LIFE CYCLE ASSESSMENT (LCA) OF GRANITE AND MARBLE STONE COUNTERTOPS BY POLYCOR

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Contents

1 INTRODUCTION

1.1 Opportunity

Polycor is the world's leading natural stone quarrier and processor [1]. In line with their commitment to sustainability, it was important for Polycor to conduct their own company-specific Life Cycle Assessment (LCA) in parallel with their participation in the Natural Stone Institute's (NSI's) industry-wide LCA. The LCA will evaluate the environmental impacts of Polycor's stone countertops in all life cycle stages, from stone quarrying to processing, fabrication, and through to the end of life. The goal of creating this LCA is to discover the full range of environmental impacts the stone countertops have and to review these impacts along the product specific environmental declarations in order to identify processes and reduce overall impacts. This project is important to Polycor's commitment to provide information to the market to assess the environmental impacts associated with natural stone countertops.

To understand the total impact of the product through all life cycle stages, Polycor has decided to use a cradle-to-grave approach in conducting the LCA. By including all life cycle stages, more information becomes available for understanding how to reduce impacts.

Polycor intends to use the results of the LCA to develop three Sustainable Minds Transparency Reports™ (TRs), a Type III Environmental Declaration (EPD) that can be used for communication with and amongst other companies, by architects and consumers and can be utilized in whole building LCA tools in conjunction with the LCA background report and Life Cycle Inventory (LCI). This study aims at being compliant to the requirements of ISO 14040/14044, ISO 21930 standards as well as NSF's PCR for residential countertops [2].

Polycor commissioned Sustainable Minds, an external practitioner, to develop an LCA for three main product categories: stone cladding, stone flooring, and stone countertops. This document is focused on countertops. Polycor wants to communicate environmental information to the market as well as compare the industry-wide results to their own product-specific results so that they have guidance for future product improvements and can contribute towards satisfying credits in the Leadership in Energy and Environmental Design (LEED®) building rating system.

This LCA report is specific to stone countertops fabricated by Polycor. Results are presented separately for granite and marble countertops.

1.2 Life Cycle Assessment

This report includes the following phases:

- Goal and Scope
- Inventory Analysis
- Impact Assessment
- Interpretation

A critical review of the LCA and an independent verification of the TRs are required for Type III Environmental Declarations. Both are included in this project.

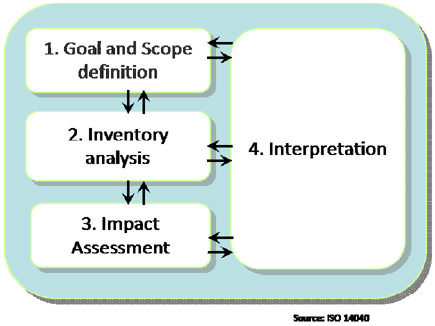


Figure 1. Phases in an LCA

1.3 Status

All information in this report reflects the inputs and outputs provided Polycor at the time it was collected, and best practices were followed by Sustainable Minds and Polycor to transform the inventory into this LCA report.

The data for all stone products were collected from Polycor covering a period of two years, January 2020 to December 2021. Data for quarry operations were collected from several facilities across eight US states and Quebec, Canada. The material and production inputs from each site was used to calculate a weighted average of those inputs based on the production share of that site, which was consolidated into three groups that could be modeled together having the same stone type and geographical region, as listed in Table .

After the stone is extracted from the quarry, it goes to a processing facility. Stone processor operations data were collected from facilities in five US states and Quebec, Canada. The material and production inputs from each site was used to calculate a weighted average of those inputs based on the production share of that site, which was consolidated into three groups that could be modeled together having the same stone type and geographical region, as listed in Table 2.

Countertops require additional operations to be performed at fabricators. Since Polycor specific data was not available for countertop fabrication, industry average data from NSI used in the generation of industry-wide EPD for natural stone countertops has been used [3].

Polycor resources and other literature data were used to develop estimates or assumptions for other upstream or downstream activities where necessary. Where relevant, this LCA uses the same assumptions as the NSI industry-wide LCA for consistency.

The LCA review and Sustainable Minds Transparency Report / EPD verification was performed by Jack Geibig, President, Ecoform and was determined to be in conformance to ISO 14040/14044 and the aforementioned PCRs.

1.4 Team

This report is based on the work of the project team led by Jasmin Randlett and Ralph Morgan on behalf of Polycor. Jasmin and Ralph were assisted by Polycor staff during the data collection, reporting, and interpretation phases.

Sustainable Minds led the development of the LCA results, report, and TRs.

1.5 Structure

The remaining sections of this report are organized as follows:
Chapter 2: Goal and scope
Chapter 3: Inventory analysis
Chapter 4: Impact assessment methods
Chapter 5: Results and Interpretation

This report includes LCA terminology. To assist the reader, special attention has been given to list definitions of important terms used at the end of this report.

2 GOAL AND SCOPE

This chapter explains the goal and scope of the study. The aim of the goal and scope is to define the product under study and the depth and breadth of the analysis.

2.1 Intended Application and Audience

This report intends to describe the application of the LCA methodology to the life cycle of stone countertops processed and fabricated by Polycor. It is intended for both internal and external purposes. The intended audience includes the program operator (Sustainable Minds) and reviewer who will be assessing the LCA for conformance to the PCR, as well as Polycor's internal stakeholders involved in marketing and communications, operations, and design. Results presented in this document are not intended to support comparative assertions. The results will be disclosed to the public in a Sustainable Minds Transparency Report / EPD (Type III environmental declaration per ISO 14025).

2.2 Stone Countertops

Polycor is the world's leading natural stone quarrier and processor [1]. Polycor produces various natural stone products.

Countertops refer to a raised, flat, and horizontal surface, built for work mainly in kitchens, bathrooms, and workrooms. This surface is mostly supported by cabinets and is positioned at a suitable height for the user to perform the intended task. Countertops often incorporate a backsplash, which is a vertical extension to the counter surface that protects the wall behind it from damage, and an edge, which is an often-beveled extension that protects the user from an otherwise sharp countertop cut and hides the intersection with cabinets or other supports. Countertops can be constructed of different materials with different attributes of functionality, durability, and aesthetics. Countertops processed and fabricated by Polycor are made of natural stone, and the different types included in this study are granite and marble. It is used in commercial, residential, and public sector buildings.

Polycor is interested in demonstrating its sustainability leadership. It is also interested in leveraging business value associated with transparent reporting of stone countertop's cradle-to-grave environmental impacts.

Natural stone extracted from quarries goes to processing facilities and then to countertop fabricators where the quarried material is processed into countertops. Once the job-specific measurements have been transferred to a template, the material is cut to size, the backsplash is incorporated, the edges are polished, and the finished countertop is sent to the job site. Since countertops can be fashioned into the shape and size required, the number of functional units that the countertop represents will vary.

The quarries and their type of natural stone are listed in Table 1. Processing facilities are listed in Table 2.

Table 1. Polycor quarries with stone type quarried and quarry locations

Polycor data group	Stone type	Quarry location(s)
American Granite Quarries	Granite	American Black Quarry, Elverson, PA; Barre Gray Quarry, Graniteville, VT; Bethel White Quarry, Bethel, VT; Concord Gray Quarry, Concord, NH; Mount Airy Quarry, Mount Airy, NC
Canadian Granite Quarries	Granite	Caledonia 4 Quarry, Quebec; Cambrian Black Quarry, Quebec; Kodiak Brown Quarry, Laurentian Rose Quarry, Quebec; Picasso Quarry, Quebec; Saint Henry Black Quarry, Quebec; Saint Sebastien Quarry, Quebec; Stanstead ROA Quarry, Quebec
American Marble Quarries	Marble	Polycor Georgia Marble Quarry, Tate, GA; Saint Clair Quarry, Marble City, OK

Table 2. Polycor producers/processors with stone type processed and plant locations

Polycor data group	Stone type	Plant location(s)
American Granite Plants	Granite	Mount Airy Plant, Mount Airy, NC; Concord Plant, Concord, NH; Jay White Plant, Jay, ME
Canadian Granite Plants	Granite	Beaudoin Plant, Quebec; Precision Plant, Quebec; Rivière-à-Pierre Plant, Quebec; Saint Sebastien Slab Plant, Quebec; Saint Sebastien Tile Plant, Quebec;
American Marble Plant	Marble	Georgia Marble Plant, Tate, GA

Since Polycor specific data was not available for countertop fabrication, industry average data from NSI used in the generation of industry-wide LCA for natural stone countertops has been used [3].

2.3 Functional Unit

The results in this report are expressed in terms of a functional unit, as it covers the entire life cycle of the product. Per the PCR, the functional unit is taken as one square meter of natural stone countertops for a service life of 10 years in residential use, inclusive of front edge and backsplash [2].

The natural stone countertop product system for granite and marble is a mixture of stone-specific and industry-average systems. While it is composed of weighted averages of Polycor's stone-specific quarries and production facilities, industry average data for countertop fabrication is used. The product systems in this study also include the ancillary materials used in the installation of the product. Polycor produces only the natural stone component while the installer purchases the ancillary materials separately. Materials required to meet the functional unit have been listed in Table 3.

Table 3. Materials required to meet the functional unit

Product	Functional unit	Materials needed to meet functional unit
Granite Countertops	One square meter (m^2) of product	Granite – 95.61 kg per m^2
Marble Countertops		Marble – 82.75 kg per m^2

Associated properties for natural stone countertops are indicated in Table 4 per relevancy, with the appropriate test method. Technical properties are specific to each stone type.

Table 4. Technical information table for natural stone countertops

Name	Natural stone		Unit	Test method
	Granite	Marble		
Thickness to achieve Functional unit	27.09	29.36	mm	NA
Product weight	95.61	82.75	kg/m^2	NA
Slab length	1.54		m	NA
Slab width[1]	0.65		m	NA
Density	[redacted]	[redacted]	kg/m^3	NA
Flexural strength	8.27	6.89	MPa	ASTM C880
Modulus of Rupture	10.34	6.89	MPa	ASTM C99
Compressive Strength	131.00	51.71	MPa	ASTM C170
Thermal conductivity (k-value)	1.73	2.07	W/mK	ASTM C518
Thermal resistance (R-value)[2]	0.56	0.49	m.K/W	ASTM C518
Liquid water absorption	0.1-1.0	0.1-1.0	% of dry weight	ASTM C97
VOC emissions[3]	0		µg/m^3	

2.4 System Boundaries

This section describes the system boundary for the product. The system boundary defines which life cycle stages are included and which are excluded.

This LCA's system boundary include the following life cycle stages:

I. A1-A5
- Raw materials acquisition, transportation, processing, and fabrication
- Distribution and installation

II. B1-B7
- Use

III. C1-C4
- Disposal/reuse/recycling

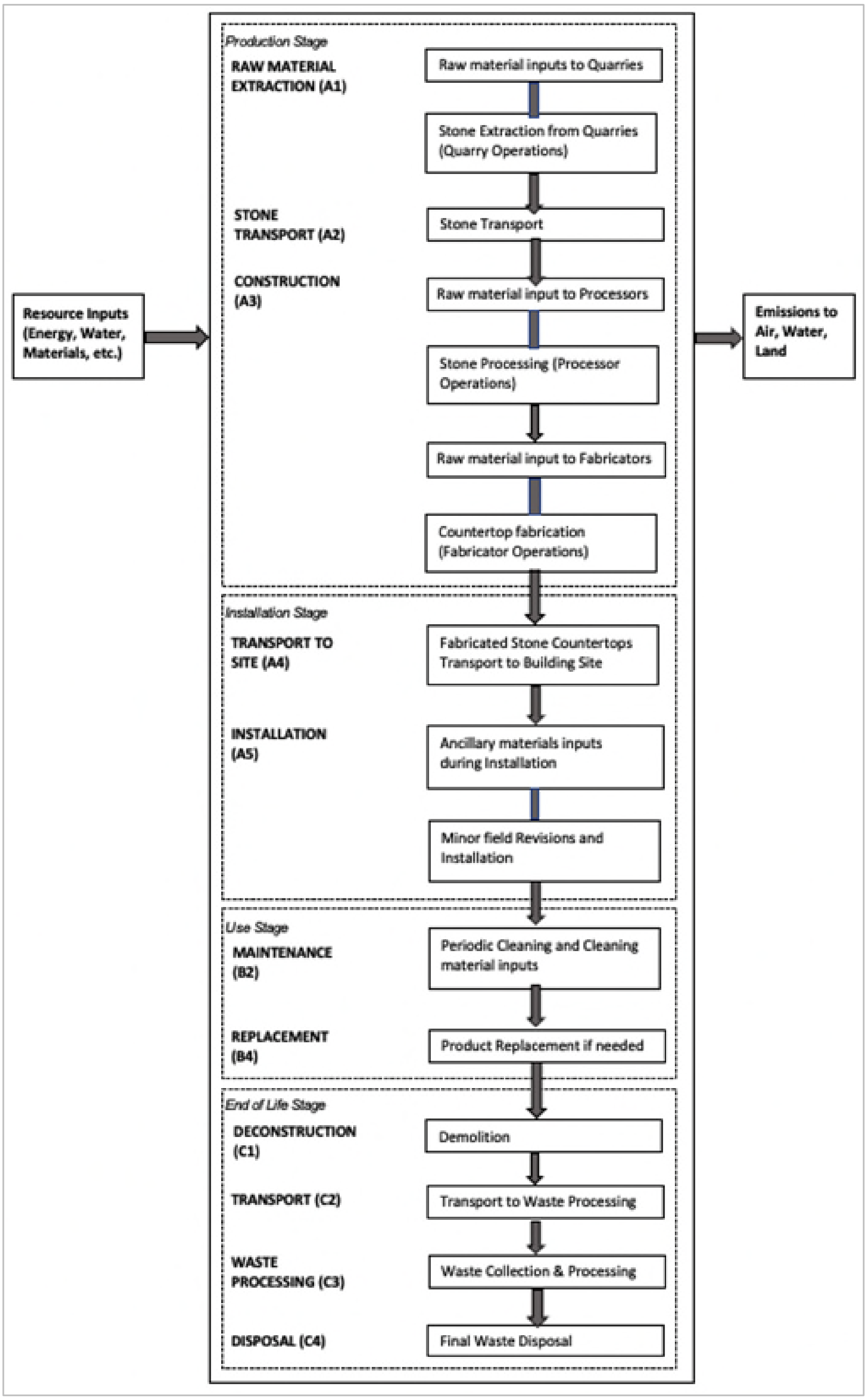
This boundary applies to the modeled product and can be referred to as 'cradle-to-grave', which means that it includes all life cycle stages and modules as identified in the PCR [2]. The life cycle includes all industrial processes from raw material acquisition and pre-processing, production, product distribution, use and maintenance, and end-of-life management. Figure 2 represents the life cycle stages for natural stone countertops

