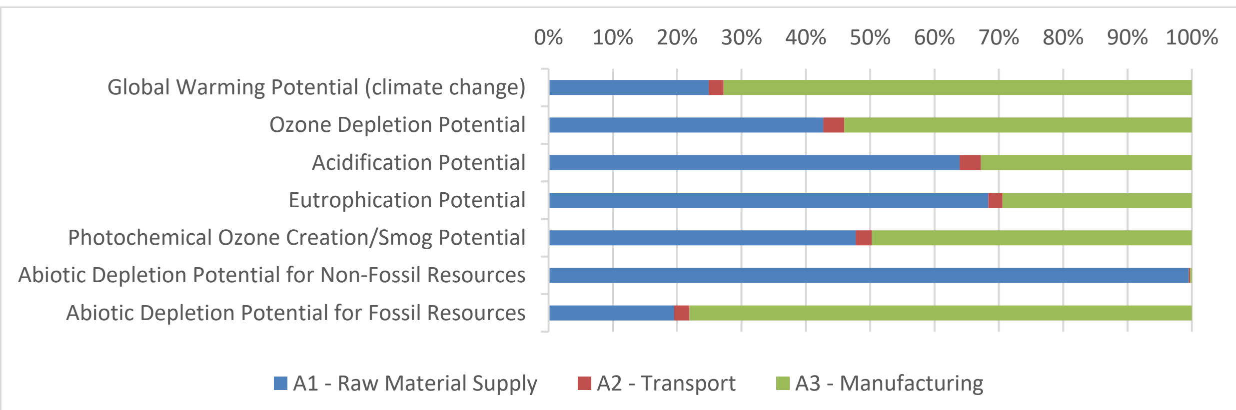

Figure 2a. Contribution analysis for ceramic tiles

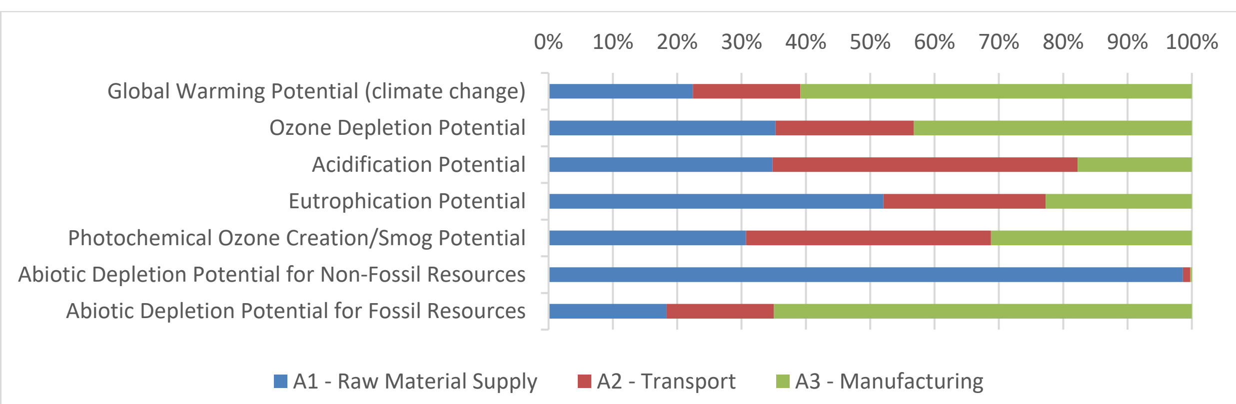

Figure 2b. Contribution analysis for porcelain tiles

The sanitary ceramics shows similar results pattern than the tiles, however the impact from transportation is much higher due to longer transportation distances. Over one third of the overall impacts are related to transportation. In the impact category GWP over 50% of the impacts come from the manufacturing process (A3). Here as well, the combustion of natural gas for heat in the drying process plays a major role.

