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Life Cycle Inventory of cutting technologies in the ornamental stone supply chain

By

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Declaration

I hereby declare that, the contents and organization of this dissertation constitute my own original work and does not compromise in any way the rights of third parties, including those relating to the security of personal data.

Isabella Bianco

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The only true wisdom is in knowing you know nothing

Socrates

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Abstract

The main goal of the PhD research project is to contribute to the development of methodologies and Life Cycle Inventory data of the most representative techniques and technologies in the ornamental stone supply chain. The realisation of Life Cycle datasets, currently scarcely available in Life Cycle databases, aims to provide a practical tool to enterprises and researchers dealing with sustainability issues in the stone sector. The interest in enhancing the stone supply chain sustainability has been boosted by the recent European policies on Circular Economy and Raw materials, which are encouraging the passage from a linear economy (made of the phases of extraction-production-use-disposal) to a circular economy, *where the value of products, materials and resources is maintained in the economy for as long as possible* (European Commission, 2015). Moreover, sustainable supply chain improvements are urged by the market competition, represented by stone materials from developing countries and by other Italian construction materials, whose sectors have started thinking in terms of sustainability from quite a long time, gaining a priority with, for examples, Green Public Procurements. In this context, the Life Cycle Assessment (LCA) has been identified as the *best framework for assessing the potential environmental impacts of products* by the European Commission's Integrated Product Policy Communication (COM (2003) 302). LCA is indeed a scientific and standardized tool which considers the entire life cycle of a product/process in order to quantify materials, energy and emissions and to evaluate the environmental consequences. Nevertheless, in the stone sector, LCA is hindered by the current scarce availability of Life Cycle Inventory datasets on the specific stone supply chain

techniques and technologies. In this context, the PhD project here presented gives a contribute to fill the gap in LCI datasets availability and quality. To this aim primary data were collected in Italian quarries, transformation plants and cutting tool enterprises (in particular, 4 marble quarries, 10 gneiss quarries, 7 transformation plants and 3 tool producers). When necessary, secondary data (from papers, patents and technical sheets) were also collected to complete the inventory or to cross-check the measured data. On the basis of these data, the average datasets of the stone supply chain techniques were modelled using Gabi software. Finally, primary data uncertainty on the collected data was handed through the calculation of the standard deviation, to assess the value ranges around the mean values and to evaluate the consequent precision of the LCI datasets. The modelled LCI datasets have been also submitted to an internal quality control based on impact assessment results. Uncertainty analyses have been developed through the calculation of standard deviation on some impact results and through Monte Carlo stochastic simulations (run with 1000 iterations), which evaluate the stability of the results toward random parameters constellations.

In addition, the developed LCI datasets on stone technologies have been organised in a cradle-to-gate LCA model which, through editable parameters, can be easily adapted to perform LCA of specific stone supply chains. It has been created a unique model comprehending technologies for both soft and hard stones, in order to allow the model to be employed also by enterprises working with both the materials in the same plant.

Finally, a collaboration with the Brazilian CETEM research centre, led to the development of a preliminary study on Social Life Cycle Assessment (SLCA). Following the UNEP/SETAC guidelines on SLCA (2009), secondary data have been collected for both the Italian and the Brazilian ornamental stone sectors.

Questionnaires to collect primary data are proposed with the aim of supporting future works on stone social sustainability.

This PhD study is therefore expected to boost to use of the LCA tools among stone enterprises and to provide data able to support researchers and decision makers.

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Chapter 1

Italian ornamental stone sector and sustainability requirements

1.1 Overview of the ornamental stone sector in Italy

The composite geological nature of the Italian territory is responsible of a significant lithological variety, which has been an important source of a big variety of ornamental stones all over the centuries. The Italian cultural heritage reflects the large use of ornamental stones (also known as natural, dimension or building stone) as raw materials for the realization of buildings, civil constructions and design elements. Stone has been the raw material for both important historical architectures and more modest constructions (Zerbinatti, 2014). As stated by Dino and Cavallo (2015) and Borghi et al. (2014), referring to the Piedmont territory, the abundance of this resource established a relationship between "stones and culture", and "territory and its resources", developing a strong architectural identity. Analogous considerations can be done for other Italian regions. Examples are the sandstone and the travertine, important stone materials for the Tuscan historical architecture (Fratini and Rescic, 2013), while Carrara marble is historically and worldwide known for its high pureness (Bruschi et al., 2004); in the south of Italy, marble is largely employed in Campania (Allocca et al., 2010), together with volcanic stones (Langella et al., 2009) and in Sicily (Traverso et al., 2010) regions. Sardinia region is abundant in constructions where granite, marble and a variety of volcanic rocks have been employed (Primavori, 2011).

