Politecnico di Torino
Dipartimento di Ingegneria dell'Ambiente, del Territorio e delle Infrastrutture

PIETRA NATURALE AUTENTICA

Life Cycle Assessment (LCA) of Botticino Classico slabs (company: Marmi Ghirardi S.r.l.)

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Summary

The production process of stone slabs is divided into the phases of stone extraction, cutting into slabs, surface finishing and packaging of the slabs. The Pietra Naturale Autentica (PNA) Network, which includes companies operating in each of these phases, commissioned the Politecnico di Torino to carry out a study aimed at quantifying the environmental impacts of 1 m^2 of slab with a thickness of 2 cm. This study is configured as the update and expansion of a previous analysis carried out in 2024, with the additional objective of obtaining an EPD for the sector based on an average product (1 m^2 of average slab with a thickness of 2 cm). For this purpose, the Life Cycle Assessment (LCA) methodology was used, based on the ISO14040-44 standard and the European Commission guidelines, and the study was carried out following the indications in the Product Category Rules (PCR) for construction products 2019:14 Version 2.0.1 and EN 15804:2012+2019:A2/AC:2021.

15 materials extracted and processed in Italy were analyzed. For each material, the environmental impacts of 1 m^2 of slab were calculated. The impact on climate change is between 3.4 and 37.9 kg CO_2 eq./m^2. Taking into account all the materials analyzed, the weighted average of the impact on climate change is 13.5 kg CO_2 eq./m^2 for the A1-A3 modules (cradle-to-gate), to which are added 0.94 kg CO_2 eq./m^2 for end of life of the slab considering a 100% disposal scenario (modules C1-C4 + D). This report provides, in addition to the overall results of the study, detailed information regarding the Botticino Classico slabs. Specifically**, the climate change impact of a 2 cm slab in Botticino Classico is found to be 15.4 kg CO2 eq/m².**

The energy (electricity and diesel) consumed both in the extraction and transformation phases gives a significant contribution (about 80%) to the total impact of the A1-A3 module of the average slab. However, the contribution of energy is quite variable, as it depends on the energy sources used, the characteristics of the stone, the technologies used and the processing yield. The materials consumed and the waste produced in the quarry are almost always very limited, while during the cutting/finishing phases, they give a non-negligible contribution, equal to an average of 14.7%. This last contribution is given above all by the consumption of diamond tools, abrasives and resin.

The study is accurate because it is based almost entirely on data collected directly in the quarry or at the processing plants. It is also sufficiently representative from a geographical point of view, as it considers different lithotypes from different geographical areas of central and northern Italy, as shown in Figure 1. The temporal representativeness is excellent, as the data of all the materials are recent (year 2024).

The study is the LCA report for the sector EPD environmental certification for slabs produced in Italy. Furthermore, at an international level, the study contributes to the future definition of guidelines for the harmonization of LCA studies in the ornamental stone sector.

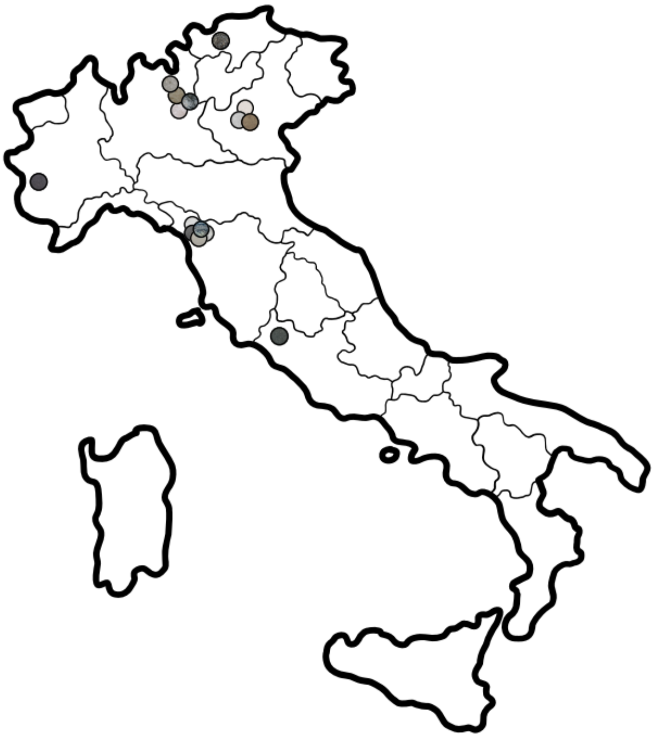

Figure 1. Geographical location of quarries and processing plants analyzed for the 15 materials.

Version

Final version of the LCA report, 2025-08-08

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1. Context and objectives of the study

This study was commissioned by the Pietra Naturale Autentica (PNA) Network, which is made up of dozens of companies working in the Italian stone supply chain. Rete PNA, therefore, includes companies involved in stone extraction and subsequent cutting and finishing transformations, as well as the production of machinery and tools.
This study is configured as an update and further study of a previous analysis carried out by the same research team in 2024, and is aimed at obtaining the sector EPD certification based on an average product.

The report briefly describes the LCA methodology (Chapter 2), identifies the specific objectives of the study and the boundaries of the analysis (Chapter 3), provides details of the inventory data used in the LCA modelling for each material (Chapter 4), and quantifies and declares the environmental impacts (Chapter 5) of 1 m^2 of finished slab, as an average of all the materials analyzed. Finally, Chapter 6 reports recommendations and conclusions of the authors of the study.

Annex 2 describes the defined follow-up procedure to monitor the validity of the declared EPD.

2. LCA Methodology

In this study, the LCA (Life Cycle Assessment) methodology was used following the ISO 14040-44 standard, the International Reference Life Cycle Data System (ILCD) and Product Environmental Footprint (PEF) guidelines of the European Commission, the Product Category Rules (PCR) 2019:14 Version 2.0.1 and international scientific literature.

2.1 Introduction to the LCA methodology

The Life Cycle Assessment (LCA) methodology, codified by the UNI EN ISO 14040 series standards, can be defined as an objective environmental assessment technique for quantifying the environmental impacts of a product or process during all phases of the life cycle, through the systematic measurement of all physical exchanges to and from the environmental system.

This methodology (Figure 2) is based on objective criteria that allow the identification and evaluation of the potential environmental impacts and energy loads of a product/production process, through the identification of the incoming flows (materials, resources and energy) and outgoing flows (waste and polluting emissions into the environment) throughout the life cycle.

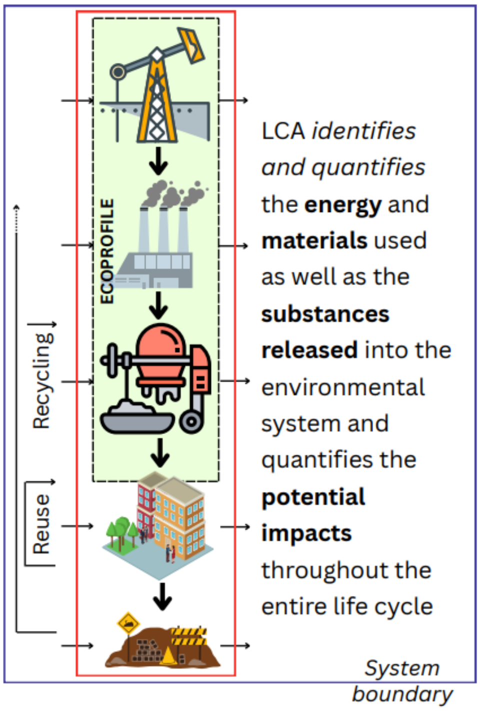

Figure 2. Operational scheme of the LCA.

The LCA approach, of a quantitative nature and therefore strictly engineering, was developed in the early 70s and has seen increasing diffusion since the 90s. It is an innovative methodology for addressing environmental issues related to a product or process, as it allows for a comprehensive assessment of impacts throughout the entire life cycle.

Through a "cradle to grave" analysis, the production system is considered in its entirety: for this reason, any hypotheses and/or attempts at specific improvement are evaluated with reference to the entire life cycle.

The assessment includes the phases of extraction and treatment of raw materials, production, transportation and distribution, up to use, reuse, recycling and final disposal.

Initially adopted mainly in the industrial sector, LCA analysis is now widely applied in different fields, demonstrating its versatility and transversal relevance.

According to ISO 14040, the phases of an LCA life cycle analysis (Figure 3) are as follows:

1. *Goal and Scope Definition*

This is the initial phase, in which the purposes and scope, the functional unit and the boundaries of the LCA study are defined. This phase, therefore determines the entire setup of an LCA study, describes the system being studied and determines the categories of data to be collected, the assumptions and the limits.

2. *Life Cycle Inventory Analysis (LCI)*

This phase includes the collection of data and calculation procedures that allow the quantification of the incoming and outgoing flows of a product system. It is certainly the most important phase in an LCA study: it creates a model of the real system examined and allows the determination of the physical inputs and outputs according to the objectives of the study. For this reason, this phase is usually supported by dedicated software and databases.

3. *Life Cycle Impact Assessment (LCIA)*

It is the processing phase of the acquired inventory results, with the aim of evaluating the extent of the potential environmental impacts and therefore highlighting the extent of the environmental modifications that are generated following the releases into the environment (emissions or waste water) and the consumption of resources caused by the production activity.

4. *Life Cycle Interpretation and Improvement*

It is the final phase of the life cycle assessment, in which the results obtained in the inventory analysis and impact assessment are combined consistently with the pre-established objective and the purpose to be achieved. The Interpretation phase aims to obtain conclusions and recommendations necessary to reduce the environmental impact of the processes or activities considered, evaluating them iteratively with the same methodology.

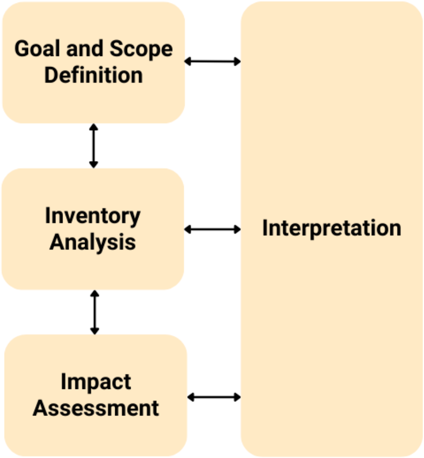

Figure 3. LCA scheme according to ISO 14040.

2.2 Multi-output processes: allocation[1] and expansion[2] of the system

In the case where the same process generates two or more by-products, the distribution of impacts can be carried out with different approaches. The main distribution methods used in LCA are allocation and system expansion, respectively. Since the choice strongly depends on the objectives of the study, the system boundaries identified and the type of process, there is currently no method that is more widely shared by the scientific community.

Allocation is the process by which the environmental impacts generated by a system are divided among the different output co-products. This distribution can be done according to different criteria, depending on the specific characteristics of the case study. It is possible to make an allocation on a physical basis, in which the impacts are distributed according to physical properties of the co-products, such as mass, volume or energy content.

However, this approach may be inadequate when the co-products have very different qualities or values. In such situations, it is possible to adopt an economic criterion, which attributes the environmental impacts in proportion to the market value of the individual co-products.

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[1] Procedure used in this study.

[2] Not used in this study, reported for completeness and informational purposes.

This approach is the one used in the study presented here, in accordance with the provisions of the Product Category Rules (PCR) 2019:14.