1 Kitchen countertop depth varies but a typical depth is 25.5 inches, equivalent to 0.65 m.
2 Thermal resistance or R-value depends on the thickness of the material. These values have been calculated for a 1" thick dimension stone sample. https://www.naturalstoneinstitute.org/designprofessionals/technical-bulletins/rvalue/
3 Natural Stone is inherently non-emitting per LEED credit. https://www.usgbc.org/credits/new-construction-core-and-shell-schools-new-construction-retail-new-construction-data-38

included in this LCA study. Table 5 lists specific inclusions and exclusions for the system boundary.

Table 5. System boundary inclusions and exclusions

Included	Excluded
• Raw material extraction • Processing of raw materials • Transport of raw materials • Stone extraction operations at quarries • Stone transport from quarries to processors • Processor operations (countertop production) • Energy production • Outbound transportation of stone countertops • Packaging of final stone countertops • Installation at building site • Periodic cleaning using soap water and resealing (use of silicone-based sealant) • End-of-life, including transportation	• Construction of capital equipment • Maintenance and operation of support equipment • Manufacture and transport of packaging materials not associated with final product • Human labor and employee transport • Building operational energy and water use not associated with final product • Overhead energy (e.g., heating, lighting) of manufacturing facility, when separated data were available



*B1, B3, B5, B6, & B7 stages have no associated activities and are not shown in this flow diagram

Figure 2. Applied system boundary for natural stone countertops

Since this PCR was developed before the ISO 21930 framework existed, a mapping has been performed as shown in Table 6 between the system boundary defined by ISO 21930 and the PCR for easy understanding of equivalent life cycle stages.

Table 6. Mapping life cycle stages between residential countertop PCR and ISO 21930

PCR life cycle stages	ISO 21930 life cycle stages
Material acquisition and pre-processing stage (Quarry + transport from quarry)	Raw material acquisition (A1)
	Upstream transport (A2)
Countertop Construction stage (Stone processors + Countertop fabricators)	Construction / Manufacturing (A3)
Installation stage	Transport to building sites (A4)
	Installation (A5)
Use and maintenance stage	Product use (B1)
	Maintenance (B2), Repair (B3), Replacement (B4), and Refurbishment (B5)
	Operational energy use (B6) and water use (B7)
End-of-life stage	Deconstruction (C1) and Transport to waste processing/disposal (C2)
	Waste processing (C3) and Disposal (C4)

2.4.1. A1-A3: Raw materials acquisition, transportation, & construction

Raw materials acquisition and transportation (A1-A2) These stages start when the material is extracted from the nature. This stage includes stone quarrying and ends when the stone reaches the gate of the processor/production facility. A1-A2 stage includes the following processes:

- Extraction and processing of raw material inputs to quarries (A1)
- Transport of raw materials from suppliers to quarries (A1)
- Quarry operations for stone extraction from mines (A1)
- Quarry stone scrap (A1)
- Transport of quarried stone from quarries to stone processors (A2)

Manufacturing (A3) This stage starts when the natural stone enters the stone processor and ends with the final countertop leaving the stone processor. This stage includes:

- Extraction and processing of raw material inputs to processing facilities
- All processor and fabricator operations
- Processing and fabrication waste (scrap stone and others)

The production of energy consumed by the quarries is modeled in A1, and the production of energy consumed during processor operations is modeled in A3.

2.4.2. A4-A5: Distribution and installation

Distribution (A4) Product distribution starts with the product leaving the gate of the production facility and ends after the product reaches the customer/building site.

Installation (A5) Product installation occurs after the customer takes possession of the product and before the customer can start using the product. The installation process is considered to be manual (no energy use). This stage includes:

- Electricity and ancillary materials specifically required for installation
- Installation waste product and packaging
- Waste transport and treatment as applicable.

2.4.3. B1-B7: Use

The use stage begins when the consumer starts using the product. Stone countertops requires no energy in the Product Use phase (B1).

Maintenance (B2) is related to any activities to maintain the function of the product in its lifetime. Based on discussions with NSI during the development of the industry-wide LCA, we assume the countertop requires occasional cleaning with soap and water. In the absence of primary data, we used maintenance quantities from an EPD for natural stone processed and fabricated in Turkey [4]. Non-granite countertops also requires re-sealing every 5 years. The same assumption is used for this Polycor's marble countertops.

Repair (B3), Replacement (B4), and Refurbishment (B5) are not relevant to stone countertops. Estimated service life of buildings (ESL) is taken to be 75 years. A product's RSL depends on the product properties and reference in-use conditions. Due to the nature of natural stone, it is anticipated that stone countertop will last for the lifetime of the building. Since the PCR specifies the service life of countertop to be 10 years, no replacement will be needed during the entire ESL.

Operational Energy Use (B6) and Operational Water Use (B7) are also not relevant.

2.4.4. C1-C4: Disposal/reuse/recycling

The end-of-life stage begins when the used product is ready for disposal, recycling, reuse, etc. and ends when the product is landfilled, returned to nature, or transformed to be recycled or reused. Processes that occur because of the disposal are also included within the end-of-life stage.

When the stone countertop is done being used, it is collected as construction and demolition waste.

The following life cycle stages are used to describe the end-of-life processes.

Deconstruction (C1) This stage includes dismantling/demolition of the product. Since the dismantling is assumed to be manual, there is no energy use during uninstallation.

Transport (C2) This stage includes transport of the product or disassembled product components from building site to final disposition. The waste transport distance is 32 kilometers, as prescribed by the PCR [2].

Waste processing (C3) This stage includes processing required before final disposition.

Disposal (C4) This stage includes final disposition (recycling or reuse). An end-of-life scenario of 31.5% landfilling and 68.5% recycling is considered using US EPA's construction waste disposal scenarios [5].

2.4.5. D: Benefits and loads beyond the system boundary

This study does not account for benefits and loads beyond the system boundary.

3 INVENTORY ANALYSIS

This chapter includes an overview of the obtained data and data quality that has been used in this study. A complete life cycle inventory calculation workbook, which catalogs the flows crossing the system boundary and provides the starting point for life cycle impact assessment, is available to the reviewer.

3.1 Data Collection

Data used for this project represents a mix of primary data collected from Polycor on the stone extraction (quarriers), stone processing (processors), countertop fabrication (fabricators), and background data from databases available in SimaPro, primarily ecoinvent. Overall, the quality of the data used in this study is considered to be good and representative of the described systems. All appropriate means were employed to obtain the data quality and representativeness as described below.

- **Gate-to-gate:** Data on stone extraction, processing materials, and fabricating the stone countertop were collected in a consistent manner and level of detail to ensure high quality data. All submitted data were checked for quality multiple times on the plausibility of inputs and outputs. All questions regarding data were resolved with Polycor. Inventory calculations were developed by an Analyst at Sustainable Minds and subsequently checked by a supporting consultant.

- **Background data:** The model was constructed in SimaPro with consistency in mind. Expert judgment was used in selecting appropriate datasets to model the materials and energy for this study and has been noted in the preceding sections. Detailed database documentation for ecoinvent can be accessed at: https://www.ecoinvent.org/database/database.html.

All primary data were provided by Polycor for operations between January 2020 and December 2021. Countertop fabrication operations are not operated by Polycor; therefore, fabrication data was used directly from NSI's industry-wide LCA for natural stone countertops [3]. Upon receipt, data were cross-checked for completeness and plausibility using mass balance and benchmarking. If gaps, outliers, or other inconsistencies occurred, Sustainable Minds engaged with individual Polycor to resolve any questions.

3.2 Primary Data

Natural stone countertop is produced in several steps that involve extraction of stones, its processing, and countertop fabrication. The finished stone countertop is then distributed to construction sites where they are installed, and the packaging is disposed. Countertops routinely perform their designed function until they are replaced for aesthetic rather than functional reasons (e.g., changes in consumer color preferences or replacing the countertop in conjunction with replacing the cabinet furniture). For this reason, the reference service life for residential countertops is 10 years according to the PCR. While the countertop may last well beyond this initial time period, this study assumes that at the end of the reference service life the countertop is removed and disposed.

Data used in this analysis represent the stone countertop production from Polycor. The material and production inputs from each quarry and processor site were used to calculate weighted averages of those inputs based on the production share of the site.

Results were then scaled to reflect the functional unit. Primary data was collected from both stone quarries and processors including all relevant extraction, processing, and fabrication stages from facilities operated by Polycor. Primary data is used for processes under the control of Polycor.

3.2.1. Quarry operations and transport to processors (A1-A2)

This stage includes raw materials inputs to the quarries and the extraction of stone from the quarries which are then transported to processors.

The stones quarried by Polycor in this study are granite and marble. Stones occur in the form of natural rock masses or layers either on the surface or underground. The process of extraction of suitable stones from those natural rock layers is called quarrying. There are multiple techniques used by Polycor quarries and those techniques can be divided into two main categories – with and without blasting.

Quarrying of stones with blasting
This method uses explosives to break stones from hard rocks of granites, quartzites, sandstones etc. A small quantity of explosive material (ANFOs - ammonium nitrate/fuel oil) is exploded at a calculated depth within the rocks to create cracks and loosen large stone blocks. There are a series of operations including drilling of blast holes, charging of blast holes with explosives, and then firing the shots. Blast holes can be driven either manually or mechanically. The loading or charging of blast holes with explosives needs to be done with great caution. For firing the shots, detonators are used.

Quarrying without blasting
This method does not use any explosive material; blocks of rocks are broken loose from their natural layers using hand tools or special purpose machineries. Quarrying is either done following a wedge method or channeling method. In the wedge method, holes are dug on the rock using manual chisels, hammers, or hammer drills. Steel wedge is inserted in the holes which are struck with the hammer to generate cracks. In the channeling method, channelizers are used which have reciprocating cutting tools and are power driven.

Polycor uses various quarry techniques depending on the stone deposit and development of the quarry. Polycor provided quarry data as part of the parallel industry-wide LCA, including relevant raw material inputs, water inputs, energy sources, waste practices and total stone production. Refer to section 3.5.1 for details on the upstream processes of producing the energy required. A weighted average inventory per kg of stone quarried for each stone type (granite, and marble) was developed.

Electricity and fuels used for office activities have been excluded. In most quarries, extracted blocks and stone that do not meet specifications are crushed and sold as aggregate material. Fuels used for this crushing has also been excluded from the inventory. The inventory includes transport of waste and hazardous waste to either the landfill centers or recycling centers, which are assumed to be transported 161 km via diesel powered trucks. The generation of scrap is embedded in the unit data used. Excess process materials (EPM) is generated in all the quarries in the form of waste blocks, cut-off stones, grouts, fragments, trimmings, and others. These stone pieces are predominantly either kept onsite to fill in older sections of the quarry or sold to others.

The quarries extracted [redacted] stone during the reporting time frame (2 years). A weighted inventory table was developed as depicted in Table 7 to represent 1 kg of natural stone extracted, each for granite and marble.