The widespread presence, in the Italian territory, of good quality ornamental stones lead to the development of traditional activities related to stone extraction and processing. Before the industrial revolution the production chain was almost entirely manual and the stone resource was basically employed locally. When canals and railways were developed, the trades begun to be more international and in the XIX century machineries were progressively introduced. As stated by Bertolazzi (2015), in the ‘70s the development of new quarrying and cutting technologies lead to a more intensive exploitation of the stone resource and to the improvement of the workers condition. In the last decades, despite the technologies basically remained the same, continuous enhancements were introduced, especially by Italian producers, which lead Italian stone cutting machineries to be known and exported worldwide. Chapter 5 of this thesis describes the most common technologies of quarrying, cutting and polishing of stone slabs and tiles according to the Italian current practices, for both “soft stones” (such as marbles) and “hard stones” (gneiss, granites).

Still nowadays the Italian stone sector plays an important role in the economy of the country. The Italian stone sector is mainly composed by small and medium enterprises, often with family-run business: according to IMM statistics (Gussoni, 2016), the 88% of the 10800 stone companies have less than 10 employees. According to the annual Legambiente quarry report (Zanchini and Nanni, 2017), Sicily, Trentino, Lazio and Tuscany are the regions with the highest ornamental stone extraction, with a total of 53,4% of the total national extractions, for an absolute value of 3,1 million of cubic meters. Follow the regions of Umbria, Puglia and Piedmont, all extracting more than 200 thousand cubic meters per year. Just in the Carrara marble district, an increase of 8,8% has been registered between 2015 and the first semester of 2016. Each year in Carrara are extracted about 1 million tons of marble blocks and 4 million tons of extractive waste. Of the average annual turnover of the Italian ornamental stone sector (3,6 billion Euros), about 45% comes from export.

Nevertheless, in the international panorama the leading position in terms of exported volumes is held by China. According to the IMM report 2016 the Chinese companies account for 42,4% of the world exported values, followed by Italy (12,4%), Turkey (11,2%), India (9,8%) and Brazil (6,8%). In 2016 Italy was in decline of one percentage point in relation to 2015 export values, but the absolute value of export raised by 6,3%. This means that the Italian export growth was lower than the increase in world exports, almost exclusively due to China, but also to the strong increase in demand by the US market.

The strong competitiveness of China is mostly due to the lower cost of the Chinese labour and to the high quantities of material extracted. Nevertheless, according to an interview to prof. Lattanzi (Dell'Olio, 2010) in occasion of the Xiamen stone fair in 2010, the machineries employed in China were already basically the same of the ones used in Italy and Chinese enterprises were starting looking not just for quantity but also for quality.

As a consequence, the Italian ornamental stone sector is currently facing an important international concurrence. Italian enterprises are now stressing the attention on the quality excellence of the Italian stone and on the historical cultural and esthetical value.

Moreover, in the European context, the Italian stone production chain has to align to the sustainability requirements of the European Commission. As stated since the "Our common future" report (Brundtland et al., 1987), the sustainable development is defined as the development that has to meet the needs of the present without compromising the ability of future generations to meet their own needs. From that moment, the sustainable development has been one of the European priorities, and after the Treaty of Amsterdam (2 October 1997) it has been among the goals of the EU policy. These goals have been integrated in the policies and in the legislation through the EU Sustainable Development Strategy, the EU 2020 Strategy, and the EU's Better Regulation Agenda. Next paragraph cites the main regulations in the field of sustainability, with focus on the stone sector.

1.2 European sustainability policies and specific requirements for the construction materials' sectors

As stated in Paragraph 1.1, the sustainable development is among the priorities of the European policies. To this aim, the European Commission set transversal objectives and priority challenges. In particular, in response to the Rio+20 Conference (General Assembly, 2012), the United Nations General Assembly adopted the 2030 Agenda for Sustainable Development (UN General Assembly, 2015) defining 17 goals (shown in Figure 1), each with specific targets to be achieved.

Figure 1: The17 Sustainable Development Goals defined by the 2030 Agenda for Sustainable Development (source: https://ec.europa.eu/europeaid/policies/sustainable-development-goals_en)

The sustainable development is indeed a complex goal, which is characterized by aspects of different nature with causal relationships and feedbacks. The global sustainability is the integration of environmental, social and economic aspects (defined as the three pillars of sustainability). Overall aim of the EU policies is the development of communities able to manage and use resources efficiently, able to guarantee economic prosperity and social cohesion. Figure 2 graphically summarizes the concept of sustainability as the integration of the three pillars of sustainability, where the global sustainability does not have to be intended as the sum of the three aspects but as a system where the three spheres are interlinked.