For example, in the case of quarrying stone, it is possible to assign market values to regular blocks, shapeless blocks and earthy shards and thus distribute the impacts of extraction in proportion to the economic value of each output product. Assuming, for example, that 1 t of extracted material produces 0.3 t of regular blocks (at market price: €150/t), 0.1 t of irregular blocks (€ 90/t) and 0.6 t of earthy rubble (€ 2/t), for a total value of: 0.3*150 + 0.1*90 + 0.6*2 = € 55.2, we have:

- Impacts allocated to regular blocks: (0.3*150)/55.2 = 82%
- Impacts allocated to irregular blocks: (0.1*90)/55.2 = 16%
- Impacts allocated to the earthy rubble: (0.6*2)/55.2 = 2%

Figure 4 illustrates the concept underlying the applied economic allocation.

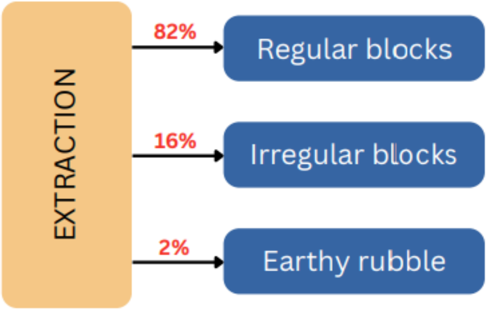

Figure 4. Multi-output processes: economic allocation approach to impact calculations.

In the system expansion approach, co-products are considered as substitutes for other products on the market. This method allows for taking into account the indirect impacts (or benefits) deriving from interconnected and interdependent production systems, subtracting the environmental impacts associated with the products that are avoided thanks to the availability of the analyzed co-products. However, the application of this approach requires a careful identification of the production processes that are actually avoided, which can introduce a fair degree of uncertainty. In the specific case of the stone supply chain, the identification of alternative supply chains for the production of co-products deriving from extraction (such as shapeless blocks or earthy shards, as illustrated in the previous example) is questionable and not very significant. These materials do not represent the main products even in other types of supply chains. For this reason, the system expansion approach has not been considered in this study.

3. Definition of objectives and working hypotheses

In an LCA study, it is essential to precisely define the objectives in order to have a tool capable of capturing all the environmental implications associated with the system analyzed and of providing coherent answers to the issues considered relevant.

This study was carried out on behalf of the Rete PNA, and it is preparatory to the publication of the environmental product declaration at The International EPD® System (EPD International AB Box 210 60, SE-100 31 Stockholm, Sweden), in particular the sector EPD declaration for the Italian stone sector.

Therefore, the main objective is to analyze, quantify and verify the average environmental impacts generated by the life cycle of 1 m^2 of 2 cm thick slab extracted and processed within the Italian borders, through the LCA methodology and in compliance with the provisions of the Product Category Rules (PCR) 2019:14 – Construction products, Version 2.0.1 and the General Programme Instructions (GPI) for the International EPD® System, Version 5.0.0.

Since a specific c-PCR (Complementary PCR) is not currently available for the material under study, reference was made to the general requirements established in the PCR and in the relevant international standards: EN 15804:2012+2019:A2/AC:2021, ISO 14040:2006, ISO 14044:2018, ISO 14025:2010 and ISO 21930:2017.

In particular, the study applies to 15 products manufactured by 11 companies part of the PNA network and listed in Table 1. To obtain the environmental declaration, an impact analysis will be presented for an "average" slab among all those included in the study (sector EPD).

Table 1. Companies and related materials included in the study.

Agency	**Material**	**Region**	**Bulk density [t/m³]**
CMP Solmar S.r.l.	Pietra del Cardoso	Tuscany	2.7
Marmi Faedo	Marmo Grolla	Veneto	2.7
Franchi Umberto Marmi S.p.A.	Marmo Bettogli	Tuscany	2.7
Marmi Minucciano	Cipollino	Tuscany	2.7
	Bianco Cattani	Tuscany	2.7
Grassi Pietre S.r.l.	Bianco Avorio	Veneto	1.9
	Grigio Alpi	Veneto	2.4
Marini Marmi	Ceppo di Gré	Lombardy	2.5
Nikolaus Bagnara	Alps Glitter	Trentino-Alto Adige	3
Marmi Ghirardi S.r.l.	Botticino Classico	Lombardy	2.7
	Breccia Aurora Classica	Lombardy	2.7
	Breccia Marina Blu	Lombardy	2.7
Beltramo Fratelli s.n.c.	Pietra di Luserna	Piedmont	2.7
Basaltina S.r.l.	Basaltina	Lazio	2.5
Marmi e Graniti d'Italia S.r.l.	Caldia	Tuscany	2.7

The broader environmental objective is to estimate the average environmental impacts associated with the complete life cycle of stone slabs with surface finishing up to their end-of-life scenario. A further objective of the study is to identify the processes most responsible, on average, for the potential impact on climate change, thus providing useful information for environmental improvement interventions.

The primary target group of this sector EPD is business-to-business (B2B) stakeholders, such as architects, designers, construction companies and procurement professionals. These results may also be used for business-to-consumer (B2C) communication, providing transparent environmental data to end users and clients interested in the sustainability of natural stone materials.

3.1 Product description and content declaration

The products analyzed in the LCA study are natural stone slabs with a thickness of 2 cm, intended for a wide range of **applications** in the construction sector, including interior and exterior cladding and flooring, as well as elements for architectural works. The materials analyzed, previously listed, represent varieties of limestone widely used in the Italian construction sector. By the United Nations classification, the products fall under the UN CPC code 15120 - "Marble and other calcareous monumental or building stone", under category 151 "Monumental and building stone", and are characterized by high durability and stable technical performance over time. In this regard, the **Reference Service Life** (RSL) of the products, taking into account their nature and intended applications, was assumed to be equal to 50 years, corresponding to the average useful life of the building. However, it should be noted that natural stone has a potentially infinite intrinsic longevity, making it a material particularly suitable for durable and sustainable construction strategies.

From a **chemical safety** perspective, none of the products studied contain substances included in the SVHC (Substances of Very High Concern) list drawn up by the European Chemicals Agency (ECHA) in concentrations above 0.1% by weight, thus ensuring compliance with REACH requirements for human health and the environment.

Finally, the materials were procured exclusively from quarries located on Italian territory, distributed in different regions, as illustrated in Table 1, contributing to reducing the impact of transport and enhancing the national ornamental stone supply chain.

For the evaluation of the impacts related to the downstream and beneficial modules, an average material bulk density of 2.6 t/m^3 is considered, so 1 m^2 of 2 cm thick slab corresponds to 0.052 t.

Table 2 and Table 3 present the Product **Content** Declaration and the declaration of packaging content, with information on biogenic content and other details regarding the analyzed product and packaging. A C content of 50% in the wood and a calorific value of 17 MJ/kg are assumed. No recycled materials as input/output to/from the system are present.

Table 2. Product Content Declaration – Sector average.

Component	**Average bulk density [kg/m^3]**	**Average weight [kg]**	**Post-consumer recycled material, weight-% of product**	**Biogenic material, weight-% of product**
Ornamental stone	2600	52	-	-
TOTAL	-	52	-	-

Table 3. Declaration of packaging content – sector average.

Packaging material	**Weight [kg/m²]**	**Weight [% of declared unit weight]**	**Biogenic carbon weight [kg C/m²]**
Wood	0.21	0.41%	0.11
Polyethylene	0.004	0.01%	-
Polystyrene	0.002	0.004%	-
Steel	0.0002	0.0004%	-
TOTAL	0.22	0.42%	0.11

3.2 System boundary

The definition of the system boundary represents one of the most crucial and delicate aspects of an LCA study, since the choices made in this phase significantly impact the final results and their interpretation.

It is therefore essential to establish precisely which phases of the product life cycle and which segments of the production chain are included in the analysis. This step allows for ensuring methodological coherence and completeness in the assessment of environmental impacts.

In the case of stone slab production, environmental impacts are not limited to the processes carried out within the plants directly controlled by the extraction, cutting and finishing companies. In fact, indirect environmental consequences, i.e. those that occur outside the physical boundaries of the plants but that are attributable to the product analyzed, can be even greater than the direct ones.

The boundary of the system under study is therefore not limited to the physical boundaries of the quarries and plants, but extends upstream and downstream to include the entire supply chain, including the **following subsystems**:

- the production and supply of raw materials and auxiliary materials (diamond wire, explosives, discs, blades, abrasives, ...);
- the production and use of energy consumed in various processes(from the production of primary fuels to the sale of electricity);
- the use of road and naval transport systems;
- the internal processing activities in the quarries and plants: extraction, squaring, cutting and surface finishing;
- waste treatment and management;
- the packaging and preparation operations of the finished product;
- end-of-life phases, including demolition, treatment, disposal.

The **geographical boundaries** are identifiable as:

- in the Italian national area (IT) concerning the extraction and transport phases of raw materials and for the processing carried out in individual companies;
- Global (GLO) for the end-of-life scenario of products (module C) and Europe (EU27) for the benefits of module D.

The **time boundaries** refer to the calendar year 2024, and therefore include all consumption, production and transport data relating to this period, from 1 January 2024 to 31 December 2024.

3.2.1 Exclusions from the system boundaries

Additionally, the following exclusions from the system boundaries have been made in line with the guidance of the reference PCR:

- the construction of company buildings and related infrastructure (i.e. capital goods);
- the production and maintenance of machinery and equipment (i.e. capital goods);
- staff-related activities (i.e. personnel processes);
- the maintenance and production of spare parts with a life cycle exceeding three years;
- the maintenance operations of quarry vehicles;
- the waste flows not strictly related to processing activities;
- all company operations not related to the processing of the material considered in the study.

3.2.2 Cut-off criteria and proxy data

No cut-off criteria were applied: all known inputs and outputs were taken into account. No proxy data have been used for this study.

3.2.3 Declared modules and content of life cycle phases

This study complies with EN 15804:2012+2019:A2/AC:2021 and adopts a "cradle-to-gate with modules C1-C4 and module D" approach, specifically including modules C1–C4 and module D, related to end-of-life and potential benefits.

Below, Table 4 provides an overview of the life cycle information modules declared in the study, specifying for each of them the geographical scope of reference, the source of the data and the expected coverage according to the standard. To ensure a coherent, transparent and comparable environmental assessment, the study uses a model divided into three main phases: upstream, core and downstream, with the inclusion of module D. Table 5 describes the specific contents included in each phase of the life cycle, following the structure defined by the reference standard.

Table 4. Declared modules, geographical coverage and data origin.

	Product stage			Construction process stage		Use stage							End of life stage					Resource recovery stage
	Raw material supply	Transport of raw materials	Manufacturing	Transport to customer	Installation	Use	Maintenance	Repair	Replacement	Refurbishing	Operational energy use	Operational water use	Deconstruction/Demolition	Transport to waste processing	Waste processing	Disposal		Reuse – Recovery - Recycling potential
Module	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4		D
Declared module	X	X	X	ND	ND	ND	ND	ND	ND	ND	ND	ND	X	X	X	X		X
Geography	IT	IT	IT	-	-	-	-	-	-	-	-	-	GLO	GLO	GLO	GLO		EU27
Specific data	>90%			-	-	-	-	-	-	-	-	-	-	-	-	-		-
Variation - Products	-71%/+177%			-	-	-	-	-	-	-	-	-	-	-	-	-		-
Variation - Sites	Not applicable			-	-	-	-	-	-	-	-	-	-	-	-	-		-

Table 5. Structure and contents by life cycle phase according to EN 15804.