Table 7. Polycor inventory to quarry 1 kg of natural stone (granite and marble)

Resource category	Inputs & outputs	Unit	Granite	Marble
Electricity	Electricity	kWh	[redacted]	[redacted]
Fuels	Gasoline	liters	[redacted]	[redacted]
	Gasoline E10	liters	[redacted]	[redacted]
	Diesel (100% petroleum-based)	liters	[redacted]	[redacted]
	Biodiesel 70%	liters	[redacted]	[redacted]
	Propane	liters	[redacted]	[redacted]
	Heating oil	liters	[redacted]	[redacted]
Waste Generation	Total EPM generated	kg	3.10E+00	8.94E+00
	EPM kept onsite	kg	2.65E+00	4.56E+00
	EPM sold	kg	4.58E-01	4.38E+00
	Solid waste to landfill	kg	9.86E-04	9.36E-03
	Waste to recycling	kg	1.22E-03	1.57E-04
	Hazardous waste to recycling	kg	5.30E-05	1.62E-04
Material inputs	ANFO	kg	[redacted]	[redacted]
	Detonating cord	kg	[redacted]	[redacted]
	Stainless steel	kg	[redacted]	[redacted]
	Wood products	kg	[redacted]	[redacted]
	Hydraulic fluid	kg	[redacted]	[redacted]
	Lubricant	kg	[redacted]	[redacted]
	Motor oil	kg	[redacted]	[redacted]
	Tires	kg	[redacted]	[redacted]
	Antifreeze	kg	[redacted]	[redacted]
	Diamond belts/ wires/blades	kg	[redacted]	[redacted]
Waste transport	Diesel powered truck	tkm	3.64E-04	1.56E-03

Stone blocks extracted from quarries are then transported to the processing plants. Some quarries and processing plants are located next to each other, which require insignificant stone transport distance, while some plants are located farther from the quarries. Polycor provided primary data on this stone transport. In some cases, stone was picked up by customers and no distance information was available. The transport distance varies and the weighted transport distances for granite and marble are 83 km and 157 km respectively. In the cases with no primary distance available, we assumed a conservative stone transport distance of 100 km via truck & trailer.

3.2.2. Manufacturing (A3) – Processor operations

Natural stone processing plants process the quarried stone as needed for end product applications, including countertop fabrication, cladding, flooring, and others. Stone blocks go through a series of block saws and saw slabs, and later to bridge saws to complete cut-to-size pieces and profiling. For countertops, the stone blocks are first cut into slabs using high-speed gang saws fitted with several blades that make simultaneous parallel cuts. The slabs are then sent through a polishing machine that puts the desired finish on the piece. During this stage, slab is also calibrated, working down to a relatively uniform thickness across the length of the material. All products are checked for quality control and then stacked on pallets. Stone pallets are stored in a yard until shipped to the building site.

The processors use various energy sources to power the operations. Diesel fuel is used to power the front-end loaders, portable generators, haul trucks, skid steers, and sawing equipment. Gasoline is used mainly for pickup trucks and cars. The plant is powered via grid electricity and uses various fuels. Major consumable materials used in the plants include saw blades, diamond-tipped cutting tools, lumber for pallets, and banding. Packaging materials used include wooden pallets, plastic banding, and shrink-wraps.

The generation of scrap is embedded in the unit data used. EPM is generated in all the processors in the form of waste blocks, cut-off stones, grouts, fragments, trimmings, and others. Much of the generated EPM is reclaimed or recycled. Methods for recycling include filling on premises and processing/crushing into aggregate.

The inventory also includes transport of waste and hazardous waste generated in processors to either the landfill centers or recycling centers, which is assumed to be 161 km via diesel powered trucks. Electricity and fuels used for office activities; fuels used from crushing of coproducts in the processor plants have been excluded.

Polycor processors processed [redacted] stone during the reporting time frame (2 years). A weighted average inventory per m^2 of stone processed for each stone type applicable to stone countertops (granite and marble) was developed as represented in Table 8. Consistent with the NSI industry-wide LCA, this study also assumes that the energy consumed for processing countertops stone is 10% more than the average energy consumed to process other stone products because of the heavy polishing countertop stone goes through.

Table 8. Polycor inventory to process 1 m^2 of stone countertops (granite and marble)

Resource category	Inputs & output	Unit	Granite	Marble
Electricity	Electricity	kWh	[redacted]	[redacted]
Fuels	Gasoline	liters	[redacted]	[redacted]
	Diesel	liters	[redacted]	[redacted]
	Propane	liters	[redacted]	[redacted]
	Natural gas	MJ	[redacted]	[redacted]
	Heating oil	liters	[redacted]	[redacted]
Material inputs	Wood products	kg	[redacted]	[redacted]
	steel banding	kg	[redacted]	[redacted]
	plastic banding	kg	[redacted]	[redacted]
	Diamond blades/wires	kg	[redacted]	[redacted]
	Cardboard	kg	[redacted]	[redacted]
Waste Generation	Waste to landfill	kg	3.74E-01	8.91E+00
	Recycling	kg	1.80E-01	9.83E-02
	Hazardous (to recycler)	kg	6.74E-02	3.36E-02
Waste transport	Diesel powered truck	tkm	1.00E-01	1.46E+00

Polycor provided primary data as part of the corresponding industry-wide LCA, including energy, water, waste, and production. Refer to section 3.5.1 for details on the upstream processes of producing the energy required. Net production units of each stone type including the percentage of each stone type going to end stone applications (cladding, flooring, countertops, slabs, blanks, and others) was collected. This information is shown in Table 9.

Table 10 lists the stone mass per m^2 and weighted density calculation of stone produced from processors for different stone types.

Table 9. Share of end applications for produced stone

End stone application	Granite stone share	Marble stone share
Cladding	[redacted]	[redacted]
Flooring	[redacted]	[redacted]
Countertops	[redacted]	[redacted]
Others	[redacted]	[redacted]

Table 10. Stone mass per m^2 and final density

Stone category	Input stone kg per m^2 of processed stone	Produced stone kg per m^2 of processed stone	Weighted Density (kg/m^3)
Granite	[redacted]	[redacted]	[redacted]
Marble	[redacted]	[redacted]	[redacted]

3.2.3. Construction (A3) – Fabricator operations

Countertop goes through additional operations at fabricator facilities. Stone is offloaded at fabricators with fork trucks. Someone from the fabrication team is sent to the job site to take the measurements for templating purpose. Based on the template, the stone is cut to size, the backsplash is incorporated, the edges are polished, and the finished countertop is then strapped onto an A-frame on a delivery truck and sent to the job site. Figure 3 represents the operations, inputs, and outputs at fabricator facilities.

In the absence of Polycor's primary data for countertop fabrication, primary data used in NSI's industry-wide LCA for natural stone countertops was used directly [3]. Production data on both mass and area units, and number of fabrication jobs for different NSI fabricators was used.

The thickness breakdown from the participant NSI fabricators was deemed to accurately reflect the thickness for Polycor countertops. Average thickness of granite and marble countertops was 27.09 mm and 29.36 mm respectively.

Table 11 lists the stone mass per m^2 and weighted density calculation of countertop fabricated for different stone types (granite and marble). The generation of scrap is embedded in the unit data used. The difference between the input stone and produced stone mass per m^2 of countertops represents the scrap stone generated during countertop fabrication.

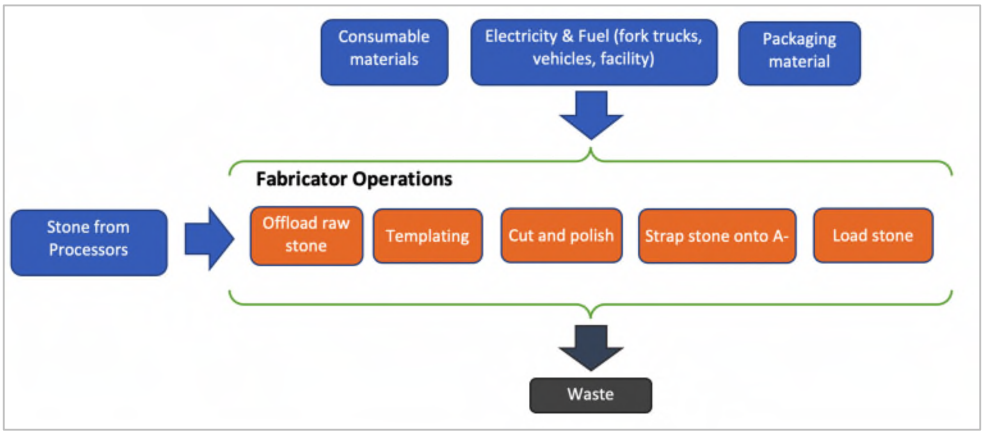


Figure 3. Countertop fabrication steps at fabricator facilities

Table 11. Fabricated countertops mass per m²

Stone category	Input stone kg per m² of countertop	Produced stone kg per m² of countertop
Granite	[redacted]	95.61
Marble	[redacted]	82.75

3.3 Secondary Data

For life cycle stages after the fabrication of stone countertops, secondary data sources are used to develop assumptions and generate the results.

3.3.1. Distribution (A4)

Distribution refers to the transport of the produced countertops from the fabricator facilities to the building sites for installation. Distribution includes two legs of transportation to the end user site. First one is an initial visit to measure the room dimensions via passenger vehicle. Second leg is for the delivery of the countertop, for which primary data on the amount of fuels consumed for countertops shipping were provided by the participant fabricators in NSI's industry wide LCA for stone countertops [3]. This data on fuel is used to calculate an estimate for an initial site visit, which was 80 km.

3.3.2. Installation (A5)

Installation refers to the installation of stone countertop in the buildings. Even though countertop fabrication (cutting and finishing to required size) is done at the fabricator plants and is typically delivered to the job site ready for installation, minor changes may be necessary to accommodate design revisions. Based on discussion with NSI fabricators, the scrap generated is insignificant and will be recycled if generated, so an installation scrap rate of 0% is assumed.

Primary data used in the NSI industry-wide LCA for stone countertops was used directly to accurately represent the amount of ancillary materials required for installation of countertops, and a weighted average inventory for 1 m² of countertop was developed. Major ancillary materials used are adhesives (0.017 kg), resins (0.089 kg), acrylics (0.0005 kg), sealers (0.009 kg), silicones (0.078 kg), etc. Drills and grinders used for installation use 12 Amps, which at 115 Volts is equal to 1.38 kW of power.

In the absence of primary data, electricity consumed for each job site per functional unit was calculated with an assumption that teams typically use a drill/grinder for 15 minutes on each job site. Waste generated in this stage includes packaging waste, and the waste transport distance is taken to be 32 km per the PCR.

3.3.3. Use (B1-B7)

This stage is related to any activities to ensure the functionality of stone countertop in its lifetime. Reference service life (RSL) for residential countertops is 10 years. Due to the nature of natural stone, it will last longer than 10 years and will need no replacements during the service life.

Natural stone countertops routinely perform their desired function and will mostly require no additional sealing or grouting in the service life. The quality of sealer significantly influences the frequency of sealing, and some sealer manufacturers recommend doing it every 5 years. Although people rarely re-seal their countertops, we have taken a conservative assumption that marble stone countertops will be resealed every 5 years with the use of 0.165 kg silicone-based sealing[4]. For the reference service life, only one cycle of sealing will be needed. This is consistent with the NSI's industry-wide LCA of stone countertops.

Under normal operating conditions, stone countertop also requires periodic cleaning and the cleaning agent used is water with soap. We assumed a weekly cleaning schedule using detergent and rinsing with tap water – 5 grams of detergent with 0.1 liter of water is consumed during each cycle of cleaning per m^2 of stone countertop [4].

3.3.4. Deconstruction (C1)

Per PCR, manual deconstruction is considered for all stone countertops. There will be no operational energy use and thus, no impacts associated with the deconstruction work after the service life ends.

3.3.5. End of Life Transport (C2)

Deconstructed stone countertops are then shipped to the end-of-life disposal centers. We assumed that the transport for final countertop disposal is 32 km as prescribed by the PCR.

3.3.6. Waste Processing (C3)

We assume that no waste processing is required before either the landfill or the recycling process.

3.3.7. Final Disposal (C4)

Based on US EPA's data on construction end waste disposal scenarios, it was assumed that 31.5% of stone countertop will be landfilled for inert disposal, while the rest will be recycled for various purposes [5].

[4] https://www.naturalstonetiles.com.au/2016/09/23/guide-sealing-natural-stone-tiles/
Assumed 1 liter of sealant coat used for 5-10 square meters of non-granite stone countertops (same amount as stone tiles).

3.4 Data selection and quality

Data requirements provide guidelines for data quality in the LCA and are important to ensure data quality is consistently tracked. Data quality considerations include precision, completeness, and representativeness.

Precision describes the variability of the inventory data. This study applies a combination of primary data, estimates and assumptions for some inventory inputs. We apply secondary data for non-stone consumable and ancillary materials. Since the inputs/outputs for both quarries and producers were directly measured by Polycor, we consider inventory data to have good precision.

Completeness is a measure of the flows (mass, energy, emissions) that are included in the study in relation to the total flows covered in the scope of the product life cycle. We developed separate data collection forms for quarries and producers and worked extensively with Polycor to obtain a comprehensive set of primary data associated with the fabrication processes. We considered the dataset complete based on our understanding of the processor and fabrication sites and a review with key stakeholders on the Polycor team. Even though we observe cut-off criteria consistent with those prescribed in the PCR, no known flows are deliberately excluded from this analysis other than those defined to be outside the system boundary as stated in Table 5.

Representativeness describes the ability of the data to reflect the system in question. We measure representativeness with the time, technology, and geographic coverage of the data. An evaluation of the data quality about these requirements is provided in the interpretation chapter of this report.