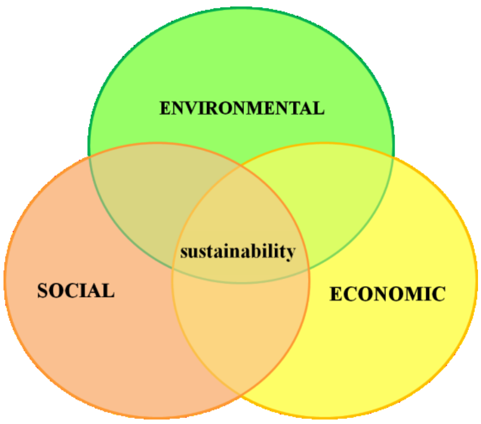


Figure 2: Three pillars of sustainability

In 2011, the European Commission launched the flagship initiative called "A Resource-Efficient Europe", where the scientific approach of the **Life Cycle Thinking (LCT)** has been defined as a key approach for a smart and sustainable growth in the EU. The Life Cycle Thinking focuses on the entire life of products, services or projects in order to minimise environmental, economic and social impacts and avoid burden shifting. Through the LCT approach, EU is boosting the passage from a linear economy (with the extraction-production-use-disposal phases) to a **circular economy**, *where the value of products, materials and resources is maintained in the economy for as long as possible* (European Commission, 2015). The principle of circular economy is to prevent wastes and, when this is not feasible, to give them new value by reintegrating them in the same or other product life cycles. In particular, the Directive 2008/98/EC (Waste Framework Directive) (European Commission, 2008a) explains the priority order of actions for the waste management, summarized in Figure 3.

Figure 3: Waste management hierarchy defined by the Directive 2008/98/EC (source: http://ec.europa.eu/environment/waste/framework/)

In this general context, ornamental stone sector is called to follow the policy for raw materials, which is regulated by the Raw Material Initiative (European Commission, 2008b), a strategy aiming at ensuring to the EU sustainable access to raw materials. This initiative is composed by the following three pillars:

(1) ensure access to raw materials from international markets under the same conditions as other industrial competitors;

(2) set the right framework conditions within the EU in order to foster ***sustainable supply of raw materials*** *from European sources;*

(3) boost overall ***resource efficiency*** *and promote recycling to reduce the EU's consumption of primary raw materials and* ***decrease the relative import dependence.***

As far as concern waste produced by extractive industries, the **Extractive Waste Directive** (2006/21/EC) (European Commission, 2006) provides measures, procedures and guidance for waste management able to avoid or minimize the effects on human health and on the environment, with particular reference to water, air, soil, fauna and flora and landscape. The Directive is in line with the circular economy principles and it requires to Member States the development of waste management plans. These latter shall be conceived to prevent or reduce the waste production and its harmfulness, to recover extractive waste by means of recycling, reusing or reclaiming and to ensure short and long-term safe disposal.

In light of these raw material policies, also the ornamental stone sector is expected to update and improve the sustainability of its production chain. In particular, construction materials are the focus of the European Regulation n. 305/2011 (European Commission, 2011), which entered into force in 2013, repealing the former Directive 89/106/EEC. This regulation establishes harmonised rules on how to express the product performances and on the use of CE marking, which is necessary for placing on the market the construction products which are covered by harmonised standards[1]. Annex I of this regulation lists the basic requirements for construction works as a whole and in their separate parts. In particular, the 7th requirement concerns the *sustainable use of natural resources*, meaning that construction works and their parts have to ensure: *(a) reuse or recyclability [...] after demolition; (b) durability; (c) use of environmentally compatible raw and secondary materials.* Moreover, the European Commission, in 2008, published the Communication "Public procurement for a better environment" (European Commission, 2008c), where the Green Public Procurement (GPP) has been defined as *a process whereby public authorities seek to procure goods, services and works with a reduced environmental impact throughout their life cycle when compared to goods,*

[1] Harmonised standards in the natural stone sector are: EN 12326-1:2014 (Slate and stone for discontinuous roofing and external cladding), EN 1341:2013 (Slabs of natural stone for external paving), EN 1342:2013 (Setts of natural stone for external paving), EN 1343:2013 (Kerbs of natural stone for external paving), EN 12057:2015 (Natural stone products - Modular tiles), EN 12058:2015 (Natural stone products - Slabs for floors and stairs), EN 1469:2015 (Natural stone products - Slabs for cladding), EN 771-6:2015 (Specification for masonry units), EN 12326-1:2014 (Slate and stone products for discontinuous roofing and cladding).

services and works with the same primary function that would otherwise be procured. In this framework, Italy developed its National Action Plan on GPP, which established, with the Law 221/2015, the mandatory application of Minimum Environmental Criteria for all the public procurements. The last update of the Italian Minimum Environmental Criteria (CAM, Criteri Ambientali Minimi) (Ministero dell'Ambiente e della Tutela del Territorio e del Mare, 2017), dates January 2017. As far as concern flooring and covering materials (such is the case of ornamental stones), this document states that these materials have to be compliant with the Ecological Criteria laid down by the Decisions 2010/18/CE30, 2009/607/CE31 and 2009/967/CE32 and their modifications and updates. The minimum criteria can be certified by:

- An environmental declaration of I type, according to the regulation UNI EN ISO 14024:2001. These declarations are based on multi-attribute criteria developed by a third party.
- An environmental declaration of III type, according to the regulation UNI EN 15804:2014 and UNI EN ISO 14025:2010. This type of labels quantify the environmental impacts through a Life Cycle Assessment.