Phase	**Module**	**Main contents**
UPSTREAM	A1	Stone extraction Production of auxiliary materials Quarry waste treatment and management
	A2	Transport of blocks and auxiliary materials to the production plant
CORE	A3	Internal marble processing processes (cutting, squaring and surface finishing) Treatment and management of waste produced in sawmills and polishing plants Packaging for shipping the finished product (if applicable)
DOWNSTREAM	C1	Removal and demolition of slabs at the end of their useful life
	C2	Transport of materials to the treatment or disposal facility
	C4	Landfill disposal (100% disposal scenario)
BENEFITS	D	Recovery, reuse or recycling activities of stone material that has reached the end of its life

3.3 Declared unit

For the comparison and evaluation of the average environmental impacts of natural stone slabs, the declared unit adopted is equal to 1 m² of slab with surface finish, 2 cm thick, ready to be delivered to the consumer, in compliance with the reference PCR.

However, for the purposes of calculating the environmental impacts along the various phases of the product life cycle, specific declared units have been defined for each module, in relation to the nature of the processes involved, as reported in Table 6.

Table 6. Declared units adopted for each life cycle module.

Modules	Declared unit
A1	1 t of extracted material
A2	1 t of material transported to the plant
A3	1 m^2 of 2 cm thick slab packed for delivery
C + D	1 m^2 of disposed slab

Specifically, in cases where the declared unit is not expressed in mass, a conversion factor based on the bulk density of the material is applied (Table 1) in line with the provisions of the reference legislation. For the assessment of the impacts related to the downstream and benefit modules, an average material bulk density of 2.6 t/m^3 is considered, so 1 m^2 of a 2 cm thick slab corresponds to 0.052 t.

3.4 Data quality assessment and LCA IT tools

Each company participating in the project provided specific data relating to its production, both in the quarries and in the processing plants. All primary data used in the model were collected through questionnaires filled out by company representatives between March and May 2025 and referred to the solar year 2024, from 1 January 2024 to 31 December 2024. All data employed in the model for the module A3 are data from the data collection, so the reference year is 2024.

Table 7 declares the source, reference year, data category, and the share of primary data of GWP-GHG results for all processes contributing more than 10% to the GWP-GHG results of modules A1-A3, plus other relevant processes, which altogether contribute to more than 80% of the declared results. The share of primary data is calculated based on GWP-GHG results. It is a simplified indicator for data quality that does not capture all relevant aspects of data quality. The indicator is not comparable across product categories.

Table 7. Declaration of sources, reference years, categories and share of primary data.

Process	Source type	Source	Reference year	Data category	Share of primary data, of GWP-GHG results for A1-A3
Diesel for A1-A3	Data collection	Participating companies	2024	Primary data	30.6%
Electricity for A1-A3	Database – Activity data collection	AIB - Italian 2022 Residual Mix – participating companies	2024	Primary data	51.7%
Resin for finishing stage	Data collection	Participating companies	2024	Primary data	6.9%
Transport (A2)	Data collection	Participating companies	2024	Primary data	1.3%
Total share of primary data in GWP-GHG results for modules A1-A3					>90%

In particular, data on energy, water and material consumption were collected for modules A1–A2–A3 regarding the production year 2024. In the case of multi-output processes, companies also provided the economic data necessary for economic allocation (see paragraph 2.2).

Due to the partial unavailability of data from the reference companies, it was necessary to integrate the information, where missing, with data relating to a technically similar material considered representative. The percentage of primary data specific to the modeling of each company remains, however, higher than 90%.

For the production of auxiliary materials used in the stone supply chain (e.g. diamond wire, chain cutter inserts, explosive, discs and blades), data from previous studies conducted by the authors of this report were used [5, 6]. Regarding metallic, resinoid and synthetic abrasives, reference was made to data provided in the past by the company Adria Abrasivi, not directly involved in this study. Therefore, these data were classified as representative secondary data, compatible with the quality criteria required by EN 15941.

Annex 1 presents the **data quality assessment**, based on Annex E of EN 15804:2012+A2:2019 (UN Environment Global Guidance on LCA database development), considering representativeness of the data, and accounting for the precision, completeness, consistency and data sources.

The **IT tools** supporting the development and analysis of the LCA model are the following:

- LCA Software: SimaPro 9.6.0.1
- LCA database: The Ecoinvent 3.10 database developed by the Swiss Centre for Life Cycle Assessment was used as a source of selected generic data.

4. Inventory Analysis (LCI)

This chapter describes the "subsystems" that constitute the LCA models of the production of blocks and slabs for each material analyzed. A subsystem is a subset of activities/processes, or a specific sequence of process units (ISO14040) within the life cycle.

The processes and/or activities within the sequence that constitute the life cycle of the slabs are described as they were entered into the SimaPro software application.

Each single process unit is conceived as an input/output system, where the incoming and outgoing flows of materials, emissions and energy are quantified.

To ensure methodological consistency and simplify data collection, it was decided to structure the analysis for each company, associating it with the relevant information modules. This approach allows for a clearer and more direct representation of the specific flows of materials, energy, emissions and waste related to the processes actually carried out by each company.

All primary data used in the model were collected through questionnaires filled out by company representatives between March and May 2025. Furthermore, to fill the gaps in the data provided and make assumptions as representative as possible of each specific situation, direct meetings were held between LCA technicians and company managers to collect data through personal communication.

The life cycle considered in the study is illustrated in Figure 5, which represents the process diagram used to define the system boundaries of the LCA analysis relating to the production of natural stone slabs. The diagram highlights the main phases of the production cycle, the related information modules and the processes included in each phase. For each step, the environmental inputs and outputs are indicated, i.e. the flows of materials and energy, the emissions generated and the waste produced. The blue dotted line delimits the system boundaries used to calculate environmental impacts throughout the entire life cycle of the product, up to the end-of-life phases (100% disposal scenario).

In the general case, the cycle begins with the detachment from the bed and the cutting into blocks (A1). In this phase, the extraction activity in the quarry is carried out either with horizontal and vertical cuts made by diamond wire and chain cutting machines or with detonating methods. Subsequently, the blocks of chosen commercial dimensions are transported to the plant (A2). The block is then squared (A3), performed with giant discs or diamond wires, and cut into slabs (A3), performed using multi-wire diamond or multi-blade metal grit systems, with high energy and water consumption. The slabs obtained are then subjected to surface finishing (A3), which includes smoothing, polishing and resin-coating treatments using abrasives and resins, depending on the desired degree of finishing.

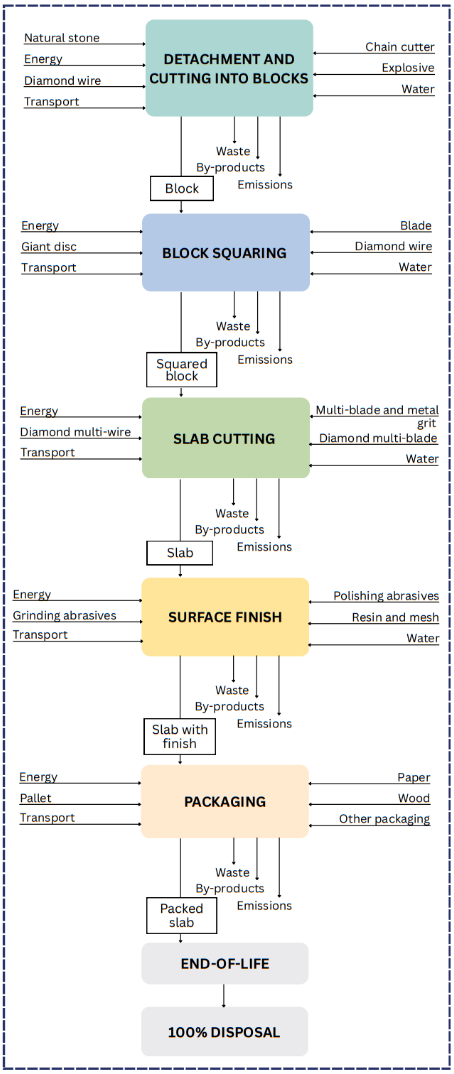

Figure 5. LCA system boundaries: the blue dashed line delimits the system boundaries for calculating the impacts of the slabs during their life cycle.

Once the processing is completed, the product is packaged (A3) for shipping, using materials such as wooden pallets, paper, plastic and other packaging materials. The packaging step of the A3 module is presented and described only for companies that use packaging to prepare the slabs for shipping. Other companies do not use packaging but only reusable metal stands. Each phase is accompanied by energy and material inputs, as well as waste generation.

The life cycle ends with the end-of-life phase, which includes the demolition of the product (C1), the subsequent waste treatment (C2) and its final disposal. The slabs are assumed to be sent to specialized plants for landfill disposal. In the analysis conducted, a total 100% disposal scenario has been assumed (C4).

The electricity mix used in this study was modelled based on the Italian residual mix from Ecoinvent 3.10 dataset "Electricity, medium voltage {IT}| electricity, medium voltage, residual mix | Cut-off, S". This dataset considers the 2022 Italian residual mix from the AIB report 2023 (Table 8).

Table 8. Italian energy mix for the year 2022 (AIB, 2023).

	RE total	RE unspecified	RE biomass	RE solar	RE geothermal	RE wind	RE hydro	**Nuclear**	**FO total**	FO unspecified	FO hard coal	FO lignite	FO oil	FO gas
IT	**9.4%**	0.0%	1.68%	5.97%	0.0%	0.84%	0.54%	**2.62%**	**88.34%**	2.73%	12.2%	0.02%	4.47%	68.92%

Table 8 reports the composition of the residual energy mix for Italy in 2022, expressed in percentages of the different production sources. The residual mix represents a virtual mix of electricity, referring to non-traceable consumption, i.e. that is not covered by certification tools such as Guarantees of Origin (GO). The shares of the different sources were calculated on the basis of the statistical data provided by AIB, following the methodology defined by Grexel (2020).

The climate impact (in kg CO2 eq./kWh using the GWP-GHG indicator) of electricity purchased in the manufacturing process in A3, considering the dataset presented above, is 0.64 kg CO2 eq./kWh.

4.1 Botticino Classico (company: Marmi Ghirardi Srl)

Botticino Classico is a marble extracted from the site in Menga Bassa, in Botticino (BS), where the plant which transforms blocks into slabs is also located. The data collected refers to the production of the year 2024.

4.1.1 Botticino Classico extraction phase (A1-A2)

Table 9 reports the inventory data for the extraction phase of 1 t of Botticino Classico. 1 t of Botticino Classico is equivalent to 0.37 m^3 (bulk density of 2.7 t/m^3). All quantities indicated have been elaborated starting from information provided by Marmi Ghirardi Srl.

Table 9. Inventory relating to the extraction of 1 t of regular blocks of Botticino Classico.

Flows	Amount	Ecoinvent Dataset	Notes
Output			
Regular block of Botticino Classico [t]	1		Allocation: 91%
Co-product 1: shapeless blocks	0.11		Allocation: 4%
Co-product 2: shrapnel [t]	3.8		Allocation: 5%
Other splinters [t]	0.95		Allocation: 0%
Earth [t]	0.65		Allocation: 0%
Input			
Natural stone [t]	6.52	Stone (elementary flow)	
Water [kg]	470	Water, rain (elementary flow)	Rainwater
Electricity from generator [MJ]	79.1	Diesel, burned in diesel-electric generating set, 18.5kW {GLO}|	

		diesel, burned in diesel-electric generating set, 18.5kW | Cut-off, S	
Diesel [MJ]	505	Diesel, burned in building machine {GLO}| market for | Cut-off, S	
Iron rods [p]	0.002	Drilling rod, LC (modeled according to [6])	
Black powder [g]	0.78	Black powder	
Slow burning fuse [m]	0.013	Slow-burning fuse (modeled according to [5])	
Detonating fuse [m]	2.27	Detonation cord (modeled according to [5])	
Diamond wire [m]	0.063	Diamond wire (modeled according to [5])	
Flywheel protection rubber [m]	0.012	Synthetic rubber {GLO}| market for | Cut-off, S	Hypothesis: 2.4 kg/m
Detonators [p]	0.011	Detonator, LC (modeled according to [5])	

4.1.2 Cutting and finishing phase of Botticino Classico (A3)

Table 10, Table 11 and Table 12 report the inventory data for the squaring, cutting into slabs and surface finishing phases of Botticino Classico. The quantities indicated have been elaborated starting from information provided by Marmi Ghirardi Srl.