Time coverage. Time coverage describes the age of the inventory data, and the period of time over which data is collected. Polycor provided primary data for a time period of January 2020 to December 2021. This time period of 2 years will be able to represent typical operations of quarries and production facilities. Background data for upstream and downstream processes (i.e., raw materials, energy resources, transportation, and ancillary materials) were obtained from the ecoinvent database and U.S. ecoinvent (US-EI) database.

Technology coverage. Data were collected for Polycor quarries and producers in covering a range of technologies as described earlier in this document. Incorporation of this range provides a representative depiction of the industry average.

Geographical coverage. Data were collected from quarries and producers mainly operating in North America (mainly the US and Canada). Quarries in North America are responsible for the total quarried stone included in this study. As such, the geographical coverage for this study is based on North American conditions. Whenever geographically relevant background data were not readily available, other geographies were used as proxies. Following production, stone countertop is shipped for use within North America. Installation, use and end-of-life impact were modeled using background data that represents average conditions.

3.5 Background data

This section details background datasets used in modeling for stone countertop. Each table lists dataset purpose, name, source, reference year, and location. All datasets used are market datasets representing unit processes. Market based datasets already include the transportation of the material from average producers to average consumers.

3.5.1. Fuels and energy

National and regional averages for fuel inputs and electricity grid mixes were obtained from databases in SimaPro. For fuels, specific US based datasets for specific fuels were used if available. In cases where fuel mixes were specified (e.g., fossil and biofuel mixes), manual datasets were created to reflect the fuel ratios. Manual electricity datasets were developed to represent average Polycor quarry and Polycor producer facilities based on the grouping of data provided. Countertop fabrication data collected for NSI's industry-wide LCA for natural stone countertops was used directly to represent countertop fabrication for Polycor as well. Electricity datasets were chosen from each geographical region, as shown in Table 12, and assigned the same weighting as the share of production from those regions. Table 12 shows the most relevant LCI datasets used in modeling the product systems.

Table 12. Key energy datasets used in inventory analysis

Energy source	Dataset used	Primary source	Reference year	Geography
Electricity – Quarry	Manual dataset based on production share: - e-grid datasets for US based quarries / US average electricity dataset*, - Canadian average electricity dataset for Canada based quarries*	US -EI 2.2, Ecoinvent v3 (for Canada)	2018	US, Canada
Electricity – Producer	Manual dataset based on production share: - e-grid datasets for US based processors / US average electricity dataset*, - Canadian average electricity dataset for Canada based processors*	US -EI 2.2, Ecoinvent v3 (for Canada)	2018	US, Canada
Electricity – Fabricator**	Manual dataset based on production share Manual dataset based on production share: - e-grid datasets for US based fabricators	US -EI 2.2	2018	US (includes different e-grid regions)
Gasoline	Gasoline, combusted in equipment NREL	US -EI 2.2	2018	US
Diesel (100% petroleum based)	Diesel, combusted in industrial equipment NREL	US -EI 2.2	2018	US
Propane	LPG combustion, at industrial furnace	US -EI 2.2	2018	US
Natural Gas	Natural gas, combusted in industrial equipment NREL	US -EI 2.2	2018	North America
Heating Oil	Heat, light fuel oil, at industrial furnace	US -EI 2.2	2018	US
Oil	Heat, heavy fuel oil, at industrial furnace	US -EI 2.2	2018	US
Gasoline E10	Manual dataset with 90% petroleum + 10% corn ethanol	US -EI 2.2	2018	US
Biodiesel 70%	Manual dataset with 30% diesel + 70% soybean biodiesel*	US -EI 2.2	2018	US

**represents proxy datasets used.*
*** used directly from NSI's industry-wide LCA for natural stone countertops*

3.5.2. Quarry, Processor, Fabricator operations, and Installation

Datasets for all upstream and downstream raw materials were obtained from the ecoinvent v3.8 database. Table 13 shows the LCI datasets used in modeling the main raw materials used in either of quarries, producers, fabricators or during installation/use phase.

Table 13. Material datasets used in inventory analysis

Materials and water	Dataset used	Primary source	Reference year	Geography
Ammonium nitrate (95.5% in ANFO)	Ammonium nitrate*	Ecoinvent v3	2020	North America
Blasting caps	Explosive, tovex*	Ecoinvent v3	2021	Global
Detonating cord	70% explosive tovex* + 30% plastic tube (polyethylene)	Ecoinvent v3	2021	Global
Stainless steel Razor blades	Steel, chromium steel 18/8	Ecoinvent v3	2020	Global
Wood products	Wood pellet	Ecoinvent v3	2020	Rest of World (non-Europe)
Sealer	Silicone product	Ecoinvent v3	2021	Rest of World (non-Europe)
Rubber Caulk	Synthetic rubber	Ecoinvent v3	2021	Global
Hydraulic fluid	White mineral oil	US-EI 2.2	2018	US
Lubricant Motor oil	Lubricating oil	Ecoinvent v3	2021	Global
Antifreeze	Ethylene glycol	Ecoinvent v3	2021	Global
Polyurethane Foam packaging	Polyurethane, flexible foam	Ecoinvent v3	2021	Rest of World (non-Europe)
Diamond	Boron carbide*	Ecoinvent v3	2021	Global
Carbide tooling	Silicon carbide*	Ecoinvent v3	2021	Global
Plastic Tape	Polypropylene, granulate	Ecoinvent v3	2021	Global
Epoxy & resin	Epoxy resin, liquid	Ecoinvent v3	2021	Rest of World (non-Europe)
Cardboard	Corrugated board box	Ecoinvent v3	2018	Rest of World (non-Europe)
Adhesive	Polyurethane adhesive	Ecoinvent v3	2020	Global
Fiber glass rodding	Glass fiber reinforced plastic, polyester resin	Ecoinvent v3	2021	Global
Sandpaper Garnet	Sodium silicate, solid	Ecoinvent v3	2021	Europe
Paper rag	Kraft paper*	Ecoinvent v3	2020	Rest of World (non-Europe)
Cloth rag	Fibre, cotton	Ecoinvent v3	2021	Global
Lacquer thinner	White Spirit*	Ecoinvent v3	2021	Global
Detergent for cleaning	Soap	US-EI 2.2	2018	US
Denatured alcohol	Ethanol from ethylene*	Ecoinvent v3	2021	Rest of World (non-Europe)
Acrylics	Acrylic binder	US-EI 2.2	2018	US
Flocculant (water purifier)	Aluminium sulphate, powder*	US-EI 2.2	2018	US
Well water	Well water	Input from nature	N/A	US
Municipal water	Tap water, at user	Ecoinvent v3	2018	US
Surface water	River water	Input from nature	N/A	US

**represents proxy datasets used.*

3.5.3. Transportation

The following data sets were used to represent typical transport modes.

Table 14. Transportation datasets used in inventory analysis

Transportation	Dataset name	Source	Year of publication	Geography
Transport for initial site visit for measurements	Transport, passenger car, petrol, fleet average	US -EI 2.2	2018	US
Transport of stone between facilities and then to building sites for installation	Transport, lorry, lorry, >32 metric ton, EURO5	US -EI 2.2	2018	US
Transport of waste/scrap to end of life scenarios	Transport, lorry, lorry 16-32 metric ton, EURO5	US -EI 2.2	2018	US

3.5.4. Disposal

Disposal processes were also obtained from ecoinvent database to represent disposal scenarios in US. Table 15 presents the relevant disposal datasets used in the model.

Table 15. Disposal datasets used in inventory analysis

Material & Disposition	Dataset name	Source	Year of publication	Geography
Septic water output	Sewage to wastewater treatment	US EI-2.2	2019	US
Solid waste to landfill	Disposal, inert waste to inert materials landfill	US EI-2.2	2019	US
Hazardous waste to landfill	Disposal, hazardous waste, for underground deposit	US EI-2.2	2019	US

3.5.5. Emissions to air, water, and soil

Polycor reported no direct emissions to air, water, or soil.

3.6 Limitations

A life cycle assessment of a product system is broad and complex, and inherently requires assumptions and simplifications. The following limitations of the study should be recognized:

- This study is based on the aggregated primary data of country- and stone-specific quarries and production facilities, so as to effectively represent the stone-specific results, but actual operations at each of the quarries and producers vary.
- Some of the facilities provided partial primary data on materials consumed. For gaps in materials data, an average from other facilities was assumed. Total material consumed was normalized with the total production mass to generate material consumption per production mass of each stone type.
- As it was very difficult to collect primary transportation data for purchased materials, market-based datasets are used, which inherently includes the average transport distance from suppliers to consumers. Actual transport data will vary based on supplier location for each facility and for each material.
- For the quarries with partial or no primary data on stone transport to processors, we have taken a conservative stone transport distance of 100 km via truck & trailer, higher than the weighted transport distance from the primary data. The actual distance likely varies.

- Countertop processing in processors is limited to cutting the quarried stone into slabs and polishing to be shipped to fabricators. Although other stone products like cladding and flooring go through additional operations, because of the heavy polishing, it is assumed that countertop processing requires 10% more energy than other products. A sensitivity analysis is included in this study to see the robustness of this estimate.
- In the absence of primary data for Polycor's countertop fabricators, fabrication data from NSI's industry-wide LCA for natural stone countertops has been used in this study. There was no stone specific data available so same inventory was used to represent both granite and marble countertop fabrication.
- Generic data sets used for material inputs, transport, and waste processing are considered good quality, but actual impacts from material suppliers, transport carriers, and local waste processing may vary.
- The impact assessment methodology categories do not represent all possible environmental impact categories.
- Characterization factors used within the impact assessment methodology may contain varying levels of uncertainty.
- LCA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks.

3.7 Criteria for the exclusion of inputs and outputs

All energy and material flow data available were included in the model and comply with the PCR cut-off criteria. No known flows were excluded from the analysis.

- The cut-off criteria on a unit process level can be summarized as follows: All inputs and outputs to a (unit) process shall be included in the calculation of the pre-set parameters results, for which data are available. Data gaps shall be filled by conservative assumptions with average, generic or proxy data. Any assumptions for such choices shall be documented.

- Particular care should be taken to include material and energy flows that are known or suspected to release substances into the air, water or soil in quantities that contribute significantly to any of the pre-set indicators of this document. In cases of insufficient input data or data gaps for a unit process, the cut-off criteria shall be 1 % of renewable primary resource (energy), 1 % nonrenewable primary resource (energy) usage, 1 % of the total mass input of that unit process and 1 % of environmental impacts. The total of neglected input flows per module shall be a maximum of 5 % of energy usage, mass and environmental impacts. When assumptions are used in combination with plausibility considerations and expert judgment to demonstrate compliance with these criteria, the assumptions shall be conservative.

- All substances with hazardous and toxic properties that can be of concern for human health and/or the environment shall be identified and declared according to normative requirements in standards or regulation applicable in the market for which the EPD is valid, even though the given process unit is under the cut-off criterion of 1 % of the total mass.

In this report, no known flows are deliberately excluded; therefore, these criteria have been met.

3.8 Allocation

Whenever a system boundary is crossed, environmental inputs and outputs must be assigned to the different products. Where multi-inputs or multi-outputs are considered, the same applies. The PCR prescribes where and how allocation occurs in the modeling of the LCA. This LCA follows the polluter pays principle.

No co-product allocation was necessary in the quarry operations since each quarry produces a single stone type. The quarry inputs and outputs were divided evenly among the quarried stone by mass. Similarly, no co-product allocation was required for processor operations since each processing plant processes a single stone type, and processing data was collected from those plants specific to each stone type. The processor inputs and outputs were divided evenly among the processed stone by area. Countertop stones receive more polishing than other product types and therefore more resources were allocated (10% more than the average, based on the best judgement of industry experts) to the countertop production.

Co-product allocation was not needed for countertop fabricator operations as well; inputs and outputs were divided evenly among the fabricated countertops by area.

3.9 Software and database

The LCA model was created using SimaPro Developer 9.4. Ecoinvent and other databases listed in section 3.5 provide the life cycle inventory data of the raw materials and processes for modeling the products.

3.10 Critical review

This is a supporting LCA report for two Polycor Stone Countertops Transparency Reports – one each for granite and marble – which will be evaluated for conformance to the PCRs according to ISO 14025 [7] and the ISO 14040/14044 standards [8].

4 IMPACT ASSESSMENT METHODS

4.1 Impact assessment

The environmental indicators as required by the PCR are included as well as other indicators required to derive the SM2013 single score [9] (see Table 16). The impact indicators are derived using the 100-year time horizon[5] factors, where relevant, as defined by TRACI 2.1 classification and characterization [10]. Long-term emissions (> 100 years) are not taken into consideration in the impact estimate. USEtox indicators[6] are used to evaluate toxicity. Global warming potential (GWP) based on AR6 methodology developed by the Intergovernmental Panel on Climate Change (IPCC) 2021 was also calculated in addition to the GWP from TRACI methodology [11]. This GWP includes fossil-based, biogenic, CO_2 uptake, and land transformation CO_2 with a timeframe of 100 years.

