Life Cycle Datasets for the Ornamental Stone Sector

Isabella Bianco, Gian Andrea Blengini

***Abstract*—**The environmental impact related to ornamental stones (such as marbles and granites) is largely debated. Starting from the industrial revolution, continuous improvements of machineries led to a higher exploitation of this natural resource and to a more international interaction between markets. As a consequence, the environmental impact of the extraction and processing of stones has increased. Nevertheless, if compared with other building materials, ornamental stones are generally more durable, natural, and recyclable. From the scientific point of view, studies on stone life cycle sustainability have been carried out, but these are often partial or not very significant because of the high percentage of approximations and assumptions in calculations. This is due to the lack, in life cycle databases (e.g. Ecoinvent, Thinkstep, and ELCD), of datasets about the specific technologies employed in the stone production chain. For example, databases do not contain information about diamond wires, chains or explosives, materials commonly used in quarries and transformation plants. The project presented in this paper aims to populate the life cycle databases with specific data of specific stone processes. To this goal, the methodology follows the standardized approach of Life Cycle Assessment (LCA), according to the requirements of UNI 14040-14044 and to the International Reference Life Cycle Data System (ILCD) Handbook guidelines of the European Commission. The study analyses the processes of the entire production chain (from-cradle-to-gate system boundaries), including the extraction of benches, the cutting of blocks into slabs/tiles and the surface finishing. Primary data have been collected in Italian quarries and transformation plants which use technologies representative of the current state-of-the-art. Since the technologies vary according to the hardness of the stone, the case studies comprehend both soft stones (marbles) and hard stones (gneiss). In particular, data about energy, materials and emissions were collected in marble basins of Carrara and in Beola and Serizzo basins located in the province of Verbano Cusio Ossola. Data were then elaborated through an appropriate software to build a life cycle model. The model was realized setting free parameters that allow an easy adaptation to specific productions. Through this model, the study aims to boost the direct participation of stone companies and encourage the use of LCA tool to assess and improve the stone sector environmental sustainability. At the same time, the realization of accurate Life Cycle Inventory data aims at making available, to researchers and stone experts, ILCD compliant datasets of the most significant processes and technologies related to the ornamental stone sector.

***Keywords*—**LCA datasets, life cycle assessment, ornamental stone, stone environmental impact.

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I. Introduction

THE environmental sustainability of construction materials is a field of growing interest because of the recent European regulations (e.g. EU n. 305/2011 [1]) and of the increasing competition from imported products and among different materials. Dimension stone (such as marble and granite) is a construction material with a long tradition. Before the industrial revolution ornamental stones were worked manually and employed locally. The development of canals and railways led to the internationalization of trades and in the XIX century machineries were progressively introduced. In the 70s working tools and quarrying techniques were further improved, leading to a more intensive exploitation of this resource. Since stone is a non-renewable material formed in the geological past, a strict view of sustainability might suggest to avoid this material. Nevertheless, it is necessary to consider the issue in its entire complexity, examining the overall costs and benefits of this material. As far as the production chain is concerned, for example, stone is a natural material and, as a consequence, impacts related to the material production are limited [2]; in addition, the lifetime of stone can be much longer in comparison with other construction materials [3], and at the end of life, stone can be reused in the original structure, recovered in other structures build of compatible material, or crushed and transformed in aggregate [4], [5]. These characteristics help stone materials to be in line with the Circular Economy Package adopted by the European Commission, which aims at extracting “the maximum value and use from raw materials, products and waste, fostering energy savings and reducing Green House Gas emissions” [6]. However, still a lot of effort is required to consider stone materials as sustainable. The operations of extraction and processing are still quite traditional and have to be enhanced and updated in order to minimize the use of resources and energy and to reduce wastes and emissions into air, water, and soil. To reach this aim and to avoid impact shifting, the system has to be analyzed throughout the entire life cycle of the product. The LCA is a scientific tool to calculate the potential impacts, standardized by UNI 14040-44 regulations [7], [8] and by the ILCD guidelines of the European Commission [9]. In the field of ornamental stones, some LCA have been performed by different research groups in the major stone production countries [10]-[13]. Nevertheless, the main obstacle is that the LC databases (such as Ecoinvent, Thinkstep, ELCD) lack of stone production datasets. To face this problem, the Brazilian research center CETEM (Centro de Tecnologia Mineral) developed and currently updates the national LC database on ornamental stones based on the most widespread technologies employed in Brazilian quarries and transformation plants [14]. On the contrary, no datasets are available for the stone processes commonly carried out in Europe. As a consequence, assessments performed with secondary data are often inaccurate because of the high number of assumptions and approximations. The main aim of the PhD project presented in this paper is to provide Life Cycle (LC) data of the most significant processes of stone production chain, with particular reference to Italian quarries and transformation plants. At the same time, aim of the study is to build a flexible LC model allowing stone firms to assess their specific environmental impacts.