Table 10. Inventory relating to the squaring of Botticino Classico blocks.

Flows	Amount	Ecoinvent Dataset	Notes
Output			
Square block of Botticino Classico [t]	1		Allocation: 100%
Solid waste: shards [t]	23.4	Inert waste, for final disposal {CH}| treatment of inert waste, inert material landfill | Cut-off, S	Disposal in authorized landfill
Sawmill sludge [t]	39.1	Slurry waste treatment, filter-press, Botticino	
Input			
Regular block of Botticino Classico [t]	1.06		
Electricity [kWh]	4.69	Electricity, medium voltage {IT}| electricity, medium voltage, residual mix | Cut-off, S	
Diamond wire [m]	0.031	Diamond wire (modeled according to [6])	
Water [kg]	6.26	Water, well, IT (elementary flow)	

Table 11. Inventory relating to the production of Botticino Classico slabs.

Flows	Amount	Ecoinvent Dataset	Notes
Output			

Raw slab of Botticino Classico, 2 cm [m2]	1		
Sawmill sludge [kg]	22.8	Slurry waste treatment, filter-press, Botticino	
Input			
Square block of Botticino Classico [kg]	76.8		
Water [kg]	48	Water, well, IT (elementary flow)	
Diamond blade [p]	0.002	Diamond blade (modeled according to [6])	
Electricity [kWh]	6.6	Electricity, medium voltage {IT}| electricity, medium voltage, residual mix | Cut-off, S	

Table 12. Inventory relating to the surface finish of Botticino Classico slabs (2 cm thick).

Flows	**Amount**	**Ecoinvent Dataset**	**Notes**
Output			
Botticino Classico slab with surface finish, 2 cm [m2]	1		100% polished and resinated slabs
Sawmill sludge [kg]	3	Slurry waste treatment, filter-press, Botticino	
Input			
Raw slab of Botticino Classico [m2]	1		
Water [kg]	4.8	Water, well, IT (elementary flow)	Recirculating water and well
Magnesite abrasive [p]	0.0051	Magnesite abrasive, for stone polishing (modeled with Adria Abrasives data)	
Synthetic resinoid abrasive [p]	0.0072	Synthetic resin abrasive; for stone polishing (modeled with Adria Abrasives data)	
Diamond resin abrasive [p]	0.0026	Resin diamond abrasive; for stone polishing (modeled with Adria Abrasives data)	
Resin [kg]	0.721	Epoxy resin, liquid {RER}| market for epoxy resin, liquid | Cut-off, S	
Resin net [g]	47.2	Glass fiber reinforced plastic, polyester resin, hand lay-up {RER}| production | Cut-off, S	
Electricity [kWh]	1.68	Electricity, medium voltage {IT}| electricity, medium voltage, residual mix | Cut-off, S	

4.2 End-of-Life phase

4.2.1 Description of scenario

This scenario, although hypothetical, is required to allow a complete environmental comparison. In reality, it is difficult to make generalizations as practices may differ depending, for example, on regulations for waste produced by construction and demolition activities.

The construction sector, due to the intense use of natural resources, is one of the main responsible for environmental impacts on the territory, contributing significantly to the impoverishment of non-renewable raw materials. According to the European Environment Agency, the construction sector is responsible for over 30% of the total waste generated in Europe and consumes approximately 50% of all extracted resources.

In this context, the European Union has set ambitious targets to improve waste management. With the update of Directive 2018/851/EU, which amends the previous Waste Framework Directive (2008/98/EC), part of the Circular Economy Package, new targets for municipal waste recycling have been introduced: at least 55% by weight by 2025. This target will aim at 60% by 2030 and 65% by 2035.

The product life cycle ends with the end-of-life phases, modelled according to the modules provided by the EN 15804 standard. Following the reference PCR 2019:14 and considering a RSL of 50 years, as anticipated in paragraph 3.1, the end-of-life scenario described in Table 13 has been considered:

- 100% disposal scenario, which includes modules C1-C2-C4 and D, assuming complete disposal of the EoL slabs in a landfill.

The following modules, as well as the respective results presented in Chapter 5, have been elaborated assuming a standard average 1 m^2 slab with an average thickness of 2 cm, a bulk density of 2.6 t/m^3 and a weight of 52 kg. The values , therefore, consider both the average bulk density of the material and the operations necessary for the removal of the slabs.

Table 13. End of life scenario.

Process	**Units (per declared unit and material type)**	**Values (kg/m^2)**
Collection process	kg collected separately	52
	kg collected together with construction waste	0
Recovery system	kg for reuse	0
	kg for recycling	0
	kg for energy recovery	0
Disposal	kg of material for final disposal	52

4.2.2 Analysis of modules C + D

The modelling of the end-of-life scenario was carried out in compliance with the general rules indicated in the EN 15804 standard, as reported in the reference PCR. These rules establish that the end-of-life scenario must be realistic and representative of the most likely alternatives, considering the geographical context in which the product is used. They must also exclude processes not currently in use or not proven to be practicable. In accordance with what is expected, the scenario declared in this study, even if not always corresponding to local practice, ensures comparability between environmental declarations of similar products.

In particular, in the absence of specific primary data for the reference market (e.g. data on demolition methods, average transport distances, recovery rates or final destinations of materials), it was decided to adopt the default data indicated in the PCR following regulatory requirements. This choice ensures methodological coherence, allows filling data gaps and guarantees alignment with international standards, preserving the reliability of the model.

Table 14 summarizes the assumptions for module C, which were developed based on default data and standardized assumptions provided by PCR 2019:14 and EN 15804, in the absence of specific primary data for the market context. The material is not reused or subjected to valorization treatments; instead, it is delivered directly to authorized plants, in compliance with current legislation. For this reason, C3 is set to 0 since no recycling processes are assumed. More details on the modeling are provided in the following sections.

Table 14. Parameters assumed for modelling end-of-life C modules.

Module	Process	Energy vector	Quantity [kWh/t]	Distance	Means of transport
C1	Demolition/removal of masonry, tiles and blocks	Diesel	5	-	-
C2	Transport (for products/materials not intended for incineration)	-	-	80 km	Truck 16–32 t (EURO 5), load factor 50%
C4	Compaction of inert construction waste for landfill	Diesel	1.6	-	-

- **Removal and demolition (C1)**

The removal of the marble slabs occurs simultaneously with the demolition of the entire building. In line with the PCR, this phase was modeled assuming a process similar to the Demolition/deconstruction of masonry, tiles, and paver blocks, using the dataset "Diesel, burned in building machine {GLO} | market for diesel, burned in building machine | Cut-off, S" from the Ecoinvent 3.10 database. The energy consumption associated with the process is 5 kWh/t of treated material.

- **Transport to treatment centers (C2)**

In this module, the transportation of waste resulting from the demolition phase to treatment or disposal centers has been modeled. After removal from the construction site, the slabs are loaded onto heavy vehicles to be transferred to end-of-life destinations.

The transportation of demolition waste to treatment or disposal centers was modeled considering an average distance of 80 km, traveled by EURO 5 diesel trucks with a mass between 16 and 32 metric tons and a load factor of 50%. The average fuel consumption is 0.0375 kg/tkm, according to data from the process "Transport, freight, lorry 16–32 metric ton, EURO5 {RoW} | market for transport, freight, lorry 16–32 metric ton, EURO5 | Cut-off, S", from Ecoinvent 3.10.

- **Landfill disposal (C4)**

The slabs that have reached the end of their life are sent to landfill as inert waste, configuring a total disposal scenario. The material is not reused or subjected to valorization treatments; instead, it is delivered directly to authorized plants, in compliance with current legislation.

The process was modelled as Compacting of inert construction waste for landfills (including backfilling), using the dataset "Diesel, burned in building machine {GLO} | market for diesel, burned in building machine | Cut-off, S" with an energy consumption of 1.6 kWh/t.

- **Benefits (D)**

Finally, module D allows for the quantification of the potential environmental benefits or loads deriving from the recovery, reuse or recycling of the product at the end of its life and from net flows leaving the product system that have passed the end-of-waste state. In terms of LCA, these benefits are accounted for "beyond the system boundaries" and contribute to improving the overall environmental balance of the product, promoting greater resource efficiency and reducing the impact of the construction sector on the environment.

The product is assumed to be disposed 100% in landfill as inert waste, and all waste flows exiting A1-A3 are sent to landfill with no recycling and no energy recovery, so there is no contribution to module D which results to be zero.

5. Impact analysis (LCIA)

The inventory data summarized in the previous chapter were used to create the LCA models of the 2 cm thick stone slabs. The impact analysis was performed with the EF 3.1 method (Environmental Footprint).

The environmental performance results are relative expression and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks. The results of the end-of-life stage (module C) should be considered when using the results of the production stage (modules A1-A3).

5.1 Impact assessment methodology

To make the results of the LCA analysis fully understandable, enhance their environmental significance and communicate them effectively to both professionals and the public, it is essential to identify specific areas of environmental interest, known as impact categories. Suitable indicators must be selected for each of them. Category indicators, i.e. indicators referring to individual environmental impacts, have the task of summarizing the potential environmental effects associated with the flows of matter and energy entering and leaving the system analyzed.

For each impact category, characterization coefficients are used to homogenize the contribution of individual emissions into the environment (into the air, soil or water). Measuring overall impacts requires an interpretation of the data and a hierarchical ordering of the impacts themselves.

The categories used for the assessment of the impacts of the products under study and the characterization factors used, in accordance with the EN 15804:2012+2019:A2/AC:2021 standard (Annex C), are reported in Table 15. In this study, in the impact analysis phase, the EN15804 + A2 method was applied through the SimaPro software. This uses the characterization factors required by the regulation and reported in Table 15. For the climate change indicator, impacts are analysed in detail along the production chain, to identify which sub-processes contribute, and to what extent, to the total impact and the individual phases required by the current EN 15804:2012+2019:A2/AC:2021 standard. A broader overview is also provided by considering additional indicators provided by the method.

Table 15. Main and additional environmental indicators (in grey) with units of measurement, warnings and characterization models.

Impact category	Indicator	Unit of measurement	Disclaimer	Model
Acidification	AP	mol H+ eq	-	Accumulated Exceedance, Seppälä et al. 2006, Posch et al., 2008
Climate change	GWP total	kg CO2eq	-	Baseline model of 100 years of the IPCC based on IPCC 2013
Climate change - Biogenic	GWP-fossil	kg CO2eq	-	
Climate change - Fossil	GWP-biogenic	kg CO2eq	-	
Climate change - Land use and LU change	GWP-luluc	kg CO2eq	-	
Eutrophication, marine	EP-marine	kg N eq	-	EUTREND model, Struijs et al., 2009b, as implemented in ReCiPe
Eutrophication, freshwater	EP-freshwater	kg P eq	-	EUTREND model, Struijs et al., 2009b,

				as implemented in ReCiPe
Eutrophication, terrestrial	EP-terrestrial	mol N eq	-	Accumulated Exceedance, Seppälä et al. 2006, Posch et al.
Ozone depletion	ODP	kg CFC11 eq	-	Steady-state ODPs, WMO 2014
Photochemical ozone formation	POCP	kg NMVOC eq	-	LOTOS-EUROS, Van Zelm et al., 2008, as applied in ReCiPe
Resource use, fossils	ADP-fossil	MJ	2	CML 2002, Guinée et al., 2002, and van Oers et al. 2002.
Resource use, minerals and metals	ADP-minerals&metals	kg Sb eq	2	
Water use	WDP	m3 world eq. depriv.	2	Available WAter REmaining (AWARE) Boulay et al., 2016
Particular matter	PM	disease inc.	-	SETAC-UNEP, Fantke et al.2016
Ecotoxicity, freshwater	ETP-fw	CTUe	2	Usetox version 2 until modified USEtox model is available from EC-JRC
Human toxicity, cancer	HTP-c	CTUh	2	
Human toxicity, non-cancer	http-nc	CTUh	2	
Ionizing radiation	IRP	kBq U-235 eq	1	Human health effect model as developed by Dreicer et al. 1995 update by Frischknecht et al., 2000
Land use	SQP	Dimensionless	2	Soil quality index based on LANCA
Disclaimer 1 – This impact category mainly concerns the potential effect of low doses of ionizing radiation on human health related to the nuclear fuel cycle. It does not consider the effects due to possible accidents.				
Disclaimer 2 – The results of this environmental impact indicator should be used with caution, as they present a high degree of uncertainty or because there is limited experience in the use of this indicator.				