In particular, among the environmental declarations of I type, the **European Ecolabel** (whose logo is shown in Figure 4) is a voluntary market tool established by the European Union to help consumers in the choice of products with lower environmental impacts. The EU Ecolabel is based on quantifiable multi-criteria, which have been determined with a scientific approach considering the entire Life Cycle of different groups of products and services. In particular, the Commission Decision 2009/607/CE (European Commission, 2009) established the ecological criteria of the group of "**hard coverings**", comprehending the two major

Figure 4: European Ecolabel logo ("The Flower")

subgroups of “natural products” and “processed products”. “Natural products” are divided into “Marble”, “Granite” and “Other” (this latter referring to natural stones whose characteristics are different from those of marble and granite), while the group of “processed product” is composed by “hardened products” (agglomerate stone, concrete paving units and terrazzo tiles) and “fired products” (ceramic tiles and clay tiles). For the group of natural stones, the categories that have to be analysed are the following ones: Raw material extraction, Raw materials selection, Finishing operations, Waste management, Packaging, Fitness for use, Consumer information and Information appearing on the ecolabel. Annex 1 resumes the criteria and the thresholds related to the extraction management that, according to Decision 2009/607/CE, natural stone products have to fulfil in order to obtain the EU Eco-label.

As far as concern the environmental declaration of III type, the **EPD** (Environmental Product Declaration) is the main program employed by Italian enterprises, and it is widespread in 38 countries all over the world. EPD is a document where information on the Life Cycle impacts of products are assessed and declared by a third party.

In parallel with the European and national legislation, also more restricted areas and municipalities can introduce measures to boost the use of sustainable materials through guidelines, promotions, incentives or obligations.

1.3 Overview on tools for sustainability assessments

The most recognized and widespread tool to assess the potential environmental impacts is the Life Cycle Assessment (LCA). LCA is an analytical and scientific tool which considers the entire life cycle of a product/process in order to quantify materials, energy and emissions and to evaluate the environmental consequences. From the scientific point of view LCA has reached a good level of maturity and it has been standardised in 2006 by the regulations ISO 14040-14044, which define and describe the four phase that have to be developed for an LCA study. LCA has been defined as the *best framework for assessing the potential environmental impacts of products* by the European Commission’s Integrated Product Policy Communication (COM (2003) 302) (European Commission, 2003) and in this context the Joint Research Center (JRC) developed the European Platform on Life Cycle Assessment (EPLCA), whose aim is to support the Life Cycle Thinking in business and policies. In this context, in 2007 JRC started developing the International Reference Life Cycle Data System (ILCD) Handbook, launched in

2010. The ILCD Handbook, fully compliant with the ISO standard, is a technical guidance for the development and the review of LCAs.

Despite its key role, LCA presents some limits and the integration with other tools can be recommended to have a more complete comprehension of the global sustainability. The Life Cycle Costing (LCC) is a tool which complements LCA with an economic approach. With the same methodological structure of LCA, LCC evaluates the costs of a product/process all along its life cycle. In particular, this tool considers the purchase prices, the operating costs (e.g. energy, fuel, water) and the End-of-Life costs, but can also include environmental externalities. This tool is more and more employed in Europe by both public authorities and industrial sectors.

Aligned with LCA and LCC there is the Social Life Cycle Assessment (SLCA), which assesses the social sustainability of the life cycle of a product/process. Despite SLCA is not yet at the same scientific level of the previous mentioned tools, it is arising the international interest. In 2009, UNEP and SETAC published guidelines for the development Social Life Cycle Assessments. This approach aims at assessing the social consequences of a product in reference to five stakeholders: workers, consumers, local communities, society and value chain actors.

Other complementary tools can be employed to integrate sustainability assessments. Examples of the most recognised methodologies are: the Multiple-Criteria Decision Analysis (MCDA), helping the evaluation and the choice of best options in case of conflicting criteria; the Risk Assessment, a methodology developed to define the risk related to particular dangers or sources of risk.; the Benefit Cost Analysis (BCA), originally developed in the economic field, is a systematic approach where benefits and costs are expressed in monetary terms with the aim of estimating the feasibility of projects or different scenarios; the Environmental Management System (EMS), developed to improve the environmental performance of organizations through the management of environmental programs, basing on the four iterative phases of "plan-do-check-act".

1.3.1 The Life Cycle Assessment (LCA) tool

According to the ISO 14040 regulation, the Life Cycle Assessment of a product/process comprises four phases:

1. Goal and scope definition;
2. Life cycle inventory (LCI);
3. Life cycle impact assessment (LCIA);
4. Life cycle interpretation.