Fig. 1 Phases of the stone production chain: (a) Quarrying of stone blocks; (b) Cutting of blocks into slabs; (c) Surface finishing. Photos were taken in quarries and transformation plants of Carrara basins (Italy)

II. Methodology

To create LC data on stone processes, the study involved analyzing, from the environmental point of view, the most common techniques of the ornamental stone production chain. Because the processes present differences in relation to the hardness of the stone, sites of both hard stones (gneiss) and soft stones (marble) were selected. Therefore, studies were carried out in the representative Italian basins of Verbano Cusio Ossola (VCO) province (where gneiss stones are quarried) and in Carrara marble basins. The analyzed system has boundaries *from-cradle-to-gate* (according to the definition of the UNI 14040). This means that objects of the study were all the processes and flows connected to the phases of: i) stone quarrying; ii) cutting of blocks into slabs and tiles; iii) surface finishing (Fig. 1). For each of these three phases, the most common and representative techniques were investigated [15]. Fig. 2 summarizes the processes analyzed in this study, with reference to techniques for both hard and soft stones. Because LC databases miss of datasets on stone processes, it was necessary to collect primary data directly on-site. The data collection was carried out mostly in quarries, transformation plants and firms connected to the stone sector (e.g. firms producing cutting tools) and information was integrated though the literature and the dialog with other research teams (among others, Centro Servizio Lapideo of Crevoladossola) and public administrations (among others, the Carrara municipality). To pursue the aim of creating LC datasets of stone processes, it was necessary to identify and quantify resources, energy and emissions of the input and output flows involved in the system. The investigation was carried out also on tools employed in quarries and transformation plants which are not available in current LC databases (such as, for example, diamond cutting tools). The collected data were then elaborated through the LC software Gabi, which allow creating and linking the processes in a model. Data were referred to the Functional Units chosen for this study: the volume of 1 m^3 of stone block (for the quarrying phase) and the surface of 1 m^2 of slab/tile (for the cutting and finishing phases). Since the quantities and features of tools employed in the stone production chain can change among the enterprises (because of stone properties, but also enterprise dimensions, availability of machineries, etc.), the LC processes were created setting up some free parameters that allow the adaptation of datasets to specific productions. In order to boost the use of LCA as a scientific tool for the evaluation of sustainability among the stone enterprises, a LC model was created with the three phases; quarrying, cutting, and finishing. Each phase contains the datasets of the processes previously created, which have been connected in an organic and flexible model that can be seized to the effective productions of stone firms.