Furthermore, three additional sets of inventory-based indicators are presented to describe resource consumption, waste categories, and output flows for each module (expressed per declared unit):

1. **Resource consumption**: PERT = Total use of renewable primary energy resources (MJ); PERM = Use of renewable primary energy resources used as raw materials (MJ); PEARS = Use of renewable primary energy excluding renewable primary energy resources used as raw materials (MJ); PENRT = Total use of non-renewable primary energy resources (MJ); PENRM = Use of non-renewable primary energy resources used as raw materials (MJ); PENRE = Use of non-renewable primary energy excluding non-renewable primary energy resources used as raw materials (MJ); SM = Use of secondary material (kg); RSF = Use of renewable secondary fuels (MJ); NRSF = Use of non-renewable secondary fuels (MJ); FWT = Total use of net fresh water (m3);
2. **Waste categories**: HWD = Hazardous waste disposed (kg); NHWD = Non-hazardous waste disposed (kg); RWD = Radioactive waste disposed (kg);
3. **Outgoing flows**: CRU = Components for reuse (kg); MFR = Materials for recycling (kg); MER = Materials for energy recovery (kg); EE = Exported energy (MJ).

5.2 Environmental impact results for single material

Table 71 shows the environmental impact values referred to 1 m² of 2 cm-thick slab, for all the materials analyzed in the study, from the extraction phase to packaging, excluding the end-of-life phase.

Table 16. Environmental impact results for 1 m^2 of slab (2 cm thick), for each material analyzed.

Impact Category	**Unit**	***1***	***2***	***3***	***4***
Acidification	mol H+ eq	2.74E-02	2.29E-02	1.55E-02	8.69E-02
Climate change	kg CO2eq	5.12E+00	4.46E+00	3.38E+00	1.56E+01
Climate change - Biogenic	kg CO2eq	3.95E-02	-6.02E-01	-6.06E-01	1.08E-01
Climate change - Fossil	kg CO2eq	5.08E+00	5.06E+00	3.99E+00	1.54E+01
Climate change - Land use and Land use change	kg CO2eq	7.15E-04	1.32E-03	1.18E-03	2.79E-03
Ecotoxicity. freshwater	CTUe	1.61E+01	1.10E+01	8.78E+00	6.72E+01
Ecotoxicity. freshwater - inorganics	CTUe	1.13E+01	6.83E+00	5.57E+00	3.15E+01
Ecotoxicity. freshwater - organics	CTUe	4.74E+00	4.17E+00	3.21E+00	3.56E+01
Particular matter	disease inc.	5.57E-07	4.27E-07	2.41E-07	1.35E-06
Eutrophication. marine	kg N eq	1.06E-02	7.91E-03	4.78E-03	3.20E-02
Eutrophication. freshwater	kg P eq	5.76E-04	5.33E-04	4.54E-04	1.94E-03
Eutrophication. terrestrial	mol N eq	1.13E-01	8.60E-02	5.17E-02	3.48E-01
Human toxicity. cancer	CTUh	1.70E-08	1.45E-08	1.08E-08	1.46E-07
Human toxicity. cancer - inorganics	CTUh	3.48E-10	2.56E-10	2.09E-10	1.92E-09
Human toxicity. cancer - organics	CTUh	1.67E-08	1.42E-08	1.06E-08	1.44E-07
Human toxicity. non-cancer	CTUh	1.86E-08	1.99E-08	1.67E-08	6.88E-08
Human toxicity. non-cancer - inorganics	CTUh	1.71E-08	1.79E-08	1.51E-08	6.43E-08
Human toxicity. non-cancer - organics	CTUh	1.52E-09	1.99E-09	1.54E-09	4.50E-09
Ionizing radiation	kBq U-235 eq	1.41E-01	1.65E-01	1.43E-01	4.25E-01
Land use	Pt	6.53E+00	1.09E+02	1.08E+02	4.05E+01
Ozone depletion	kg CFC11 eq	9.34E-08	1.15E-07	9.42E-08	2.68E-07
Photochemical ozone formation	kg NMVOC eq	3.59E-02	3.28E-02	2.09E-02	1.10E-01
Resource use. fossils	MJ	7.10E+01	8.26E+01	6.60E+01	2.12E+02
Resource use. minerals and metals	kg Sb eq	5.77E-05	9.27E-06	7.70E-06	9.52E-05
Water use	m3 depriv.	3.71E+00	1.17E+01	1.16E+01	3.44E+00
GWP-GHG	kg CO2eq	5.08E+00	5.06E+00	3.99E+00	1.55E+01

Impact Category	**Unit**	***5***	***6***	***7***	***8***
Acidification	mol H+ eq	8.07E-02	4.50E-02	5.29E-02	5.29E-02
Climate change	kg CO2eq	1.54E+01	1.07E+01	1.12E+01	1.03E+01
Climate change - Biogenic	kg CO2eq	9.08E-02	7.80E-02	7.30E-02	8.50E-02
Climate change - Fossil	kg CO2eq	1.53E+01	1.06E+01	1.11E+01	1.03E+01
Climate change - Land use and LU change	kg CO2eq	4.24E-03	3.59E-03	3.92E-03	1.90E-03
Ecotoxicity. freshwater	CTUe	1.89E+02	1.58E+02	1.70E+02	3.71E+01
Ecotoxicity. freshwater - inorganics	CTUe	8.60E+01	7.21E+01	7.75E+01	2.74E+01

Ecotoxicity. freshwater - organics	CTUe	1.03E+02	8.55E+01	9.20E+01	9.71E+00
Particular matter	disease inc.	1.37E-06	6.20E-07	7.49E-07	9.60E-07
Eutrophication. marine	kg N eq	2.79E-02	1.25E-02	1.61E-02	1.89E-02
Eutrophication. freshwater	kg P eq	2.23E-03	1.87E-03	1.94E-03	1.44E-03
Eutrophication. terrestrial	mol N eq	3.02E-01	1.34E-01	1.73E-01	2.06E-01
Human toxicity. cancer	CTUh	8.47E-08	6.87E-08	7.55E-08	3.47E-08
Human toxicity. cancer - inorganics	CTUh	1.14E-09	1.13E-09	1.24E-09	7.34E-10
Human toxicity. cancer - organics	CTUh	8.36E-08	6.76E-08	7.43E-08	3.40E-08
Human toxicity. non-cancer	CTUh	8.14E-08	7.41E-08	7.62E-08	6.19E-08
Human toxicity. non-cancer - inorganics	CTUh	7.39E-08	6.81E-08	6.99E-08	5.82E-08
Human toxicity. non-cancer - organics	CTUh	7.53E-09	5.96E-09	6.37E-09	3.77E-09
Ionizing radiation	kBq U-235 eq	5.93E-01	5.00E-01	5.09E-01	3.26E-01
Land use	Pt	3.10E+01	2.88E+01	3.38E+01	3.41E+01
Ozone depletion	kg CFC11 eq	3.44E-07	2.53E-07	2.63E-07	2.18E-07
Photochemical ozone formation	kg NMVOC eq	1.01E-01	5.03E-02	6.16E-02	6.79E-02
Resource use. fossils	MJ	2.36E+02	1.69E+02	1.77E+02	1.49E+02
Resource use. minerals and metals	kg Sb eq	7.53E-05	7.21E-05	8.19E-05	1.89E-04
Water use	m3 depriv.	5.02E+00	1.01E+01	9.95E+00	2.06E+00
GWP-GHG	kg CO2eq	1.73E+01	1.06E+01	1.11E+01	1.03E+01

Impact Category	**Unit**	***9***	***10***	***11***
Acidification	mol H+ eq	4.06E-02	1.12E-01	1.36E-01
Climate change	kg CO2eq	6.87E+00	1.64E+01	3.79E+01
Climate change - Biogenic	kg CO2eq	-8.18E-01	-2.96E+00	4.95E+00
Climate change - Fossil	kg CO2eq	7.68E+00	1.94E+01	3.30E+01
Climate change - Land use and LU change	kg CO2eq	2.12E-03	5.94E-03	5.20E-03
Ecotoxicity. freshwater	CTUe	2.03E+01	4.78E+01	8.41E+01
Ecotoxicity. freshwater - inorganics	CTUe	1.19E+01	2.76E+01	5.22E+01
Ecotoxicity. freshwater - organics	CTUe	8.40E+00	2.03E+01	3.19E+01
Particular matter	disease inc.	8.33E-07	2.55E-06	2.16E-06
Eutrophication. marine	kg N eq	1.48E-02	4.37E-02	5.38E-02
Eutrophication. freshwater	kg P eq	8.83E-04	1.64E-03	4.49E-03
Eutrophication. terrestrial	mol N eq	1.61E-01	4.77E-01	4.63E-01
Human toxicity. cancer	CTUh	2.97E-08	7.28E-08	9.86E-08
Human toxicity. cancer - inorganics	CTUh	5.72E-10	1.28E-09	2.73E-09
Human toxicity. cancer - organics	CTUh	2.91E-08	7.15E-08	9.58E-08
Human toxicity. non-cancer	CTUh	3.25E-08	7.11E-08	1.51E-07
Human toxicity. non-cancer - inorganics	CTUh	2.95E-08	6.21E-08	1.34E-07
Human toxicity. non-cancer - organics	CTUh	3.06E-09	8.95E-09	1.71E-08
Ionizing radiation	kBq U-235 eq	2.36E-01	5.05E-01	1.12E+00
Land use	Pt	1.36E+02	6.78E+02	1.83E+02
Ozone depletion	kg CFC11 eq	1.56E-07	4.82E-07	6.48E-07
Photochemical ozone formation	kg NMVOC eq	5.42E-02	1.77E-01	1.63E-01
Resource use. fossils	MJ	1.16E+02	3.63E+02	4.71E+02

Resource use. minerals and metals	kg Sb eq	4.09E-05	4.32E-05	9.25E-05
Water use	m3 depriv.	2.72E+00	3.32E+00	8.28E+01
GWP-GHG	kg CO2eq	7.69E+00	1.94E+01	3.77E+01