As it is shown in Figure 5, these phases are iterative and the interpretation phase is transversal to all the other three phases.

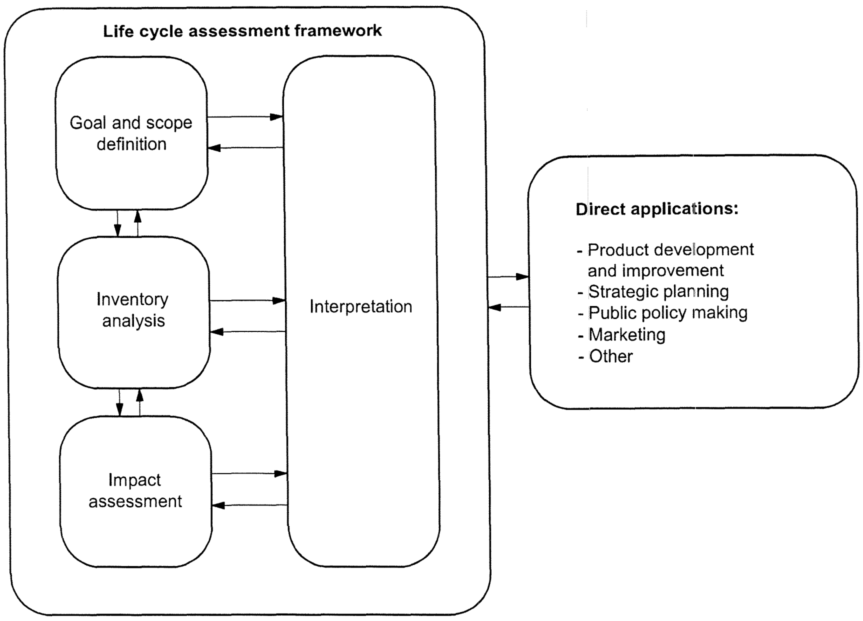


Figure 5: Stages of an LCA (source: ISO 14040:2006)

Goal and scope definition

In the goal and scope definition phase, the objectives of the study, the reasons that led to carry it out and the expected audience have to be clearly declared. This phase requires also methodological choices, such as the definition of the Functional Unit and of the System Boundaries. The Functional Unit is a reference parameter to which results of LCA are related. The choice of the Functional Unit is arbitrary, but it has to be consistent with the goal of the study and the function of the product analyzed with the LCA. The identification of the system boundaries consists in deciding the boundaries of the study and the processes that will be included in the LCA.

The identification of data quality requirements is also part of this phase: it is important to define, according to the goal of the study, the data characteristics, in terms of time, geographical and technology coverage, precision, completeness and representativeness of the data, uncertainty of the information, source of the data (primary or secondary data), gaps and cut-off criteria.

Inventory Analysis (LCI)

This phase consists in the quantification of inputs and outputs throughout the life cycle of the studied product, according to the methodological decisions taken in the first phase. Data on raw materials, energy and emissions have to be collected. In case of systems with multiple functions or multiple outputs, it could be necessary to use allocation criteria in order to partition the impacts in a way that reflect the relationships among the products. The data inventory is the most time and resource consuming phase of the LCA and, according to the expected data quality, it can be carried out mostly though on site data collection and measurements (primary data) or through data based on literature or on already existing databases (secondary data).

Data are then organized in a flowchart referred to the Functional Unit that has been chosen in the first phase. The realization of the model can be helped by different software (such as Gabi, SimaPro or OpenLCA).

Life Cycle Impact Assessment (LCIA)

The Life Cycle Impact Assessment is the phase of LCA aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system (ISO 14044:2006). In this phase, data concerning emissions and resource consumption, coming from the LCI phase, are employed to build some indicators in different Areas of Protection (AoPs) (classified in "Human Health", "Natural Environment" and "Natural Resources").

To this aim, scientific methods based on environmental mechanisms have been developed in order to convert the input/output quantities of LCI into indicators that quantify the impacts, according to different impact categories. The assessment can be done at midpoint or endpoint level. Indicators at midpoint level define impact categories such as acidification, climate change, ozone depletion, ecotoxicity; while at endpoint level the impacts quantified at the midpoint level are converted into categories that quantify the final effects on the AoPs, such as the damage to human health, damage to ecosystem quality and the damage to resources. As a consequence, indicators at endpoint level have a higher degree of uncertainty than midpoint indicators. The results of LCIA are expressed as impact scores in a unit common to all contributions within the impact category by applying the so called "characterization factor". Figure 6 shows the relationship between midpoint indicators and endpoint indicators according to Recipe2016 method (Huijbregts et al., 2017). The European Commission has evaluated the quality of the currently available impact assessment methods, both at midpoint and endpoint level. In the ILCD Handbook (Hauschild et al., 2011) the methods have been classified into three levels: *"I" (recommended and satisfactory), level "II" (recommended but in need of some improvements) or level "III" (recommended, but to be applied with caution)*.