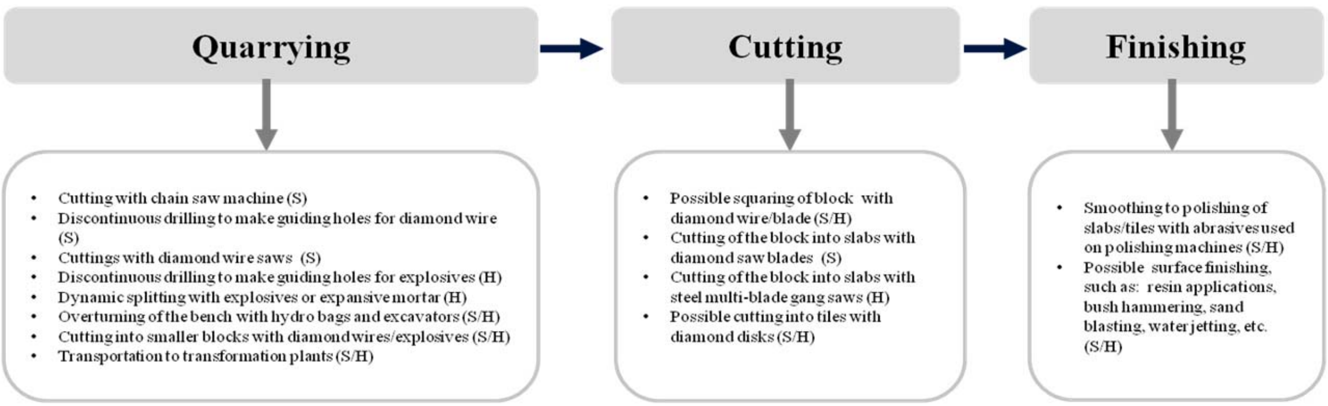


Fig. 2 Scheme summarizing the techniques that were investigated on-site during this study. Processes related to the production chain of soft and hard stones are respectively indicated with an S and H in brackets

Fig. 3 Multi-blade technique. (a) Placement of blades in preparation to the sawing process; (b) Cutting of stone blocks into slabs

III. Results

The main purpose of this work was to investigate the stone sector with a life cycle approach and to create LC datasets to be used for environmental evaluations.

Data were collected and elaborated for the processes showed in Fig. 2. In this section, the detail of the multi-blade cutting technique (Fig. 3) is showed. This latter is a technique commonly used in transformation plants for cutting hard stone blocks into slabs. A frame gives an oscillating movement to a set of steel blades which penetrate and course through the block for its total height with a defined down-feed speed. The sawing is consequence of the combined action of blades and of an abrasive slurry containing water, steel grit and lime. Quantitative data concerning resources, energy and emission related to this technique were collected in the Italian transformation plants of Verbano Cusio Ossola province, where the multi-blade sawing is commonly used for producing slabs of local stones (mostly *Beola* and *Serizzo* stones). The data collected refer to the year 2016, and the quantities employed for this study are the average values calculated on 99 block cutting. The production of a slab with the multi-blade technique requires some input resources (stone block, cutting frame, electricity, steel blades, steel grit, lime and water) and produces outputs (slabs, steel of exhausted blades and stone slurry). The steel of exhausted blades is usually recycled, while for the stone slurry different scenarios can exist. Slurry can be destined to landfill or be reemployed as secondary raw material for different applications such as, for example, the recycle in concrete [16] or environmental restorations [17]. Some research groups currently study the separation and reuse of the mineral part (coming from the rock crushing) and the metallic part (coming from steel grit) [18]. To the aim of creating a LC dataset of the multi-blade cutting technique, Gabi software was used to model the process (Fig. 4). Since the aim is to calculate the impact given by the only process of cutting (and not of the cumulative impact till that moment), the impacts related to the extraction of stone blocks are out of the system boundaries of the process. Secondary data were used for steel blades, steel grit, electricity, and lime. Water has no impacts since it is continuously recycled in a close loop, while the impact related to the frame production is not accounted because it is irrelevant considering the long lifetime of this machine. As far as concern the outputs, the process includes the credits given by the recycle of the steel blades, while, for the slurry waste, the landfill End of Life is taken into account.