Impact Category	**Unit**	***12***	***13***	***14***	***15***
Acidification	mol H+ eq	8.92E-02	4.11E-02	1.17E-01	1.17E-01
Climate change	kg CO2eq	1.87E+01	7.55E+00	1.74E+01	1.78E+01
Climate change - Biogenic	kg CO2eq	1.01E-01	3.80E-02	6.83E-02	9.18E-02
Climate change - Fossil	kg CO2eq	1.86E+01	7.51E+00	1.73E+01	1.77E+01
Climate change - Land use and LU change	kg CO2eq	4.07E-03	2.28E-03	4.25E-03	2.04E-03
Ecotoxicity. freshwater	CTUe	9.55E+01	1.32E+02	1.57E+02	3.63E+01
Ecotoxicity. freshwater - inorganics	CTUe	6.36E+01	1.23E+02	7.41E+01	2.06E+01
Ecotoxicity. freshwater - organics	CTUe	3.19E+01	9.27E+00	8.33E+01	1.57E+01
Particular matter	disease inc.	1.14E-06	7.27E-07	2.01E-06	2.79E-06
Eutrophication. marine	kg N eq	3.10E-02	1.26E-02	4.66E-02	4.85E-02
Eutrophication. freshwater	kg P eq	2.72E-03	1.09E-03	1.98E-03	1.36E-03
Eutrophication. terrestrial	mol N eq	3.35E-01	1.39E-01	5.08E-01	5.30E-01
Human toxicity. cancer	CTUh	6.70E-08	3.66E-08	8.40E-08	5.98E-08
Human toxicity. cancer - inorganics	CTUh	1.29E-09	1.23E-09	1.03E-09	9.54E-10
Human toxicity. cancer - organics	CTUh	6.57E-08	3.54E-08	8.30E-08	5.89E-08
Human toxicity. non-cancer	CTUh	9.10E-08	7.35E-07	7.88E-08	5.23E-08
Human toxicity. non-cancer - inorganics	CTUh	8.43E-08	7.32E-07	7.10E-08	4.72E-08
Human toxicity. non-cancer - organics	CTUh	6.73E-09	3.23E-09	7.75E-09	5.08E-09
Ionizing radiation	kBq U-235 eq	6.36E-01	3.45E-01	4.96E-01	3.66E-01
Land use	Pt	6.73E+01	3.94E+01	3.35E+01	2.48E+01
Ozone depletion	kg CFC11 eq	3.84E-07	1.37E-07	3.56E-07	3.12E-07
Photochemical ozone formation	kg NMVOC eq	1.12E-01	4.62E-02	1.61E-01	1.64E-01
Resource use. fossils	MJ	2.75E+02	1.10E+02	2.58E+02	2.45E+02
Resource use. minerals and metals	kg Sb eq	4.01E-04	5.86E-05	8.98E-05	3.83E-05
Water use	m3 depriv.	6.37E+00	3.44E+00	2.25E+00	2.32E+00
GWP-GHG	kg CO2eq	1.86E+01	7.53E+00	1.67E+01	1.78E+01

5.3 Sector EPD: aggregated environmental impact results

5.3.1 Declared results

Table 73 presents the aggregated impact results of the three phases A1-A3, the impacts of the end-of-life phase C1-C4 modules and the environmental benefits D related to the **sector average**. The average performed is a **weighted average,** which considers the representativeness of each material in terms of quantities produced in 2024. The weighted average was calculated by referring to the total mass of regular blocks extracted from the quarry in 2024 for each material and calculating, based on the data of each company, the resulting m^2 of slab, assuming that all regular blocks are entirely transformed into 2 cm-thick slabs. Table 72 reports this data, along with the weight each material contributes to the average.

Table 17. Reference values for weighted average calculation.

Material	Regular blocks extracted in 2024 [t]	Equivalent surface area of 2 cm-thick slab [m^2]	Weight on the average
1	14148.6	111406	9.6%
2	2452	48651	4.2%
3	2588	51349	4.4%
4	1500	22388	1.9%
5	11600	141809	12.3%
6	5006	51715	4.5%
7	1898	20343	1.8%
8	17960.18	201573	17.4%
9	11942.41	185441	16.0%
10	487	5334	0.5%
11	10540.06	128381	11.1%
12	860	8893	0.8%
13	2281.62	29825	2.6%
14	2065.85	28692	2.5%
15	17298.07	120125	10.4%

All results are relative to the declared unit of 1 m^2 of a 2 cm-thick finished slab. Specifically, for the description of the end-of-life modules, it was assumed that all the material is recovered (52 kg per 1 m^2 of slab). The EoL scenario considered the most probable given the characteristics of the product analyzed is the 100% disposal scenario, as described in section 4.17, so this is the one for which the sector weighted average of environmental performance results is declared in Table 73.

The environmental performance results are relative expression and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks.
The results of the end-of-life stage (module C) should be considered when using the results of the production stage (modules A1-A3).

Table 18. 100% disposal scenario.

EN15804+A2							
Impact Category	**Reference unit**	A1-A3	C1	C2	C3	C4	D
GWP Total	kg CO2eq	1.35E+01	9.38E-02	8.14E-01	0.00E+00	3.00E-02	0.00E+00
GWP Fossil	kg CO2eq	1.31E+01	9.38E-02	8.14E-01	0.00E+00	3.00E-02	0.00E+00
GWP Biogenic	kg CO2eq	4.02E-01	1.02E-05	1.81E-05	0.00E+00	3.28E-06	0.00E+00
GWP Luluc	kg CO2eq	2.67E-03	8.14E-06	3.23E-04	0.00E+00	2.61E-06	0.00E+00
ODP	kg CFC-11 eq.	2.66E-07	1.44E-09	1.14E-08	0.00E+00	4.59E-10	0.00E+00
AP	Moles H+ eq.	6.69E-02	8.46E-04	2.71E-03	0.00E+00	2.71E-04	0.00E+00
EP Freshwater	kg P eq	1.67E-03	2.74E-06	6.39E-05	0.00E+00	8.76E-07	0.00E+00
EP Marine	kg N eq	2.50E-02	3.93E-04	8.79E-04	0.00E+00	1.26E-04	0.00E+00
EP Terrestrial	Mole N eq.	2.59E-01	4.30E-03	9.56E-03	0.00E+00	1.38E-03	0.00E+00
POCP	kg NMVOC	8.62E-02	1.28E-03	3.78E-03	0.00E+00	4.10E-04	0.00E+00
ADP (minerals & metals)	kg Sb eq	8.28E-05	3.35E-08	2.61E-06	0.00E+00	1.07E-08	0.00E+00
ADP (fossil)	MJ	1.92E+02	1.23E+00	1.14E+01	0.00E+00	3.93E-01	0.00E+00
WDP	m3	1.31E+01	2.66E-03	5.16E-02	0.00E+00	8.50E-04	0.00E+00
Resource consumption							
Impact Category	**Reference unit**	A1-A3	C1	C2	C3	C4	D
PERT	MJ	1.37E+01	7.32E-03	1.44E-01	0.00E+00	2.34E-03	0.00E+00
PERM	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PEARS	MJ	1.37E+01	7.32E-03	1.44E-01	0.00E+00	2.34E-03	0.00E+00
PENRT	MJ	1.92E+02	1.23E+00	1.14E+01	0.00E+00	3.93E-01	0.00E+00
PENRM	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PENRE	MJ	1.92E+02	1.23E+00	1.14E+01	0.00E+00	3.93E-01	0.00E+00
SM	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RSF	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NRSF	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
FWT	m3	3.15E-01	8.77E-05	1.52E-03	0.00E+00	2.81E-05	0.00E+00
Waste							
Impact Category	**Reference unit**	A1-A3	C1	C2	C3	C4	D
HWD	kg	4.86E-03	1.12E-05	2.87E-04	0.00E+00	3.58E-06	0.00E+00
NHWD	kg	5.65E+01	7.50E-04	5.37E-01	0.00E+00	2.40E-04	0.00E+00
RWD	kg	1.06E-04	1.35E-07	2.30E-06	0.00E+00	4.31E-08	0.00E+00
Output flow							
CRU	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MFR	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
WED	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
EE	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Additional indicators							
Impact Category	**Reference unit**	A1-A3	C1	C2	C3	C4	D
GWP-GHG	kg CO2eq	1.36E+01	9.38E-02	8.14E-01	0.00E+00	3.00E-02	0.00E+00
Particular matter	disease inc.	1.24E-06	2.40E-08	6.45E-08	0.00E+00	7.69E-09	0.00E+00
Ionizing radiation	kBq U-235 eq	4.25E-01	5.50E-04	9.38E-03	0.00E+00	1.76E-04	0.00E+00

Land use	Pt	7.26E+01	8.63E-02	6.81E+00	0.00E+00	2.76E-02	0.00E+00
Ecotoxicity, freshwater	CTUe	6.80E+01	1.74E-01	3.04E+00	0.00E+00	5.56E-02	0.00E+00
Human toxicity, cancer	CTUh	5.22E-08	3.67E-10	4.22E-09	0.00E+00	1.17E-10	0.00E+00
Human toxicity, non-cancer	CTUh	7.95E-08	1.52E-10	7.10E-09	0.00E+00	4.86E-11	0.00E+00

5.4 Interpretation: contribution analysis, sensitivity analysis and uncertainty analysis

This paragraph elaborates on the impact results obtained for the climate change indicator and aims to identify the contribution that the different phases of the slab production process have on the total impact.

5.4.1 Contribution analysis

The graph in Figure 6 shows the impact on climate change of 1 m^2 of a 2 cm-thick finished slab for the 15 materials studied. The weighted average shows a value of 13.5 kg CO_2 eq/m^2.

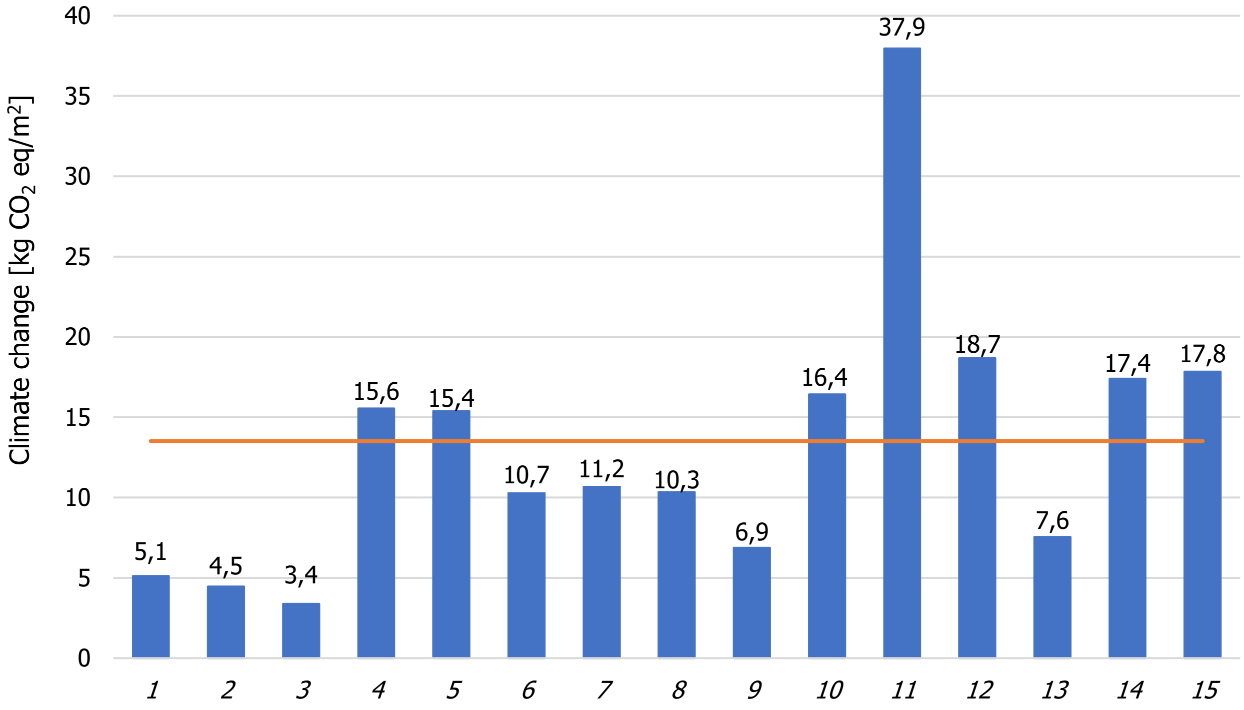

Figure 6. Climate change impacts of 1 m^2 of slab (2 cm thick) for all materials analyzed and indication of the average value (climate change total indicator, GWP-total).