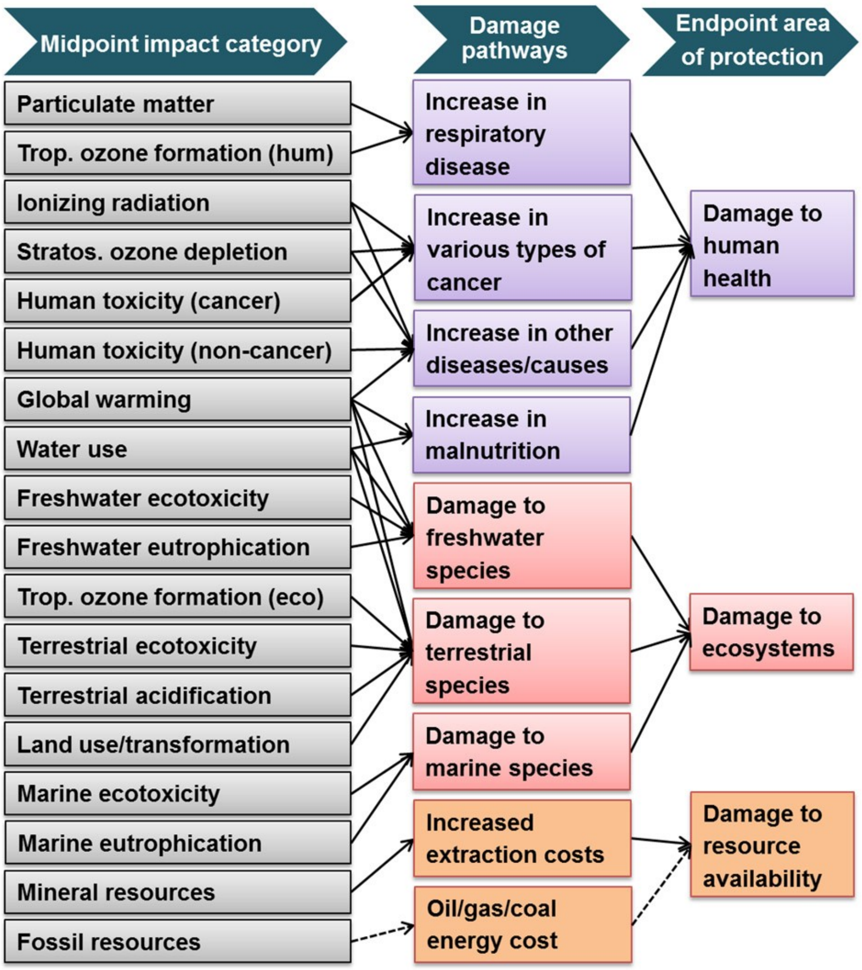


Figure 6: Overview of the impact categories covered in the ReCiPe2016 method and the relationship between midpoint and endpoint impact categories (source: RIVM Report 2016-0104a, p. 19)

Interpretation

The interpretation phase is transversal to all the three previous phases and it is essential in order to derive robust conclusions and recommendations. In this phase it is verified the consistency between the stated goal and scope and the findings of the Inventory and of the Impact Assessment. The Interpretation has to evaluate the completeness, the consistence and the sensitivity of the LCA study. This phase also aims to understand the relative contribution of the processes in order to identify the hotspots according to the impact categories analysed. Uncertainty analyses can be developed to assess the robustness of the study; according to the ISO regulations, uncertainty in LCA comprehends the cumulative effects of model imprecision, input uncertainty and data variability.

1.4 Sustainability effort: construction materials' sectors in Italy

According to the European Commission, the environmental impact of buildings is one of the most significant in EU. In particular, *the construction and use of buildings in the EU account for about half of all our extracted materials and energy consumption and about a third of our water consumption. The sector also generates about one third of all waste and is associated with environmental pressures that arise at different stages of a building's life-cycle including the manufacturing of construction products, building construction, use, renovation and the management of building waste*" (COM (2014) 445final) (European Commission, 2014).

As a consequence, the quest for an environmentally responsible building sector requires concurrent and integrated efforts from the different actors of buildings life cycle. As stated in Paragraph 1.2, the Public Procurement has nowadays to procure goods, services and works characterized by reduced environmental impacts. In this framework, construction materials' sectors are boosted to update processes and management strategies in order to fulfill the recent European Circular Economy and Raw Materials policies and to follow a market which is more and more oriented toward sustainable products. The attention to environmental issues is becoming, together with the price, element of concurrence for building materials. As a consequence, beyond cases of "greenwashing", many enterprises started developing certified environmental declarations (such as EU Eco-labels and EPD).

In Italy, particularly active in terms of sustainability have been the sectors of ceramic, clay-brick, concrete and insulating materials.