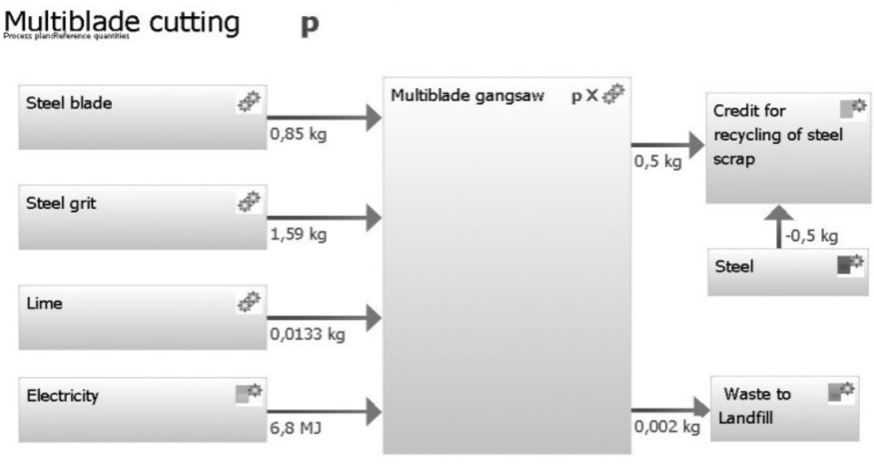
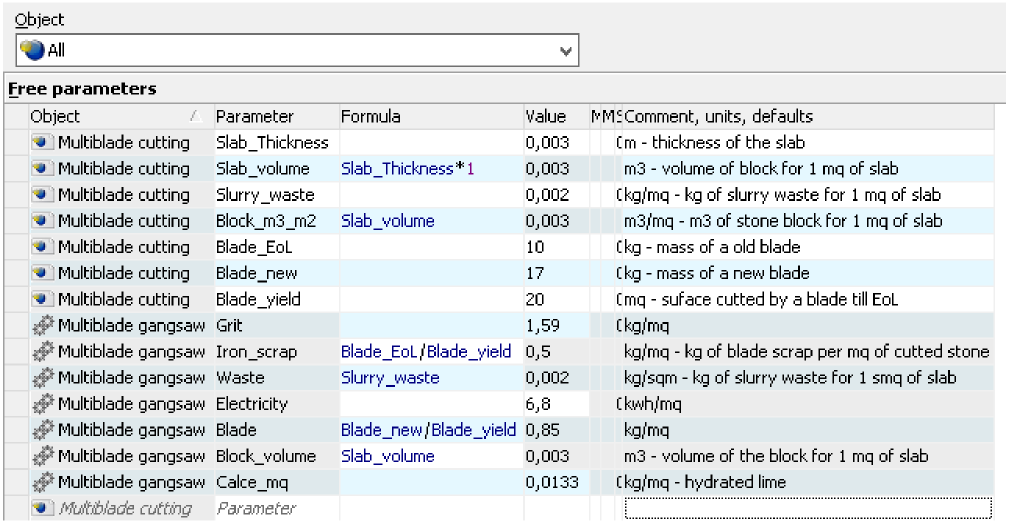


Fig. 4 Model of the multi-blade cutting technique (software: Gabi)

TABLE I
Input/Output Table of the Multi-Blade Cutting Technique

Inputs	Quantity	Outputs	Quantity
Stone block	0.03 m^3	Stone slab	1 m^2
Electricity	6.8 MJ	Exhausted steel	0.5 kg
Steel blades	0.85 kg	Slurry waste	0.002 kg
Steel grit	1.59 kg		
Lime	0.013 kg		