Table 16. Selected impact categories and units

Impact category	Unit	Description
Acidification	kg SO_2 eq (sulphur dioxide)	Acidification processes increase the acidity of water and soil systems and causes damage to lakes, streams, rivers and various plants and animals as well as building materials, paints and other human-built structures.
Ecotoxicity	CTUe	Ecotoxicity causes negative impacts to ecological receptors and, indirectly, to human receptors through the impacts to the ecosystem.
Eutrophication	kg N eq (nitrogen)	Eutrophication is the enrichment of an aquatic ecosystem with nutrients (nitrates and phosphates) that accelerate biological productivity (growth of algae and weeds) and an undesirable accumulation of algal biomass.
Global warming	kg CO_2 eq (carbon dioxide)	Global warming is an average increase in the temperature of the atmosphere near the Earth's surface and in the troposphere.
Ozone depletion	kg CFC-11 eq	Ozone depletion is the reduction of ozone in the stratosphere caused by the release of ozone depleting chemicals.
Carcinogenics	CTUh	Carcinogens have the potential to form cancers in humans.
Non-carcinogenics	CTUh	Non-Carcinogens have the potential to causes non-cancerous adverse impacts to human health.
Respiratory effects	kg $PM_{2.5}$ eq (fine particulates)	Particulate matter concentrations have a strong influence on chronic and acute respiratory symptoms and mortality rates.
Smog	kg O_3 eq (ozone)	Smog formation (photochemical oxidant formation) is the formation of ozone molecules in the troposphere by complex chemical reactions.
Fossil fuel depletion	MJ surplus	Fossil fuel depletion is the surplus energy to extract minerals and fossil fuels.

[5] The 100-year period relates to the period in which the environmental impacts are modeled. This is different from the time period of the functional unit. The two periods are related as follows: all environmental impacts that are created in the period of the functional unit are modeled through life cycle impact assessment using a 100-year time horizon to understand the impacts that take place.

[6] USEtox is available in TRACI and at http://www.usetox.org/

With respect to global warming potential, biogenic carbon is included in impact category calculations and also reported separately. Some emissions occur during blasting as explosives (ANFO, PETN) are used in quarrying. The emissions from the detonation of these explosives have been estimated using the emission factors from National Pollutant Inventory and added to the TRACI results [12].

It shall be noted that the above impact categories represent impact potentials. They are approximations of environmental impacts that could occur if the emitted substances would follow the underlying impact pathway and meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures the environmental load that corresponds to the chosen functional unit.

The results from the impact assessment indicate potential environmental effects and do not predict actual impacts on category endpoints, the exceedance of thresholds, or safety margins or risks.

4.2 Normalization and weighting

To arrive to a single score indicator, normalization [13] and weighting [14] conforming to the SM 2013 Methodology were applied.

Table 17. Normalization and weighting factors

Impact category	Normalization	Weighting (%)
Acidification	90.9	3.6
Ecotoxicity	11000	8.4
Eutrophication	21.6	7.2
Global warming	24200	34.9
Ozone depletion	0.161	2.4
Carcinogenics	5.07E-05	9.6
Non carcinogenics	1.05E-03	6.0
Respiratory effects	24.3	10.8
Smog	1390	4.8
Fossil fuel depletion	17300	12.1

5 ASSESSMENT AND INTERPRETATION

This chapter includes the results from the LCA for the products studied. It details the results per product per functional unit and concludes with recommendations. The results are presented per functional unit (per m^2 of natural stone countertops). Results provided in this report may be scaled according to different thicknesses as desired.

5.1 Resource use and waste flows

Resource use indicators, output flows and waste category indicators, and carbon emissions and removals are presented in this section. LCI flows were calculated with the help of the American Center for Life Cycle Assessment guidance to the ISO 21930:2017 metrics [15].

Resource use indicators represent the amount of materials consumed to produce not only the product itself, but the raw materials, electricity, etc. that go into the product's life cycle.

Primary energy is an energy form found in nature that has not been subjected to any conversion or transformation process and is expressed in energy demand from renewable and non-renewable resources. Efficiencies in energy conversion are considered when calculating primary energy demand from process energy consumption. Water use represents total water used over the entire life cycle. No renewable energy was used in production beyond that accounted for in the electricity grid mixes used, and no energy was recovered.

5.1.1. Resource use and waste flows – Granite countertops

Table 18 tabulates resource use, output and waste flows, and carbon emissions and removals per functional unit for granite countertops.

Table 18. Resource use; output and waste flows; carbon emissions & removals per functional unit of granite countertops

	Unit	Material acquisition and pre-processing		Countertop Construction	Installation stage		Use & maintenance	End of life	
		Quarry Operations	Quarry to Processor Transport	Construction	Transport to Building site	Installation	Use	End of Life Transport	Final Disposal
		A1	A2	A3	A4	A5	B2	C2	C4
Energy consumption, energy type, and material resources									
Renewable fuels	MJ, LHV	5.73E+00	3.43E-02	1.30E+02	6.18E+00	2.41E+00	1.14E+02	8.73E-03	2.14E-03
Virgin renewable resources	MJ, LHV	6.56E-01	0	9.52E+01	0	4.81E-01	0	0	0
Fossil fuels	MJ, LHV	1.14E+02	2.19E+01	4.39E+02	2.44E+02	7.64E+01	3.04E+01	5.58E+00	1.03E+00
Nuclear fuels	MJ, LHV	1.12E+01	1.38E-01	2.22E+02	3.22E+00	2.26E+00	4.36E+00	3.50E-02	8.56E-03
Miscellaneous fuels	MJ, LHV	8.17E-04	5.37E-06	2.12E-02	5.01E-05	1.55E-03	1.10E+01	1.37E-06	2.56E-07
Virgin non-renewable resources	MJ, LHV	1.25E+02	2.21E+01	6.54E+02	2.48E+02	7.64E+01	4.57E+01	5.62E+00	1.04E+00
Recycled resources	kg	0	0	0	0	0	0	0	0
Renewable secondary fuels	MJ, LHV	0	0	0	0	0	0	0	0
Non-renewable secondary fuels	MJ, LHV	0	0	0	0	0	0	0	0
Recovered energy	MJ, LHV	0	0	0	0	0	0	0	0
Use of net freshwater resources	m^3	7.50E+01	3.74E-03	1.44E+01	3.97E-01	1.86E+00	1.21E-01	9.52E-04	1.82E-04
Primary energy demand	MJ	1.32E+02	2.21E+01	8.86E+02	2.54E+02	8.15E+01	1.59E+02	5.63E+00	1.04E+00
Primary energy demand (fossil, nuclear)	MJ	1.25E+02	2.21E+01	6.61E+02	2.48E+02	7.86E+01	3.47E+01	5.62E+00	1.04E+00
Renewable (solar, wind, hydro, biomass)	MJ	6.38E+00	3.43E-02	2.25E+02	6.18E+00	2.90E+00	1.14E+02	8.73E-03	2.14E-03
Emissions to air									
Sulphur oxides (SO_x)	kg	1.11E-02	1.31E-03	5.97E-02	4.39E-03	7.07E-03	5.46E-03	3.33E-04	1.06E-04
Nitrogen oxides (NO_x)	kg	1.10E-01	5.45E-03	1.24E-01	1.37E-02	6.38E-02	8.65E-03	1.39E-03	8.70E-04
Carbon dioxide (CO_2)	Kg	7.82E+00	1.58E+00	4.35E+01	4.63E+00	4.61E+00	6.30E+00	4.02E-01	7.22E-02
Methane (CH_4)	kg	1.86E-02	1.61E-03	9.83E-02	4.58E-03	1.36E-02	1.32E-02	4.10E-04	4.45E-05
Nitrous oxide (N_2O)	kg	8.83E-05	6.51E-05	1.12E-03	2.18E-04	1.19E-04	1.57E-03	1.66E-05	2.44E-06
Carbon monoxide (CO)	kg	7.28E-02	2.96E-04	9.32E-02	2.22E-02	1.79E-02	6.30E-02	7.53E-05	2.24E-04
Water usage and emissions to water									
Phosphates, nitrates, dioxin, and heavy metals	kg	7.73E-04	6.00E-06	1.94E-02	2.05E-05	7.64E-04	3.59E-02	1.53E-06	3.45E-07
Consumption (total water input)	m^3	9.43E+01	4.21E-03	2.46E+01	7.84E-01	4.74E+00	1.37E-01	1.07E-03	2.10E-04
Output flows and waste category indicators									
Hazardous waste disposed	kg	7.70E-03	0	1.94E-03	0	0	0	0	0
Non-hazardous waste disposed	kg	1.43E-01	0	2.35E+01	0	2.04E+00	0	0	3.01E+01
High-level radioactive waste, conditioned, to final repository	kg	7.67E-03	1.92E-06	2.82E-01	6.49E-06	1.00E-06	5.39E-05	5.78E-07	1.12E-07
Intermediate- and low-level radioactive waste, conditioned, to final repository	kg	2.73E-06	6.15E-07	2.75E-05	1.28E-12	1.30E-10	1.88E-08	5.90E-07	4.79E-09
Components for re-use	kg	0	0	0	0	0	0	0	0
Landfill avoidance / materials for recycling	kg	4.51E+02	0	7.07E+01	0	4.10E+00	0	0	6.55E+01
Carbon emissions and removals									
Biogenic Carbon Removal from Product	kg CO_2	0	0	0	0	0	0	0	0
Biogenic Carbon Emission from Product	kg CO_2	0	0	0	0	0	0	0	0
Biogenic Carbon Removal from Packaging	kg CO_2	0	0	7.63E-02	0	3.81E-03	0	0	0
Biogenic Carbon Emission from Packaging	kg CO_2	0	0	0	0	1.12E-02	0	0	0
Biogenic Carbon Emission from Combustion of Waste from Renewable Sources Used in Production Processes	kg CO_2	0	0	0	0	0	0	0	0
Carbon Emissions from Combustion of Waste from Non-Renewable Sources used in Production Processes	kg CO_2	0	0	0	0	0	0	0	0

5.1.2. Resource use and waste flows – Marble countertops

Table 19 tabulates resource use, output and waste flows, and carbon emissions and removals per functional unit for marble countertops.

Table 19. Resource use; output and waste flows; carbon emissions & removals per functional unit of marble countertops

	Unit	Material acquisition and pre-processing		Countertop Construction	Installation stage		Use & maintenance	End of life	
		Quarry Operations	Quarry to Processor Transport	Construction	Transport to Building site	Installation	Use	End of Life Transport	Final Disposal
		A1	A2	A3	A4	A5	B2	C2	C4
Energy consumption, energy type, and material resources									
Renewable fuels	MJ, LHV	1.86E+01	8.52E-02	3.00E+01	6.18E+00	2.41E+00	1.14E+02	7.56E-03	1.85E-03
Virgin renewable resources	MJ, LHV	0	0	4.38E+01	0	4.81E-01	0	0	0
Fossil fuels	MJ, LHV	2.38E+02	5.44E+01	5.94E+02	2.44E+02	7.64E+01	3.80E+01	4.83E+00	8.91E-01
Nuclear fuels	MJ, LHV	5.34E+01	3.42E-01	2.28E+02	3.22E+00	2.26E+00	4.94E+00	3.03E-02	7.41E-03
Miscellaneous fuels	MJ, LHV	4.79E-04	1.33E-05	1.67E-02	5.01E-05	1.55E-03	1.10E+01	1.18E-06	2.21E-07
Virgin non-renewable resources	MJ, LHV	2.91E+02	5.48E+01	8.03E+02	2.48E+02	7.64E+01	5.39E+01	4.86E+00	8.98E-01
Recycled resources	kg	0	0	0	0	0	0	0	0
Renewable secondary fuels	MJ, LHV	0	0	0	0	0	0	0	0
Non-renewable secondary fuels	MJ, LHV	0	0	0	0	0	0	0	0
Recovered energy	MJ, LHV	0	0	0	0	0	0	0	0
Use of net freshwater resources	m^3	5.38E+01	9.28E-03	9.64E+00	3.97E-01	1.86E+00	1.06E+00	8.24E-04	1.58E-04
Primary energy demand	MJ	3.10E+02	5.49E+01	8.96E+02	2.54E+02	8.15E+01	1.68E+02	4.87E+00	9.00E-01
Primary energy demand (fossil, nuclear)	MJ	2.91E+02	5.48E+01	8.22E+02	2.48E+02	7.86E+01	4.29E+01	4.86E+00	8.98E-01
Renewable (solar, wind, hydro, biomass)	MJ	1.86E+01	8.52E-02	7.38E+01	6.18E+00	2.90E+00	1.14E+02	7.56E-03	1.85E-03
Emissions to air									
Sulphur oxides (SO_x)	kg	2.71E-02	3.25E-03	4.46E-02	4.39E-03	7.07E-03	6.82E-03	2.88E-04	9.19E-05
Nitrogen oxides (NO_x)	kg	1.63E-01	1.35E-02	5.31E-02	1.37E-02	6.38E-02	9.90E-03	1.20E-03	7.51E-04
Carbon dioxide (CO_2)	Kg	1.82E+01	3.92E+00	2.92E+01	4.63E+00	4.61E+00	6.30E+00	3.48E-01	6.24E-05
Methane (CH_4)	kg	4.11E-02	4.00E-03	1.74E+01	4.58E-03	1.36E-02	1.53E-02	3.55E-04	3.85E-05
Nitrous oxide (N_2O)	kg	9.27E-04	1.62E-04	6.97E-02	2.18E-04	1.19E-04	1.58E-03	1.44E-05	2.11E-06
Carbon monoxide (CO)	kg	2.03E-01	7.34E-04	1.16E-02	2.22E-02	1.79E-02	6.40E-02	6.52E-05	1.93E-04
Water usage and emissions to water									
Phosphates, nitrates, dioxin, and heavy metals	kg	8.35E-03	1.49E-05	2.02E-02	2.05E-05	7.64E-04	3.59E-02	1.37E-06	3.15E-07
Consumption (total water input)	m^3	1.06E+02	1.05E-02	1.67E+01	7.84E-01	4.74E+00	1.93E+00	9.28E-04	1.82E-04
Output flows and waste category indicators									
Hazardous waste disposed	kg	3.06E-02	0	1.94E-03	0	0		0	0
Non-hazardous waste disposed	kg	1.77E+00	0	3.27E+01	0	3.20E+00		0	26.06
High-level radioactive waste, conditioned, to final repository	kg	1.92E+00	4.58E-06	5.42E-02	6.49E-06	1.00E-06	1.98E-04	5.17E-07	9.69E-08
Intermediate- and low-level radioactive waste, conditioned, to final repository	kg	1.87E-03	6.42E-07	1.54E-08	1.28E-12	1.30E-10	6.34E-08	5.90E-07	4.15E-09
Components for re-use	kg	0	0	0	0	0	0	0	0
Landfill avoidance / materials for recycling	kg	4.59E+04	0	1.07E+02	0	6.41E+00		0	5.67E+01
Carbon emissions and removals									
Biogenic Carbon Removal from Product	kg CO_2	0	0	0	0	0	0	0	0
Biogenic Carbon Emission from Product	kg CO_2	0	0	0	0	0	0	0	0
Biogenic Carbon Removal from Packaging	kg CO_2	0	0	7.63E-02	0	3.81E-03	0	0	0
Biogenic Carbon Emission from Packaging	kg CO_2	0	0	0	0	1.12E-02	0	0	0
Biogenic Carbon Emission from Combustion of Waste from Renewable Sources Used in Production Processes	kg CO_2	0	0	0	0	0	0	0	0
Carbon Emissions from Combustion of Waste from Non-Renewable Sources used in Production Processes	kg CO_2	0	0	0	0	0	0	0	0