1.4.1 Italian ceramic sector

According to the statistics of Confindustria Ceramica referred to year 2016 (http://www.confindustriaceramica.it/site/home/eventi/articolo8608.html), the Italian ceramic sector counts almost 25.000 workers in 225 enterprises, most part located in the provinces of Modena and Reggio Emilia. In the last years this sector has been particularly attentive to sustainability issues and introduced, in its production chain, measures for the reemployment of waste and for the reduction of resources and emissions. This effort has been accompanied by a proliferation of voluntary and third-party certified environmental declaration: according to the statistics, 90 enterprises obtained environmental declarations and in 2016 the Confindustria Ceramica obtained an EPD referred to the average ceramic tile on the basis of primary data collected on 76 companies and 84 plants.

1.4.2 Italian clay-bricks sector

The long-history Italian clay-brick sector owns big industrial establishments with a high degree of mechanization. This sector experienced quite a long period of crisis, started in 2008 and having its lowest point in 2012. Nevertheless, it has been one of the firsts facing environmental issues. In the last decade the brick sector, in collaboration with Universities, analyzed the brick production chain with a Life Cycle Approach (Torricelli et al., 2009). In 2005, LCI datasets referring to the national average processes of brick production have been published. To this aim data were collected on raw materials extraction, production of waste and residues, consumption of electric energy and fuels and packaging resources. In addition to the environmental assessment of the brick production, the sector developed Life Cycle studies related to different brick architectural solutions, with particular attention to their contribute to the energetic performances of the building (Torricelli and Palumbo, 2009).

1.4.3 Italian concrete sector

The Italian concrete sector is composed of 24 enterprises (data referred to year 2016), with some multinational enterprises and other Small and Medium enterprises. Since the first years 2000, some enterprises, in collaboration with experts from Universities, started analyzing the production processes from an environmental point of view (Buzzi Unicem S.p.A., 2002). At the national level, the association AITEC (Associazione Italiana Tecnico Economica del Cemento), born in 1959, is the reference for most part of the Italian concrete enterprises. The industrial strategies during the last years have tried to reduce the environmental impacts and at the same time the association carried out an initiative that lead to the development of an Environmental Product Declaration referred to the average Italian concrete production (Strazza et al., 2010), which will be renovated in year 2018.

1.4.1 Italian insulation materials sectors

The group of insulation materials is quite heterogeneous, since the raw materials employed can comprehend products realized with different raw materials. In the last decades, in the Italian construction materials market, many insulation products emerged. Most of them have been, from their beginning, characterized by the attention to the environmental impacts. Assessments related to both the material production and to the energy performance of the product during the using phase were developed by different enterprises. For example, insulation products of vegetal origin can be mentioned, such as cellulose fibers (Regione Piemonte, 2013), kenaf-fibres (Ardente et al., 2008), wood fibers (Celenit, 2017), cork (Gil, 2014), hemp (Rosato, 2017).

1.4.1 Italian ornamental stone sector

In the dimension stone sector some enterprises are adopting measures to enhance their supply chain sustainability, despite complete environmental evaluations are still scarce. The main efforts to improve environmental performances have been registered in relation to the stone waste issue: some solutions for irregular stone blocks recycling have been identified, employing these extractive waste for artworks, civil construction or other production chains. Nevertheless, the extractive waste recycling is not yet a common and well-established practice because, as declared by some stone enterprises, it is often hindered by different factors: the production of aggregates from quarry waste is, for example, in concurrence with the very competitive market of virgin aggregates from lowland quarries, or, in other cases plants for crushing rock materials can't be located reasonably close to the stone enterprise and, as a consequence, it would not be convenient, neither from the environmental nor from the economic point of view.

Moreover, despite competitor sectors have been often awarded environmental declarations, the ornamental stone sector registers a scarce number of certified products. As stated by Baldo et al. (2002), the EU Eco-label criteria for the assessment of natural stones are affected by the difficulty of transforming the environmental good practices of the stone sector into strict ecological criteria. These criteria have been judged as not well adapted to the real situation in natural stone quarrying and quite demanding and unfavourable for SME (Gazi et al., 2013). Capitano et al. (2014) analysed the production chain of the Sicilian "Perlato" marble to practically understand the suitability for marble products of the EU Eco-label. This study outlined several conflicting points and proposed new indicators and modified criteria for future release of the current EU Decision (2009/607/EC). This latter is actually currently under revision of the European Commission (at Joint Research Centre in Seville) for the specific group "Hard Coverings" and, as a consequence, enhancements of the criteria are expected in the next future. As far as concern the environmental declaration of III type, some Environmental Product Declarations (EPD) have been developed on marble and granite products (such is the case of the Italian enterprise Savema), but the number of certified natural stone products is still significantly low.