According to the average data collected in VCO province, the process was created with the input/output values listed in Table I. Nevertheless, these quantities highly depend on many variables, such as the frame and blades characteristics, the abrasiveness of the stone, the slab dimension. In order to allow an easy adaptability of the dataset to different productions, free parameters were set up. Fig. 5 shows part of the parameter list with the correspondent relations. The hereinafter presented Life Cycle Impact Assessment (LCIA) refers to the process needed to cut 1 m^2 of gneiss slab with the multi-blade technique. This contribution analysis was carried out with the average values collected in Verbano Cusio Ossola province. The selected characterization method for the analysis is CML2001 in its most updated version (April 2013). Table II summarizes the environmental burdens of cutting 1 m^2 of slab with the multi-blade technique. More in detail, the performed contribution analysis pointed out that the use of steel grit corresponds to the higher impacts for most of the impact categories (Fig. 6). This is due to the fact that the multi-blade cutting technique requires high quantities of this material. As expected, the impact related to the steel blades is much fewer. This is related to the fact that each blade is able to cut more than one block (approximately three to five blocks, according to the hardness of the stone). Moreover, the contribution of blades has to be reduced of the credit given by the recycling of steel. As far as the output of slurry waste is concerned, the quantities and physical characteristics of the slurry can sensibly change among the enterprises. As a consequence, different scenarios for the End of Life of waste (such as the treatment and reuse as secondary raw material) could change the global impact of this process. Further work will be developed focusing on some possible different scenarios.



Object: All

Free parameters

Object	Parameter	Formula	Value	Comment, units, defaults
Multiblade cutting	Slab_Thickness		0,003	m - thickness of the slab
Multiblade cutting	Slab_volume	Slab_Thickness*1	0,003	m3 - volume of block for 1 mq of slab
Multiblade cutting	Slurry_waste		0,002	kg/mq - kg of slurry waste for 1 mq of slab
Multiblade cutting	Block_m3_m2	Slab_volume	0,003	m3/mq - m3 of stone block for 1 mq of slab
Multiblade cutting	Blade_EoL		10	kg - mass of a old blade
Multiblade cutting	Blade_new		17	kg - mass of a new blade
Multiblade cutting	Blade_yield		20	mq - suface cutted by a blade till EoL
Multiblade gangsaw	Grit		1,59	kg/mq
Multiblade gangsaw	Iron_scrap	Blade_EoL/Blade_yield	0,5	kg/mq - kg of blade scrap per mq of cutted stone
Multiblade gangsaw	Waste	Slurry_waste	0,002	kg/sqm - kg of slurry waste for 1 smq of slab
Multiblade gangsaw	Electricity		6,8	kwh/mq
Multiblade gangsaw	Blade	Blade_new/Blade_yield	0,85	kg/mq
Multiblade gangsaw	Block_volume	Slab_volume	0,003	m3 - volume of the block for 1 mq of slab
Multiblade gangsaw	Calce_mq		0,0133	kg/mq - hydrated lime
Multiblade cutting	*Parameter*			

Fig. 5 Free parameters allowing the adaptation of the multi-blade cutting dataset to specific productions

TABLE II
ENVIRONMENTAL BURDENS RELATED TO THE CUT OF 1 m^2 OF STONE SLAB WITH THE MULTI-BLADE TECHNIQUE (CML2001 METHOD)

Impact category	Unit f Measure	Total
Abiotic Depletion (ADPe)	kg Sb-Equiv.	$3.02 \cdot 10^{-7}$
Abiotic Depletion (ADPf)	MJ	$5.81 \cdot 10$
Acidification Potential (AP)	kg SO2-Equiv.	$1.07 \cdot 10^{-2}$
Eutrophication Potential (EP)	kg Phosphate-Equiv.	$7.27 \cdot 10^{-4}$
Freshwater Aquatic Ecotoxicity Pot. (FAETP)	kg DCB-Equiv.	$6.57 \cdot 10^{-3}$
Global Warming Potential (GWP)	kg CO2-Equiv.	5.49
Human Toxicity Potential (HTP)	kg DCB-Equiv.	$4.92 \cdot 10^{-1}$
Marine Aquatic Ecotoxicity Pot. (MAETP)	kg DCB-Equiv.	$6.95 \cdot 10^{2}$
Ozone Layer Depletion Potential (ODP)	kg R11-Equiv.	$4.27 \cdot 10^{-8}$
Photochem. Ozone Creation Potential (POCP)	kg Ethene-Equiv.	$2.27 \cdot 10^{-3}$