5.2 Life cycle impact assessment (LCIA)

It shall be reiterated at this point that the reported impact categories represent impact potentials; they are approximations of environmental impacts that could occur if the emitted substances would follow the underlying impact pathway and meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the chosen functional unit (relative approach). LCIA results are therefore relative expressions only and do not predict actual impacts on category endpoints, the exceeding of thresholds, safety margins, or risks.

Life cycle impact assessment (LCIA) results are shown for natural stone countertops processed and fabricated by Polycor. Unlike life cycle inventories, which only report sums for individual inventory flows, the LCIA includes a classification of individual emissions with regard to the impacts they are associated with and subsequently a characterization of the emissions by a factor expressing their respective contribution to the impact category indicator. The end result is a single metric for quantifying each potential impact, such as ‘global warming potential.’

The impact assessment results are calculated using characterization factors published by the United States Environmental Protection Agency. The TRACI 2.1 (Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts 2.1) methodology is the most widely applied impact assessment method for U.S. LCA studies [10]. USEtox indicators are used to evaluate human toxicity and ecotoxicity, results will be reported only as a contribution analysis. The SM 2013 Methodology is also applied to come up with single score results for the sole purpose of representing total impacts per life cycle phase to explain where in the product life cycle greatest impacts are occurring and what is contributing to the impacts [9].

TRACI impact categories are globally deemed mature enough to be included in Type III environmental declarations. Other categories are being developed and defined and LCA should continue making advances in their development; however, the EPD users shall not use additional measures for comparative purposes. All impact categories from TRACI are used to calculate single score millipoints using the SM2013 Methodology, but it should be noted that there are known limitations related to these impact categories due to their high degree of uncertainty.

Global warming potential (GWP) based on AR6 methodology developed by the Intergovernmental Panel on Climate Change (IPCC) 2021 was also calculated and reported [11]. This GWP includes fossil-based, biogenic, CO_2 uptake, and land transformation CO_2 with a timeframe of 100 years.

5.2.1. Life cycle impact assessment – Granite countertops

Impact Assessment Results

The impact results have been calculated per functional unit of granite countertops and have been tabulated per life cycle stage in Table 20.

For granite countertops, the cradle to gate stages (A1-A3) dominates the results for all the impact categories. Impacts generated at quarries (A1), and during construction stage (A3) are mainly because of the use of grid electricity and fuels in those stages. Material inputs in those stages generate little impacts on comparison to electricity and fuel consumed. Delivery of granite stones from quarries to processing plants (A2) and countertops delivery from fabricators to construction sites (A4) impacts are dependent of transport distance, and these stages also makes significant impacts in numerous impact categories. Installation of countertops (A5) and maintenance (B2) also make considerable impacts, but the end-of-life stages have insignificant contribution to the overall impacts.

Table 20. Potential impact results per functional unit of granite countertops

Impact category	Unit	Material acquisition and pre-processing stage		Countertop Construction stage	Installation stage		Use & maintenance stage	End of life stage	
		Quarry Operations	Quarry to Processor Transport	Construction	Transport to Building site	Installation	Use	End of Life Transport	Final Disposal
		A1	A2	A3	A4	A5	B2	C2	C4
Ozone depletion (ODP)	kg CFC-11 eq	1.58E-07	5.86E-07	1.83E-06	9.09E-07	2.67E-07	1.62E-07	8.35E-08	1.26E-08
Global warming Potential, IPCC	kg CO_2 eq	8.24E+00	2.19E+00	3.21E+01	4.83E+00	4.97E+00	4.23E-02	4.20E-01	7.42E-02
Smog (SFP)	kg O_3 eq	2.73E+00	4.45E-01	3.04E+00	3.47E-01	1.60E+00	2.54E-01	3.45E-02	2.15E-02
Acidification (AP)	kg SO_2 eq	8.82E-02	2.63E-02	1.50E-01	1.53E-02	5.21E-02	1.91E-02	1.31E-03	7.15E-04
Eutrophication (EP)	kg N eq	6.43E-03	1.55E-02	2.87E-02	2.07E-03	3.75E-03	1.46E-02	1.77E-04	6.99E-05
Carcinogenics	CTUh	3.68E-07	2.15E-08	1.23E-06	3.37E-09	1.26E-07	2.06E-08	1.74E-10	2.17E-11
Non-carcinogenics	CTUh	1.08E-06	2.97E-07	3.06E-06	1.26E-07	7.12E-07	2.19E-07	1.57E-08	8.58E-10
Respiratory effects	kg $PM_{2.5}$ eq	4.99E-03	8.06E-03	3.17E-02	1.18E-03	1.70E-03	7.56E-03	8.24E-05	9.27E-05
Ecotoxicity	CTUe	2.02E+01	4.73E+00	3.14E+01	1.17E+00	1.31E+01	3.60E+00	2.28E-01	7.04E-03
Fossil fuel depletion (ADP_{fossil})	MJ, LHV	1.59E+01	8.43E+00	5.16E+01	9.81E+00	1.11E+01	4.07E+00	8.53E-01	1.57E-01
Global warming potential (TRACI)	kg CO_2 eq	8.22E+00	2.15E+00	4.06E+01	4.81E+00	4.95E+00	1.75E-02	4.19E-01	7.40E-02

Single score results

The SM 2013 Methodology single figure millipoint (mPts) score by life cycle phase for granite countertops is presented below in Table 21. The scores are consistent with the trends in the results using the impact assessment results before normalization and weighting. For granite countertops, the construction stage (A3) dominates the results (~61%) followed by the quarry operation (A1) stage (~20%). Installation of countertops contributes to ~9% of total single score results. Transport of stone between the facilities, its final transport to installation sites, and periodic cleaning of countertops also contribute to significant single score.

Table 21. SM 2013 scores for granite countertops by life cycle stage per functional unit

Impact category	Unit	Material acquisition and pre-processing stage		Countertop Construction stage	Installation stage		Use & maintenance stage	End of life stage	
		Quarry Operations	Quarry to Processor Transport	Construction	Transport to Building site	Installation	Use	End of Life Transport	Final Disposal
		A1	A2	A3	A4	A5	B2	C2	C4
SM single figure score	mPts	1.32E+00	2.97E-01	4.09E+00	1.91E-01	6.24E-01	2.06E-01	1.77E-02	3.98E-03

Contribution Analysis

Table 22 and Figure 4 show the contributions of each stage of the life cycle for granite countertops to the environmental impact categories.

Table 22. Percent contributions of each stage to each impact category for granite countertops

Impact category	A1	A2	A3	A4	A5	B2	C2	C4
Ozone depletion	3.9%	14.6%	45.6%	22.7%	6.7%	4.1%	2.1%	<1%
Global warming, IPCC	15.6%	4.1%	60.7%	9.1%	9.4%	<1%	<1%	<1%
Smog	32.2%	5.3%	35.9%	4.1%	18.9%	3.0%	<1%	<1%
Acidification	25.0%	7.5%	42.5%	4.3%	14.8%	5.4%	<1%	<1%
Eutrophication	9.0%	21.8%	40.2%	2.9%	5.3%	20.5%	<1%	<1%
Carcinogenics	20.8%	1.2%	69.5%	<1%	7.1%	1.2%	<<1%	<<1%
Non-carcinogenics	19.7%	5.4%	55.5%	2.3%	12.9%	4.0%	<1%	<<1%
Respiratory effects	9.0%	14.6%	57.2%	2.1%	3.1%	13.7%	<1%	<1%
Ecotoxicity	27.2%	6.4%	42.2%	1.6%	17.6%	4.8%	<1%	<<1%
Fossil fuel depletion	15.6%	8.3%	50.6%	9.6%	10.9%	4.0%	<1%	<1%

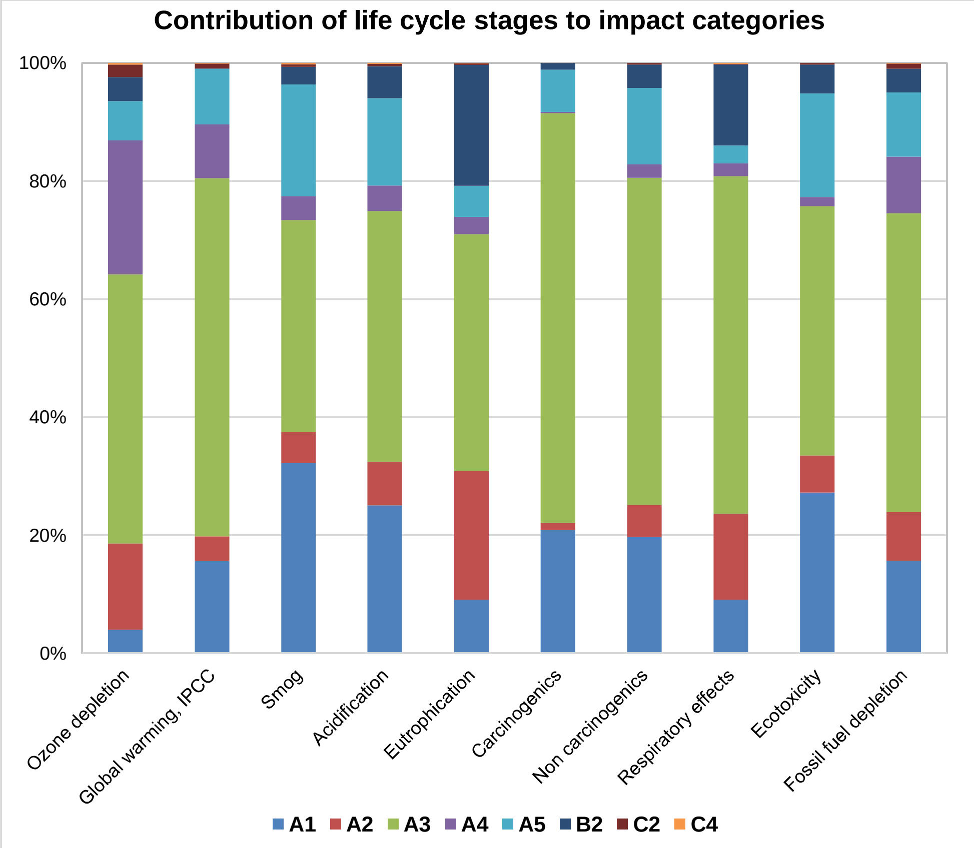


Figure 4. Contribution of each life cycle stages of granite countertops to each impact category

For granite countertops, construction (A3) stage is the highest contributor to most of the impact categories, followed by the impacts from quarry operations (A1). Cradle to gate stages (A1-A3) contribute to ~65% of the total impacts in all the impact categories.