As can be seen from the results obtained on the climate change indicator, the total impact varies depending on the material considered and ranges between 3.4 and 37.9 kg CO_2 eq./m^2. This variation, although it may appear high, is to be considered completely physiological and due to the heterogeneity of the materials studied. In particular, the main variables are:

- the very nature of the stone material, whose characteristics vary not only from material to material (harder and/or more compact stones usually require greater consumption of

materials and energy), but also considering similar materials (variations in the quarry's yield, due, for example, to the greater or lesser presence of fractures in the rock);
- uncertainties on the values obtained through data collection due to possible inaccuracies on the part of the companies.

The graph in Figure 7 shows, for each material analysed, the impact on climate change due to (i) the energy used in the extraction phase A1 (electricity and diesel), (ii) the materials consumed and the waste produced during the extraction phase A1, (iii) the transport from the quarry to the processing plant A2, (iv) the energy used for the cutting/finishing phases A3, (v) the materials and waste produced during the cutting/finishing phases A3 and (vi) the packaging phase in the A3 module.

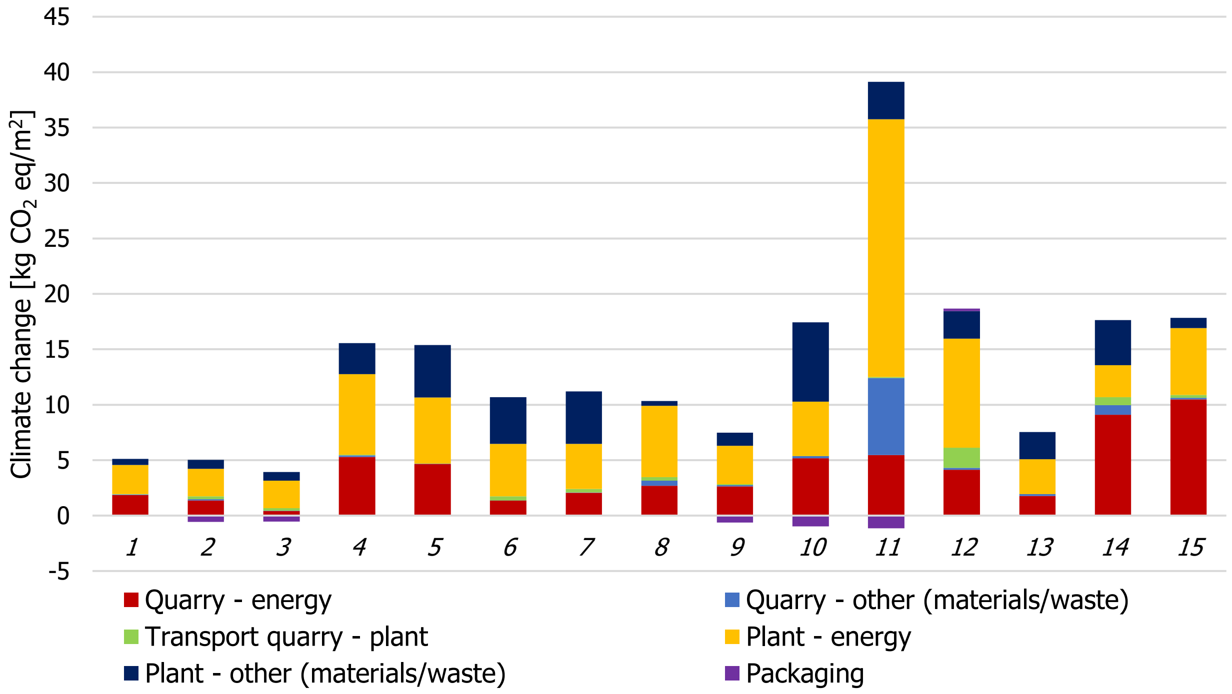

Figure 7. Contribution, in absolute value, of the various phases of the process to the climate change indicator (GWP-total).

The same results illustrated in Figure 7 are reported quantitatively in Table 19. Graph and table describe the elements present in the aggregate modules A1-A3 for each material analyzed and for the average slab subject to EPD.

Table 19. Contribution analysis on the climate change indicator: for each material, the impact due to energy (in the quarry/in the plant), the use of materials and waste treatment (in the quarry/in the plant) and transport from the quarry to the plant is indicated. The average, minimum and maximum stone value are also provided. For greater readability, the colours associated with each line are those indicated in the previous graph.

Climate change [kg CO_2 eq. / m^2]	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***
Quarry - energy	1.9	1.4	0.5	5.3	4.7	1.4	2.1	2.7	2.6
Quarry - other (materials/waste)	0.1	0.1	0.0	0.2	0.0	0.0	0.0	0.5	0.1
Transport quarry - plant	0.0	0.2	0.2	0.0	0.0	0.3	0.3	0.3	0.1
Plant - energy	2.6	2.5	2.6	7.3	6.0	4.7	4.1	6.4	3.5
Plant - other (materials/waste)	0.5	0.8	0.9	2.8	4.7	4.2	4.7	0.4	1.2

Packaging	0.0	-0.6	-0.6	0.0	0.0	0.0	0.0	0.0	-0.6
Total impact on climate change	*5.1*	*4.5*	*3.4*	*15.6*	*15.4*	*10.7*	*11.2*	*10.3*	*6.9*

Climate change [kg CO_2 eq. / m^2]	***10***	***11***	***12***	***13***	***14***	***15***	*Medium stone*	*MIN*	*MAX*
Quarry - energy	5.2	5.5	4.1	1.8	9.1	10.5	3.9	0.4	10.5
Quarry - other (materials/waste)	0.2	6.9	0.2	0.2	0.9	0.1	0.9	0.0	6.9
Transport quarry - plant	0.0	0.1	1.8	0.0	0.7	0.2	0.2	0.0	1.8
Plant - energy	4.9	23.2	9.8	3.1	2.9	6.0	6.8	2.5	23.2
Plant - other (materials/waste)	7.2	3.4	2.5	2.5	4.1	0.9	2.0	0.4	7.2
Packaging	-1.0	-1.1	0.2	0.0	0.0	0.0	-0.3	-1.1	0.2
Total impact on climate change	*16.4*	*37.9*	*18.7*	*7.6*	*17.4*	*17.8*	*13.5*	*3.4*	*37.9*

For the average slab subject to the sector EPD, the percentage contributions of the different production processes to the total of the climate change indicator for module A1-A3 are shown in Table 20.

Table 20. Percentage contributions of the different stages of the production process to the total climate change indicator for the average slab considered.

Element	**Share**
Quarry - energy	29.2%
Quarry - other (materials/waste)	6.9%
Transport quarry - plant	1.4%
Plant - energy	50.0%
Plant - other (materials/waste)	14.7%
Packaging	-2.0%

The end-of-life modules C and D have not been represented because they were developed assuming a standard average slab with an average thickness of 2 cm, bulk density of 2.6 t/m³ and weight equal to 52 kg, therefore their contribution to the climate change indicator is the same regardless of the type of material considered and can be added to the total value for A1-A3 presented in Table 19:

- The 100% disposal scenario results in 0.94 kg CO_2 eq./m^2 for the end of life of the slab.

As can be seen in Figure 7, energy consumption both in the block extraction phase and in the transformation phase plays a significant role on the total impact of the climate change indicator for modules A1-A3, constituting between extraction (module A1) and processing (module A3) about 80% of the impacts of the average slab (Table 20). However, the variability is very high. It appears that for the extraction phase, the impact due to energy varies between 0.4 and 10.5 kg CO_2 eq./m^2, while for the transformation phase between 2.5 and 23.2 kg CO_2 eq./m^2. This variability is due to a set of factors, such as:

- The use of different energy sources for electricity. Some companies need to produce electricity using a diesel generator, which has a greater impact than using electricity from the grid; in other cases, electricity with a particularly low environmental impact is used (photovoltaic);
- Different characteristics of hardness and compactness of materials. Usually, harder and/or more compact materials require higher energy consumption;

- The use of different technologies (for example, extraction with explosives or diamond wire);
- Different yields (both in the quarry and in the plant). For example, a quarry that has more fractured material will probably have a higher energy/useful material ratio than a quarry where the yield is higher;
- Possible inaccuracies in data collection by companies.

Transport contributes just under 1.5% to the impact of the average slab, because even though it travels mainly by road, the distances travelled between the quarry and the plant are limited, often being within the same Italian Region.

The use of materials and waste treatment in the extraction phase has an impact on climate change that is not very significant compared to the total impact. In the transformation phase into slabs, however, the materials and waste treatment have an average impact of 2.0 kg CO_2 eq./m^2, a minimum value of 0.4 and a maximum of 7.2 kg CO_2 eq./m^2. This impact depends mainly on the consumption of resin, diamond and metal tools.

The presence of packaging results in a benefit (negative impact) due to the characterization factors for the biogenic carbon, which is present in the wood used for the ties and EUROpallets.

5.4.2 Sensitivity and uncertainty analysis

The primary data collected during the study constitutes a representative sample of the member companies of PNA and the Italian situation in the ornamental stone sector. The primary data used present a certain level of variability, which is reflected in the environmental results previously presented and due to the heterogeneity of the materials studied. In particular, the main variables are:

- the very nature of the stone material, whose characteristics vary not only from material to material (harder and/or more compact stones usually require greater consumption of materials and energy), but also considering similar materials (variations in the quarry's yield, due, for example, to the greater or lesser presence of fractures in the rock);
- uncertainties on the values obtained through data collection due to possible inaccuracies on the part of the companies (addressed by the development of worst/best case scenarios).

For this reason, this variability is considered physiological, acceptable and representative of the current Italian situation.

Uncertainty analysis has been performed with Monte Carlo simulation through SimaPro tool and the results for the climate change impact category, took as representative, are reported in Table 76 and illustrated in Figure 8.

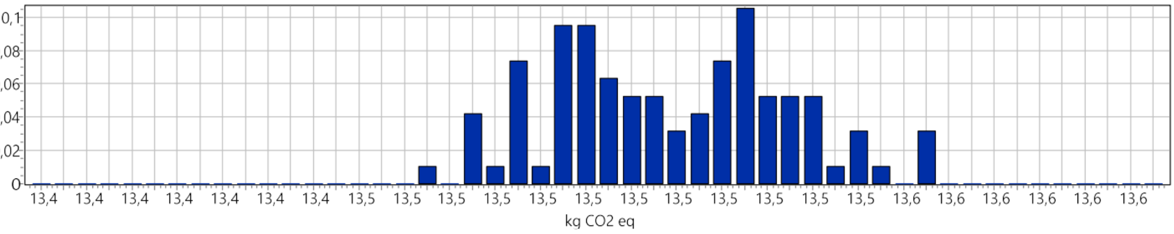

Figure 8. Uncertainty analysis of the weighted average product (1 m^2 of final slab) with method EN 15804, confidence interval: 95 %, Climate Change indicator.