IV. CONCLUSION

The sustainability of the traditional stone sector could be improved identifying the environmental hot points of the whole production chain, from the extraction of blocks till the finished stone product. Prior work has analyzed the processes with a life cycle approach. Nevertheless, since LC databases currently lack datasets on the specific stone production processes, these studies were not always significant because of the high number of assumptions. The main aim of the research project presented in this paper is to contribute to the population of databases with the most representative techniques employed in the stone production chain. To this aim primary data were collected, investigating the processes in Italian quarries, transformation plants, enterprises connected to the sector and public administrations. The investigation concerned the production of slabs and tiles of both hard Stones (gneiss form Verbanio Cusio Ossola) and soft stones (Carrara marble). An appropriate LC software allowed using the data collected to create the LC datasets of different stone production processes. Moreover, the single datasets were connected to realize a global model with boundaries *from-cradle-to-gate*, which comprehend the processes commonly used for the extraction of blocks, cutting into slabs and tiles and surface finishing. Since quantities and tools employed can vary among enterprises, datasets and model present free parameters which allow an easy adaptability to specific productions. Datasets will be published in LC databases, in order to make them available for future studies on stone sustainability. The global model will be spread among stone enterprises to encourage their direct participation and to boost the use of LCA as a scientific tool to assess and enhance the environmental sustainability. Currently, investigations are still on going to define the impacts of some specific processes (e.g. electroplating of diamond tools), which are often covered by industrial secret.

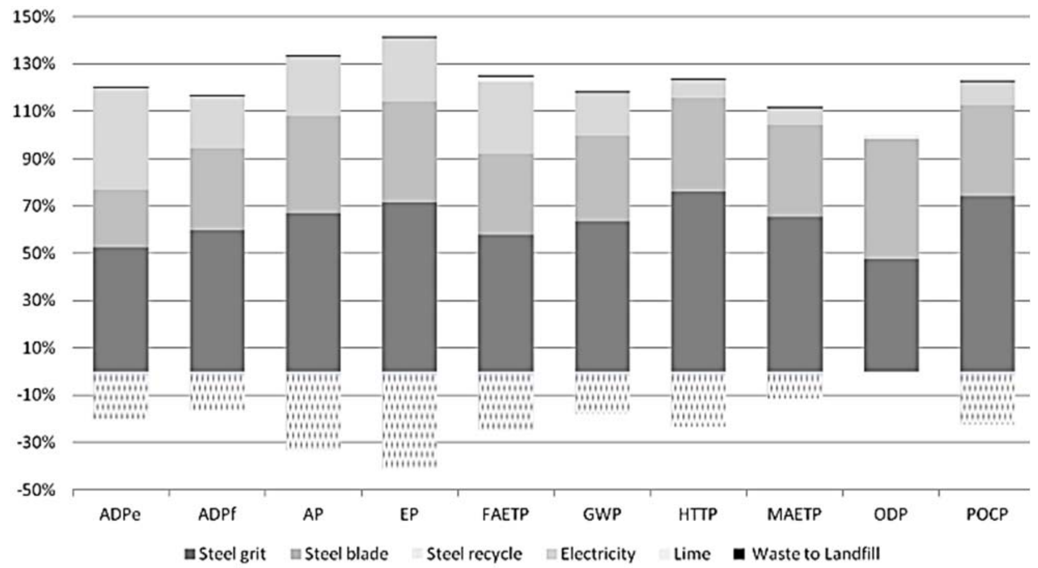


Fig. 6 Percentage contribution of the environmental burdens related to 1 m^2 of stone slab cut with multi-blade technique (CML2001 method)

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