A detailed study has been performed for global warming potential as this is deemed most relevant and of interest to Polycor and is represented by Figure 5. Construction (A3) stage is responsible for ~61% of total CO_2 emissions while quarry operations make up ~16% of total CO_2 emissions. Within construction stage for granite countertops, ~41% of the emissions come from processor operations, while rest ~59% emissions come from fabricator operations. Fuels (mainly diesel, propane, and natural gas) used for various purposes contributes to ~35%, and grid electricity contributes to ~52% of the total emissions generated from fabricators. In case of processors as well, fuels and grid electricity contribute to almost all of the total emissions, electricity contributing to ~42% while other fuels making ~50% of the emissions. Electricity and fuels used also share most of the A1 emissions; electricity makes up ~15% of total A1 emissions while combustion/use of fuels contributes to ~76%. Transport of granite from quarries to processing plants makes ~4% of total emissions while the transport of granite countertops from fabricators to installation sites shares 9% of total CO_2 emissions.

Installation makes ~9% of total CO_2 emissions, with ~82% emissions coming from the energy consumed during installation and the rest coming from ancillary materials used during installation. Maintenance and end of life stages generate insignificant CO_2 emission.

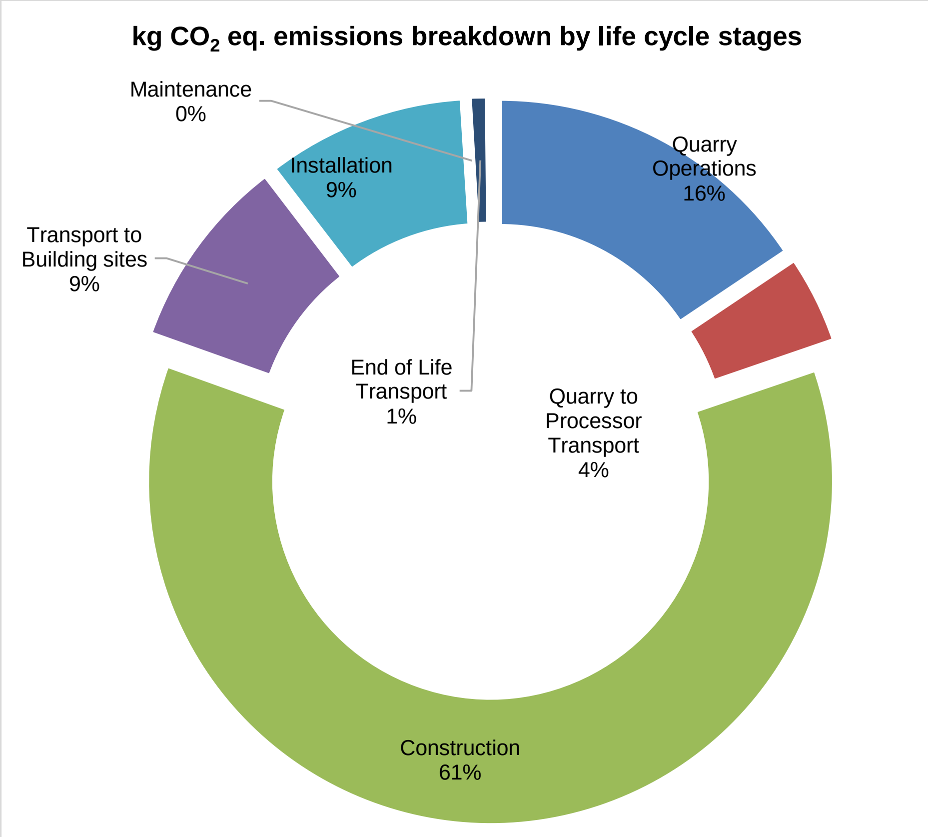


Figure 5. Breakdown of kg CO_2 eq emissions by life cycle stage for granite countertops

For other required impact categories per PCR, unit processes that contribute to more than 10% of the overall life cycle impacts of granite countertops have been identified and tabulated in Table 23.

Table 23. Drivers of life cycle impacts for granite countertops

Impact categories	**Major flows (impacts > 10%)**	**Actual contribution**
Fossil fuel depletion	Electricity used during stone processing	13.6%
	Natural gas combusted during countertop fabrication	11.4%
	Diesel combusted during stone quarrying	11.2%
Ozone depletion	Electricity for stone processing	23.3%
	Transport of countertops to building sites	22.7%
	Transport of quarried stone from quarries to processing sites	14.6%
Smog	Diesel combusted during stone quarrying	29.7%
	Diesel combusted during stone processing	13.7%
	Gasoline combusted during countertop installation	12.1%
Acidification	Diesel combusted during stone quarrying	21.2%
	Diesel combusted during stone processing	11.2%
Eutrophication	Transport of quarried stone from quarries to processing sites	21.8%
	Use of soap for periodic cleaning	20.5%

Sensitivity Analysis – Processor energy variation

Based on the recommendation provided by Polycor, impacts for processor operations specific to a m^2 of granite countertops was calculated to be 10% more than the average stone processing for m^2 of other granite products as they go through heavy polishing than other stone products and consume 10% more energy.

A sensitivity analysis was performed to check the robustness of the results when the energy consumed is +-20% of the estimate used in this study. As shown in Table 24, variations of ~8% and ~10% in the A3 stage are observed respectively in potential CO_2 equivalent emissions and fossil fuel depletion impacts. But the variation in total life cycle impacts of granite countertops is just ~5% for both potential CO_2 equivalent emissions and fossil fuel depletion impact category. Other impact categories also follow the similar trend.

Table 24. Sensitivity analysis per functional unit of granite countertops (varying processor energy)

Stone processing scenarios for stone countertops	A3 construction stage impacts				Total life cycle impacts			
	kg CO_2 eq emissions	% change from base	Fossil fuel depletion (MJ surplus)	% change from base	kg CO_2 eq emissions	% change from base	Fossil fuel depletion (MJ surplus)	% change from base
Base stone processing	32.082		51.572		52.841		101.922	
Stone processing with 20% more energy	34.697	108%	56.511	110%	55.456	105%	106.860	105%
Stone processing with 20% less energy	29.467	92%	46.634	90%	50.226	95%	96.984	95%

5.2.2. Life cycle impact assessment – Marble countertops

Impact Assessment Results

The impact results have been calculated per functional unit of marble countertops and have been tabulated per life cycle stage in Table 25.

For marble countertops, the cradle to gate stages (A1-A3) dominates the results for all the impact categories. Impacts generated at quarries (A1), and during construction stage (A3) are mainly because of the use of grid electricity and fuels in those stages. Material inputs in those stages generate little impacts on comparison to electricity and fuel consumed. Delivery of marble from quarries to processing plants (A2) and countertops delivery from fabricators to construction sites (A4) impacts are dependent of transport distance, and these stages also makes significant impacts in numerous impact categories. Installation of countertops (A5) and maintenance (B2) also make considerable impacts, but the end-of-life stages have insignificant contribution to the overall impacts.

Table 25. Potential impact results per functional unit of marble countertops

Impact category	Unit	Material acquisition and pre-processing stage		Countertop Construction stage	Installation stage		Use & maintenance stage	End of life stage	
		Quarry Operations	Quarry to Processor Transport	Construction	Transport to Building site	Installation	Use	End of Life Transport	Final Disposal
		A1	A2	A3	A4	A5	B2	C2	C4
Ozone depletion (ODP)	kg CFC-11 eq	6.88E-07	8.15E-07	2.97E-06	9.09E-07	2.67E-07	4.85E-07	7.23E-08	1.09E-08
Global warming Potential, IPCC	kg CO_2 eq	1.91E+01	4.10E+00	4.29E+01	4.83E+00	4.97E+00	5.68E-01	3.64E-01	6.42E-02
Smog (SFP)	kg O_3 eq	4.06E+00	3.36E-01	1.46E+00	3.47E-01	1.60E+00	2.85E-01	2.98E-02	1.86E-02
Acidification (AP)	kg SO_2 eq	1.43E-01	1.28E-02	1.15E-01	1.53E-02	5.21E-02	2.14E-02	1.14E-03	6.19E-04
Eutrophication (EP)	kg N eq	1.53E-02	1.72E-03	2.86E-02	2.07E-03	3.75E-03	1.48E-02	1.53E-04	6.05E-05
Carcinogenics	CTUh	2.19E-07	1.70E-09	3.90E-07	3.37E-09	1.26E-07	2.52E-08	1.51E-10	1.88E-11
Non-carcinogenics	CTUh	1.77E-06	1.53E-07	2.65E-06	1.26E-07	7.12E-07	2.67E-07	1.36E-08	7.42E-10
Respiratory effects	kg $PM_{2.5}$ eq	2.13E-02	8.03E-04	5.66E-02	1.18E-03	1.70E-03	8.03E-03	7.13E-05	8.02E-05
Ecotoxicity	CTUe	2.87E+01	2.23E+00	1.75E+01	1.17E+00	1.31E+01	3.89E+00	1.97E-01	6.09E-03
Fossil fuel depletion (ADP_{fossil})	MJ, LHV	2.97E+01	8.32E+00	6.62E+01	9.81E+00	1.11E+01	4.99E+00	7.38E-01	1.36E-01
Global warming potential (TRACI)	kg CO_2 eq	1.89E+01	4.08E+00	4.64E+01	4.81E+00	4.95E+00	5.35E-01	3.62E-01	6.41E-02

Single score results

The SM 2013 Methodology single figure millipoint (mPts) score by life cycle phase for marble countertops is presented below in Table 26. The scores are consistent with the trends in the results using the impact assessment results before normalization and weighting. For marble countertops, the construction stage (A3) dominates the results (~48%) followed by the quarry operation (A1) stage (~29%). Installation of countertops contributes to ~12% of total single score results. Transport of stone between the facilities, its final transport to installation sites, and periodic cleaning of countertops also contribute to significant single score.

Table 26. SM 2013 scores for marble countertops by life cycle stage per functional unit

Impact category	Unit	Material acquisition and pre-processing stage		Countertop Construction stage	Installation stage		Use & maintenance stage	End of life stage	
		Quarry Operations	Quarry to Processor Transport	Construction	Transport to Building site	Installation	Use	End of Life Transport	Final Disposal
		A1	A2	A3	A4	A5	B2	C2	C4
SM single figure score	mPts	1.56E+00	1.72E-01	2.60E+00	1.91E-01	6.24E-01	2.39E-01	1.53E-02	3.45E-03

Contribution Analysis

Table 27 and Figure 6 show the contributions of each stage of the life cycle for marble countertops to the environmental impact categories.

Table 27. Percent contributions of each stage to each impact category for marble countertops

Impact category	A1	A2	A3	A4	A5	B2	C2	C4
Ozone depletion	11.1%	13.1%	47.8%	14.6%	4.3%	7.8%	1.2%	<1%
Global warming, IPCC	24.9%	5.3%	55.8%	6.3%	6.5%	<1%	<1%	<1%
Smog	49.9%	4.1%	18.0%	4.3%	19.7%	3.5%	<1%	<1%
Acidification	39.6%	3.5%	31.9%	4.2%	14.4%	5.9%	<1%	<1%
Eutrophication	23.0%	2.6%	43.1%	3.1%	5.6%	22.3%	<1%	<1%
Carcinogenics	28.6%	<1%	51.0%	<1%	16.5%	3.3%	<<1%	<<1%
Non-carcinogenics	31.1%	2.7%	46.5%	2.2%	12.5%	4.7%	<1%	<<1%
Respiratory effects	23.7%	<1%	63.1%	1.3%	1.9%	8.9%	<1%	<1%
Ecotoxicity	43.0%	3.3%	26.2%	1.8%	19.6%	5.8%	<1%	<<1%
Fossil fuel depletion	22.7%	6.4%	50.5%	7.5%	8.5%	3.8%	<1%	<1%

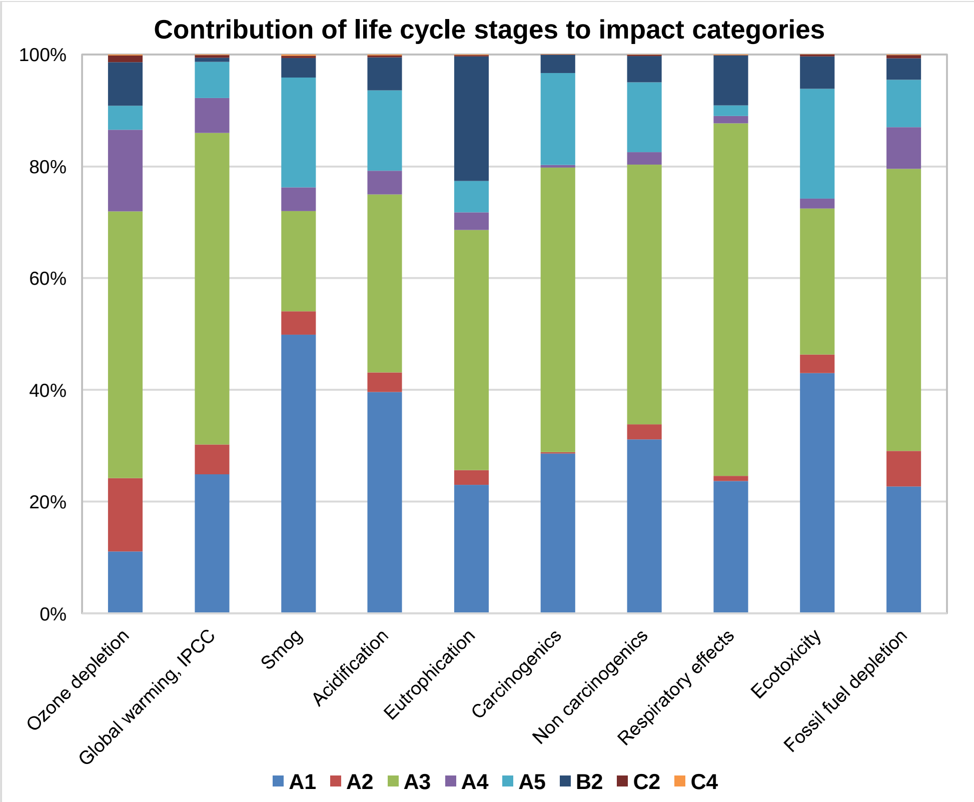


Figure 6. Contribution of each life cycle stages of marble countertops to each impact category

For marble countertops, construction (A3) stage is the highest contributor to most of the impact categories, followed by the impacts from quarry operations (A1). Cradle to gate stages (A1-A3) contribute to ~70% of the total impacts in all the impact categories.