Table 21. Uncertainty analysis performed through Montecarlo simulation (95 repetitions), results for the climate change indicator

Impact category	**Unit**	**Mean**	**Median**	**Standard deviation (SD)**	**Coefficient of variation (CV)**	**2,5%**	**97,5%**	**Standard error of the mean (SEM)**
Climate change	kg CO2 eq	1.35E+01	1.35E+01	2.31E-02	1.71E-01	1.35E+01	1.36E+01	2.37E-03

Using the available primary data, it was possible to calculate a worst-case scenario and a best-case scenario variation of results for the A1-A3 module and the environmental indicator Climate Change, to address **uncertainties** in the data collection and the **sensitivity** of the results to key parameter variations.

In particular, the key parameter of energy consumption, which between quarry and plant contributes about 80% to the Climate Change impacts for the average 2 cm-thick slab and was one of the most critical information to collect during data collection, has been varied of -20% and +20% to define two possible scenarios (respectively, best and worst case). The corresponding results for the Climate change indicator are shown in Table 77 (weighted average 2 cm-thick slab).

Table 77. Contributions of the different stages of the production process to the total climate change indicator for the average slab considered.

Climate change [kg CO_2 eq. / m^2]	***Declared weighted average***	***Worst case***	***Best case***
Quarry - energy	4.0	4.7	3.2
Quarry - other (materials/waste)	0.8	0.8	0.8
Transport quarry - plant	0.2	0.2	0.2
Plant - energy	6.8	8.2	5.4
Plant - other (materials/waste)	2.0	2.0	2.0
Packaging	-0.3	-0.3	-0.3
Total impact on climate change	*13.5*	*15.6*	*11.3*

The results show that for the worst-case scenario, the impact increases of 2.1 kg CO_2 eq. while in the best-case scenario, the impact decreases by 2.2 kg CO_2 eq. More accurate variations from the average cannot be calculated based on the data collected.

6. Conclusions and recommendations

This LCA study quantified the average impact of a 2 cm thick stone slab, adopting an approach compliant with the EN 15804+A2 standard. The environmental analysis was carried out on 15 materials extracted and processed in Italy. The geographical representativeness is in line with the objectives of the study as it includes materials extracted and processed exclusively in Italy. The temporal representativeness is excellent, as recent data are available for each material, referring to the year 2024. The accuracy of the data used in the analysis is very good, as they are based almost exclusively on primary data collected in the specific companies.

Considering all the materials analyzed, the impact on climate change (GWP-total) of an average 2 cm thick slab is 13.5 kg CO_2 eq/m^2, considering the phases related to the aggregate modules A1-A3, where the minimum value is 3.4 kg CO_2 eq/m^2 and the maximum value is 37.9 kg CO_2 eq/m^2. This variability reflects the heterogeneity of the stone material and the differences in extraction and processing methods.

The analysis of impact contribution shows that energy consumption represents the most significant share of the total: the energy used in the quarry accounts for 29.2%, while that consumed in the processing plants contributes 50.0%. Overall, almost 80% of the environmental impact of the average slab is related to the energy requirement of the two main production phases. This evidence suggests that the adoption of renewable or low-impact sources, together with an increase in energy efficiency and processing yields, could have very significant effects in terms of mitigating environmental impacts.

The impact of materials and waste in the quarry phase is very small (6.9% of the total). Instead, the consumption of materials and waste management in the transformation phase contribute 14.7% of the total climate change impact. This impact depends mainly on the use of hydrated lime, resins and diamond or metal tools. Transport, although present in all cases, accounts for only 1.4% on average due to the short distances travelled between quarry and plant.

An interesting aspect concerns the packaging, which, thanks to the biogenic carbon contained in the wood of the pallets and ties, generates an average environmental benefit (negative impact) equal to -2.0% on the total, thus contributing to reducing the overall footprint of the product.

Finally, the end-of-life phase was assessed assuming a 100% disposal scenario, which generates an impact of 0.94 kg CO_2 eq./m^2, without bringing post-consumer benefits.

In conclusion, the study represents a robust reference for the development of a sector EPD for the Italian natural stone sector. It contributes to the definition of transparent and comparable environmental metrics, useful not only for obtaining environmental certifications, but also for orienting corporate strategies towards more efficient, sustainable processes, consistent with emerging market demands and European regulations.

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Annex 1

Data quality assessment

The quality of the data used in the model was assessed according to the criteria set out in Annex E (Table E.1) of EN 15804:2012+A2:2019 (UN Environment Global Guidance on LCA Database Development) is shown in Table 77.

Table 22. Data quality assessment.

	Geographical representativeness	Technical representativeness	Time representativeness	Quality level
A1-A3				
Diesel, burned in diesel-electric generating set, 18.5kW {GLO}| diesel, burned in diesel-electric generating set, 18.5kW | Cut-off, S	Good	Very good	Very good	Selected general
Diesel, burned in building machine {GLO}| market for | Cut-off, S	Good	Very good	Very good	Selected general
Lubricating oil {RER}| market for lubricating oil | Cut-off, S	Good	Very good	Very good	Selected general
Diamond wire	Good	Good	Very good	Selected general
Synthetic rubber {GLO}| market for | Cut-off, S	Good	Good	Very good	Selected general
Transport, freight, lorry >32 metric ton, euro5 {RER}| market for transport, freight, lorry >32 metric ton, EURO5 | Cut-off, S	Good	Very good	Very good	Selected general
Electricity, Residual mix 2024, Italy	Very good	Very good	Very good	Selected general
Diamond blade	Good	Good	Very good	Selected general
Slurry waste treatment, filter-press, material, company	Good	Good	Good	Selected general
Lime, hydrated, packed {CH}| production | Cut-off, S	Good	Very good	Very good	Selected general
Tungsten carbide powder {GLO}| market for tungsten carbide powder | Cut-off, S	Good	Good	Very good	Selected general
Inert waste, for final disposal {CH}| treatment of inert waste, inert material landfill | Cut-off, S	Good	Very good	Very good	Selected general
Municipal solid waste {CH}| treatment of municipal solid waste,	Good	Very good	Very good	Selected general

sanitary landfill | Cut-off, S				
Synthetic resin abrasive; for stone polishing	Good	Good	Very good	Selected general
Resin diamond abrasive; for stone polishing	Good	Good	Very good	Selected general
Sawnwood, board, softwood, raw, dried (u=20%) {Europe without Switzerland}| market for sawnwood, board, softwood, raw, dried (u=20%) | Cut-off, S	Good	Good	Very good	Selected general
Steel blade, LC	Good	Good	Very good	Selected general
Steel grit	Good	Good	Very good	Selected general
Drilling rod, LC	Good	Good	Very good	Selected general
Slow-burning fuse	Good	Good	Very good	Selected general
Detonation cord	Good	Good	Very good	Selected general
Detonator, LC	Good	Good	Very good	Selected general
Magnesite abrasive, for stone polishing	Good	Good	Very good	Selected general
Epoxy resin, liquid {RER}| market for epoxy resin, liquid | Cut-off, S	Good	Very good	Very good	Selected general
Glass fiber reinforced plastic, polyester resin, hand lay-up {RER}| production | Cut-off, S	Good	Very good	Very good	Selected general
Black powder	Good	Good	Very good	Selected general
Explosive, tovex {CH}| explosive production, tovex | Cut-off, S	Good	Very good	Very good	Selected general
Lime mortar {GLO}| market for lime mortar | Cut-off, S	Good	Very good	Very good	Selected general
Electricity, low voltage {IT}| electricity production, photovoltaic, 3kWp slanted-roof installation, multi-Si, panel, mounted | Cut-off, S	Very good	Very good	Very good	Selected general
Hydrobag, 100x100 cm, LC	Good	Good	Very good	Selected general
Hydrobag, 100x50 cm, LC	Good	Good	Very good	Selected general
Hydrobag, 150x150 cm, LC	Good	Good	Very good	Selected general

Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, S	Good	Very good	Very good	Selected general
Metal abrasive; for stone polishing	Good	Good	Very good	Selected general
Packaging film, low bulk density polyethylene {GLO}| market for packaging film, low bulk density polyethylene | Cut-off, S	Good	Very good	Very good	Selected general
Packaging film, low bulk density polyethylene {RER}| packaging film production, low bulk density polyethylene | Cut-off, S	Good	Very good	Very good	Selected general
EUR-flat pallet {RER}| market for EUR-flat pallet | Cut-off, S	Good	Very good	Very good	Selected general
Polystyrene foam slab {GLO}| market for polystyrene foam slab | Cut-off, S	Good	Very good	Very good	Selected general
Steel, chromium steel 18/8, hot rolled {GLO}| market for steel, chromium steel 18/8, hot rolled | Cut-off, S	Good	Good	Very good	Selected general
Hazardous waste, for incineration {CH}| market for hazardous waste, for incineration | Cut-off, S	Good	Good	Very good	Selected general
Tap water {Europe without Switzerland}| market for | Cut-off, S	Good	Good	Very good	Selected general
Heat, district or industrial, natural gas {Europe without Switzerland}| market for heat, district or industrial, natural gas | Cut-off, S	Good	Good	Very good	Selected general
C1-C4				
Diesel, burned in building machine {GLO}| market for | Cut-off, S	Good	Very good	Very good	Selected general
Transport, freight, lorry 16–32 metric ton, EURO5 {RoW} | market for transport, freight, lorry 16–32 metric ton, EURO5 | Cut-off, S	Good	Very good	Very good	Selected general

Annex 2

Follow-up procedure

This procedure defines the process for monitoring and updating the sector EPD, in compliance with the provisions of EN 15804:2012+2019:A2/AC:202115804 and the General Programme Instructions (GPI) for the International EPD® System, Version 5.0.0. The aim is to ensure that the EPD remains valid, transparent, and representative of current practices throughout its five-year validity period. Monitoring activities are carried out annually, i.e. 12, 24, 36 and 48 months after initial registration of the EPD, by the EPD Owner, or LCA consultants appointed on their behalf.

The focus of the monitoring will be on the most relevant environmental hotspots identified through the interpretation of the results of the LCA study performed for the EPD and presented in this report. Such interpretation identified the environmental 'hotspots' and the key data (LCI) or processes that if changed, could trigger a +10% deviation of EPD environmental impact indicator results, as described in the following list module by module:

- **Module A1 (Raw material supply)**: changes are generally not expected, as the companies covered by the sector EPD typically extract and process their own stone slabs. Nonetheless, the location and identity of the sources should be checked to confirm that no changes have occurred.
- **Module A2 (Transport)**: the interpretation of LCA results revealed that transportation constitutes a hotspot only for bigger distances, i.e. in the order of 100 km. So, particular attention must be paid to any variation in the distance between the quarry and the manufacturing site, as well as the mode of transportation used. If the transformation site changes, and the transport distance exceeds 100 km, this can become a relevant environmental contributor (hotspot), requiring further assessment. Any change should trigger an evaluation of its impact on the declared indicators and, if material, an EPD update.
- **Module A3 (Manufacturing)**: changes in machinery and production processes must be tracked, as they directly influence energy consumption—a known hotspot for ornamental stone processing. Any upgrade or replacement of major equipment should be assessed in terms of its effect on electricity or fuel consumption. Additionally, changes in the **source or mix of energy** (e.g., switching from fossil fuels to renewable electricity) must be documented and evaluated for their impact on environmental performance.
- At the **general level**, any modifications to the declared product characteristics, raw material composition, or content declaration must be identified and reviewed. Should any significant change occur or if an error is detected in the existing EPD, a follow-up action and formal update of the EPD must be performed in accordance with GPI and PCR requirements.

The data necessary for the follow-up will be collected by means of the same questionnaires used for this LCA report, which each company will complete with updated data. Before starting the data collection, a preliminary verification by PNA is performed to state that the same companies which participated in the sector EPD are participating in the follow-up.

All monitored data, evaluations, and decisions are recorded in an internal tracking log. A complete reassessment and third-party verification of the EPD is required every five yea