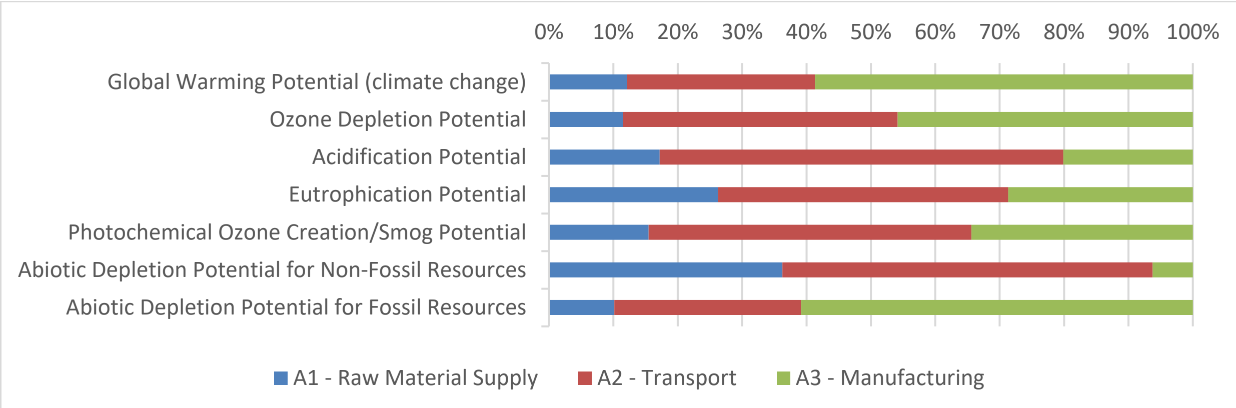

Figure 2c. Contribution analysis for Vitreous China Ceramics

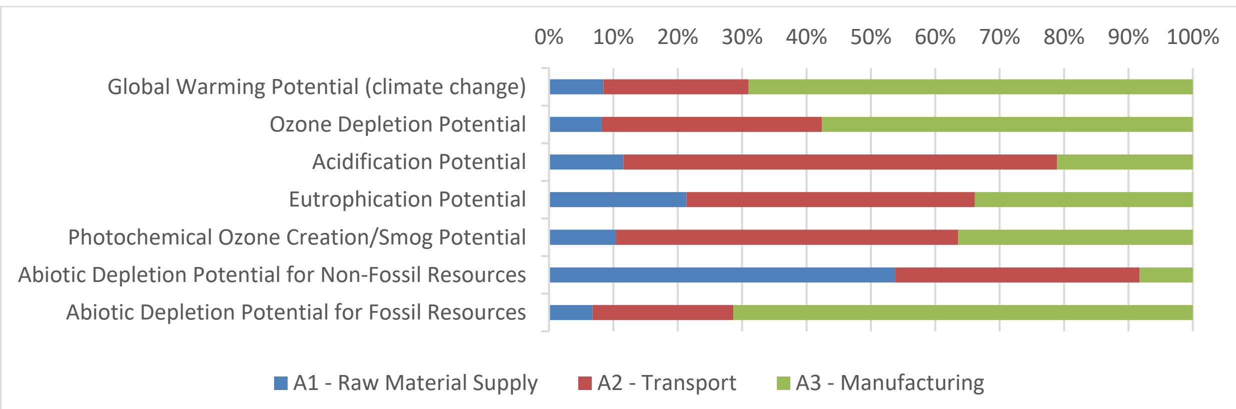

Figure 2d. Contribution analysis for Fine Fire Clay Ceramics

5.3 Limitations

The generation of hazardous and non-hazardous waste as an intermediate flow is not available for upstream life cycle stages A1 and A2. The secondary data used to model these stages include all waste processing within the system boundaries of the underlying models, but only provide the elementary flows of the resulting product system (i.e. no intermediate waste flows).

The results for the inventory indicator "consumption of water resources" overestimates the actual amount because secondary data sources do not always provide data for non-consumptive water flows. Water consumption is defined as net inputs-outputs of water within the same watershed. All inputs are assumed as net consumption and are thus conservative estimates.

This study does not report all of the environmental impacts caused by the life cycle of RAK Ceramics' products. For example, the PCRs do not include impact categories for human health impacts and thus particulate emissions that might impact human and/or ecosystem health are excluded. In order to assess the local impacts of product manufacturing on human health, land use and local ecology, additional analysis is required.

This project reports the results to benchmark the manufacture of RAK Ceramics' products. No environmental claim regarding the superiority or equivalence of RAK Ceramics' products relative to a competing product that performs the same function is implied. An EPD does not make any statements that the product covered by the EPD is better or worse than any other product. LCIA results are only relative expressions of potentials and do not predict actual impacts, the exceeding of thresholds, safety margins or risks.

Eluate analysis is not applicable because the use phase is not within the scope of the LCA and no attestations are made regarding the use phase.

6 References

1. EN 15804 +A2:2019 Sustainability of construction works – Environmental product declarations –Core rules for the product category of construction products.
2. IBU PCR Part A: Part A: Calculation Rules for the Life Cycle Assessment and Requirements on the Project report with reference to EN 15804 + A2:2019 – Version 1.0
3. IBU PCR Part B: Requirements on the EPD for ceramic tiles and panels – Version 1.1
4. IBU PCR Part B: Requirements on the EPD for sanitary ceramics – Version 1.0
5. ISO 21930: 2017 Building construction – Sustainability in building construction – Environmental declaration of building products.
6. ISO 14025: 2006 Environmental labeling and declarations - Type III environmental declarations - Principles and procedures.
7. ISO 14044: 2006 Environmental management - Life cycle assessment - Requirements and guidelines.
8. ISO 14040: 2006 Environmental management - Life cycle assessment - Principles and framework.

Glossary of Terms

Based on ISO 14040/44:2006 – Terms and Definition Section [1].

Allocation: Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems.

Life Cycle: Consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal.

Life Cycle Assessment (LCA): Compilation and evaluation of the inputs, outputs, and the potential environmental impacts of a product system throughout its life cycle.

Life Cycle Impact Assessment (LCIA): Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product.

Life Cycle Interpretation: Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations.

Life Cycle Inventory (LCI): Phase of Life Cycle Assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle.

Product system: Collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product.

System boundary: Set of criteria specifying which unit processes are part of a product system.
Note: the term system boundary is not used in this International Standard in relation to LCIA.

Based on ISO 14025:2006- Clause 3 Terms and definitions

Type III Environmental Product Declaration (EPD): providing quantified environmental data using predetermined parameters and, where relevant, additional environmental information
Note 1 the predetermined parameters are based on the ISO 14040 series of standards.
Note 2 the additional environmental information may be quantitative or qualitative.

Product Category Rules (PCR): set of specific rules, requirements, and guidelines for developing Type III environmental declarations for one or more product categories.

Based on ISO 21930:2007- Clause 3 Terms and definitions

Building product: goods or services used during the life cycle of a building or other construction works.

Declared unit: quantity of a building product for use as a reference unit in an EPD, based on LCA, for the expression of environmental information needed in information modules.

Information module: compilation of data to be used as a basis for a type III environmental declaration, covering a unit process or a combination of unit processes that are part of the life cycle of a product.

Reference service life: service life of a building product that is known or expected under a particular set, i.e., a reference set, of in-use conditions and that may form the basis of estimating the service life under other in-use conditions.