A detailed study has been performed for global warming potential as this is deemed most relevant and of interest to Polycor and is represented by Figure 7. Construction (A3) stage is responsible for ~56% of total CO_2 emissions while quarry operations make up ~25% of total CO_2 emissions. Within construction stage for marble countertops, ~56% of the emissions come from processor operations, while rest ~44% emissions come from fabricator operations. Fuels (mainly diesel, propane, and natural gas) used for various purposes contributes to ~35%, and grid electricity contributes to ~52% of the total emissions generated from fabricators. In case of processors, electricity contributing to ~92%. Electricity and fuels used also share most of the A1 emissions; electricity makes up ~47% of total A1 emissions while combustion/use of fuels contributes to ~50%. Transport of marble from quarries to processing plants makes ~5% of total emissions while the transport of marble countertops from fabricators to installation sites shares 6% of total CO_2 emissions.

Installation makes ~6% of total CO_2 emissions, with ~82% emissions coming from the energy consumed during installation and the rest coming from ancillary materials used during installation. Maintenance and end of life stages generate insignificant CO_2 emission.

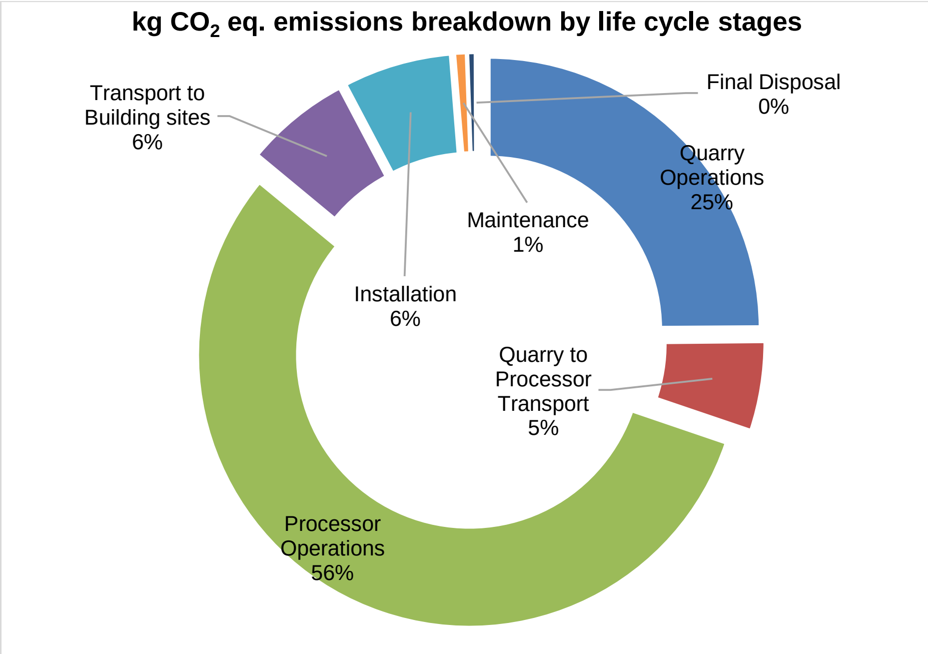


Figure 7. Breakdown of kg CO_2 eq emissions by life cycle stage for marble countertops

For other required impact categories per PCR, unit processes that contribute to more than 10% of the overall life cycle impacts of marble countertops have been identified and tabulated in Table 28.

Table 28. Drivers of life cycle impacts for marble countertops

Impact categories	Major flows (impacts > 10%)	Actual contribution
Fossil fuel depletion	Electricity used during stone processing	24.7%
	Diesel combusted during stone quarrying	10.5%
	Natural gas combusted during countertop fabrication	10.4%
Ozone depletion	Electricity for stone processing	32.6%
	Transport of countertops to building sites	14.6%
	Transport of quarried stone from quarries to processing sites	13.1%
Smog	Diesel combusted during stone quarrying	35.9%
	Gasoline combusted during countertop installation	12.6%
Acidification	Diesel combusted during stone quarrying	24.8%
	Electricity for stone processing	17.4%
Eutrophication	Use of soap for periodic cleaning	21.9%
	Electricity for stone processing	21.4%

Sensitivity Analysis – Processor energy variation

Based on the recommendation provided by Polycor, impacts for processor operations specific to a m^2 of marble countertops was assumed to match the average stone processing for 1 m^2 of marble, although different stone products go through variety of processing operations.

A sensitivity analysis was performed to check the robustness of the results when the energy consumed is +-20% of the estimate used in this study. As shown in Table 29, variations of ~11% and ~12% in the A3 stage are observed respectively in potential CO_2 equivalent emissions and fossil fuel depletion impacts. But the variation in total life cycle impacts of granite countertops is just ~6% for both potential CO_2 equivalent emissions and fossil fuel depletion impact category. Other impact categories also follow the similar trend.

Table 29. Sensitivity analysis per functional unit of marble countertops (varying processor energy)

Stone processing scenarios for stone countertops	A3 construction stage impacts				Total life cycle impacts			
	kg CO_2 eq emissions	% change from base	Fossil fuel depletion (MJ surplus)	% change from base	kg CO_2 eq emissions	% change from base	Fossil fuel depletion (MJ surplus)	% change from base
Base stone processing	42.880		66.154		76.894		130.968	
Stone processing with 20% more energy	47.654	111%	74.009	112%	81.669	106%	138.823	106%
Stone processing with 20% less energy	38.105	89%	58.300	88%	72.119	94%	123.114	94%

5.3 Overview of relevant findings

This study assessed a multitude of inventory and environmental indicators. The primary finding, across the environmental indicators and for the products considered, was that cradle to gate impacts (A1-A3) contribute largely to most impact categories, which is mostly driven by use of grid electricity and fuels in quarrying and construction stage. Within A1-A3, construction stage (A3) contributes the most to the total impacts, followed by quarry operations (A1). Transport of quarried stone from quarries to processor plants (A2) also has significant contribution to the total impacts.

A1-A3 stage covers the large portion of overall impacts, which is followed by A4 and A5 stages. Installation impacts are driven by the use of fuels and electricity during installation. Both granite and marble countertops require monthly cleaning and marble countertops also needs periodic resealing every five years to achieve its reference service life, which is modeled as 10 years. However, these maintenance activities have insignificant impacts on the total life cycle impacts for both granite and marble countertops. No replacements are necessary during the service life; therefore, results represent the impacts associated with one square meter of natural stone countertops.

At the end of life, stone countertops is removed from the building with a portion being landfilled, and the rest recycled. End of life contributes little to the overall impacts.

5.4 Discussion on data quality

Inventory data quality is judged by its precision (measured, calculated or estimated), completeness (e.g., unreported emissions), consistency (degree of uniformity of the methodology applied on a study serving as a data source), and representativeness (geographical, temporal, and technological). Primary data has been used, when available, for all unit processes that contribute over 15% to any indicator result. In the absence of primary data for cleaning, secondary sources have been used.

Precision and completeness

- *Precision*: As the relevant foreground data is primary data or modeled based on primary information sources of the owner of the technology, precision is considered to be high. Background data are from ecoinvent databases with documented precision to the extent available.
- *Completeness*: All relevant process steps for the product system were considered and modeled. The process chain is considered sufficiently complete with regards to the goal and scope of this study. The product system was checked for mass balance and completeness of the inventory. Capital equipment was excluded as required by the PCR. Otherwise, no data were knowingly omitted.

Consistency and reproducibility

- *Consistency*: Assumption, methods, and data were found to be consistent with the study's goal and scope. Primary data were collected with a similar level of detail, while background data were sourced primarily from the ecoinvent database, while other databases were used if data were not available in ecoinvent or the data set was judged to be more representative. Other methodological choices were made consistently throughout the model. System boundaries, allocation rules, and impact assessment methods have also been applied uniformly.
- *Reproducibility*: Reproducibility is warranted as much as possible through the disclosure of input-output data, dataset choices, and modeling approaches in this report. Based on this information, a knowledgeable third party should be able to approximate the results of this study using the same data and modeling approaches.

Representativeness

- *Temporal*: Primary data were determined to be representative of typical operations. Secondary data were obtained from the ecoinvent databases and are typically representative of the recent years. Temporal representativeness is considered to be good.
- *Geographical*: Primary data are representative of Polycor quarries and processors from North America (US and Canada). Secondary data for countertop fabrication is also from US based fabricators. When possible, secondary data were selected to represent US conditions. Global datasets have been used for most of the materials. Electricity datasets are country averages based on the geographical distribution of the facilities, and fuels for US conditions have been selected as most production occurs in US. Geographical representativeness is considered to be fair.
- *Technological*: All primary and secondary data were modeled to be specific to the technologies under study. Technological representativeness is considered to be good.

5.5 Conclusions and recommendations

The goal of this study was to conduct a cradle-to grave LCA on Polycor's natural stone countertops to develop two SM Transparency Reports / EPDs, specific to granite countertops and marble countertops. The creation of these Transparency Reports will allow consumers in the building and construction industry to make better informed decisions about the environmental impacts associated with the products they choose. Overall, the study found that environmental performance is driven primarily by cradle-to-gate activities for both granite and marble countertops. Operations at quarries to quarry the natural stone and operations at processors and fabricators to process quarried stone into final stone countertops drive environmental performance. Delivery of countertops to the installation sites, and the installation also result into significant impacts. Maintenance of both type of countertops and the end-of-life stages account for minimal contribution to life cycle performance.

The major potential source of impact reduction is in cradle to gate stages. Within this stage, there are several opportunities, including quarry facilities, processor plants, and countertop fabricator sites. Quarry and processor operations are two important area for Polycor to focus their efforts since they can directly influence their own operations. Most of the impacts in both quarries and processors are coming from the use of grid electricity and fuels. Polycor can reduce their operations impacts by decreasing the use of electricity and fuels. They can achieve this by either using latest and more effective technologies/equipment or incorporate green energy sources to reduce the dependence on grid electricity. Scrap stone is generated in both quarries and processors, so this issue should be periodically revisited to incorporate new technology considerations for further improvement mainly to reduce the stone scrap. Polycor can directly influence these areas so are good candidates for prioritizing reduction activity.

Another opportunity for reduction of environmental impact is in the installation stage, though it is also outside of Polycor's control. Energy consumed during installation has a significant contribution to the impact categories for both granite and marble countertops. Polycor should consider engaging partners to investigate more environment friendly energy options.

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ACRONYMS

ISO	International Standardization Organization
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact analysis
NSI	Natural Stone Institute
PCR	Product Category Rule document
TR	Transparency Report / EPD™
IPCC	Intergovernmental Panel on Climate Change
USLCI	US Life Cycle Inventory

GLOSSARY

For the purposes of this report, the terms and definitions given in ISO 14020, ISO 14025, the ISO 14040 series, and ISO 21930 apply. The most important ones are included here:

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
Close loop & open loop	A closed-loop allocation procedure applies to closed-loop product systems. It also applies to open-loop product systems where no changes occur in the inherent properties of the recycled material. In such cases, the need for allocation is avoided since the use of secondary material displaces the use of virgin (primary) materials. An open-loop allocation procedure applies to open-loop product systems where the material is recycled into other product systems and the material undergoes a change to its inherent properties.
Cradle to grave	Addresses the environmental aspects and potential environmental impacts (e.g. use of resources and environmental consequences of releases) throughout a product's life cycle from raw material acquisition until the end of life
Cradle to gate	Addresses the environmental aspects and potential environmental impacts (e.g. use of resources and environmental consequences of releases) throughout a product's life cycle from raw material acquisition until the end of the production process ("gate of the factory"). It may also include transportation until use phase
Declared unit	Quantity of a product for use as a reference unit in an EPD based on one or more information modules
Functional unit	Quantified performance of a product system for use as a reference unit
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 inventory - LCI	phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle
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

APPENDIX

- Compilation of data from Polycor and LCI development workbook
- Polycor Stone Countertops LCA results workbook