In other words, despite the growing interest of the stone sector in enhancing its sustainability, systematic studies and solutions are currently scarce, mainly for the following reasons:

- as explained in Paragraph 1.1, the Italian stone sector is composed by many Small and Medium enterprises, often with a familiar conduction, and whose main priorities are currently more oriented to worker safety issues and to the exportation market;
- since ornamental stone is a natural material, extraction and processing activities are far from being industrial activities where processes are homogeneous and strongly standardised (as it is the case of the above mentioned construction products' sectors); as a consequence, this hinders the structural enhancement of sustainability and the coordination of shared initiatives among enterprises of the stone sector;
- from the scientific point of view, just few specific studies have been developed with a Life Cycle approach. The difficulty in carrying out a complete sustainability assessment is mainly due to the scarce availability of Life Cycle datasets of the most common and widespread technologies of quarrying, cutting and finishing of stone materials (cf. Chapter 2).

1.5 Qualitative overview on sustainability aspects of stone materials

In the general opinion, stone materials do not gain a high consensus in terms of environmental sustainability, often because of a bad perception linked to stone quarries. In this regard, the stone sector is actually responsible of the extraction of a **non-renewable raw material**, whose quarried quantity sensibly increased after the introduction of new technologies in the ‘70s. Another problem of the ornamental stone sector is the **production of extractive wastes**. The percentage of waste is very variable (about from 30% to 70%) from quarry to quarry but also within the same quarry. This is due to the fact that stone is a natural material and, as a consequence, its properties (both mechanical and esthetical) are not homogeneous; moreover some quarrying techniques can cause irreversible damages to stone benches (in particular during the execution of some techniques such as the dynamic splitting and the overturning of benches) and in other cases natural discontinuities can cause bench ruptures. Even if in minor percentages, also the cutting of stone blocks into final products (such as slabs, tiles, etc.) is responsible of losses of material, which generally vary between the 5% and the 30%. As a consequence, following the indication of the Waste Framework Directive (cf. Paragraph 1.2), the stone sector should find solutions to decrease the percentage of waste, or, when this is not feasible, to transform it into co-products to be used for other applications. For example, according to the report published by Tuscany Region (Regione Toscana, 2007) good quality marble extractive waste is currently employed in chemical, paper and cosmetic industries or transformed into aggregates for the civil construction sector. Alternatively, valuable pieces of stone (even if little and irregular) can be used for handcrafts, such is the virtuous example of the social enterprise “recycled stones – Narrazioni degli Scarti” located in Ossola Valley (Italy). Moreover, the scientific community, together with enterprises, is currently investigating both the technologies able to minimize the waste production and the possible treatments and reuses of slurry waste from transformation plants. Different stone waste have been analyzed and characterized in order to identify the more appropriate treatments and the most feasible applications (Carraro and Castelli, 2005; Dino et al., 2017; Marras et al., 2010; Vola et al., 2011). Zichella et al. (2016) are studying how to separate and reuse both the mineral and the metallic fractions of the stone waste. Some research groups focused the attention on the application of stone sludge for the production of concrete (Medina et al., 2017; Rana et al., 2016; Singh et al., 2016; Sogancioglu et al., 2016), as additives for the stabilisation of clayey soil

(Sivrikaya et al., 2014), as fillers for asphalt pavements (Santagata et al., 2017), for structural geopolymer composites (Roper et al., 2015) and for glazed ceramic (Hastenreiter et al., 2017).

Another issue related to the stone production chain is the **concentration in atmospheric particulate matter**, especially caused by dry processes (Cuccia et al., 2011) and by lorry transportation of blocks near built-up areas. To solve this latter problem, some measure have been taken: in Carrara district, for example, it was built a road for the passage of lorries in order to avoid inhabited areas and a system of lorry washing has been created to minimize the production of particulates. If dry processes cause particulate matter problems, processes using water increase the **risk of contaminating surface water and aquifers** (Bellini, 1992; Doveri, 2008) with suspended (TSS) and dissolved solids (TDS), in particular heavy metals and hydrocarbon. In Carrara basin, specific studies have been carried out through the use of spores in order to understand which quarries majorly contributed to the aquifer contamination (Baldi, 2004) and consequently minimize the use of water in these areas. Nevertheless, also with minimization of processing water, the problem persists with rainwater, which, falling in the quarry area, gathers and transports the contaminants to surface water or, when fractures are present, to groundwater.

Despite the sustainability problems that have been cited, some characteristics of stone materials are well aligned with the principles of sustainability and circular economy. Firstly, stone materials usually have a **life time** that is much **longer** than most part of other construction materials: as stated by Khatib (2009), heritage structures enduring weathering over hundreds of years are proof of this durability. Secondly, if the buildings are designed taking into account the selective demolition, after the lifetime of the building, stone materials **can be reused** in other buildings or recycled for different applications. Moreover, unlike industrial materials such as ceramics and bricks, stone doesn’t have to be produced, and, a as a consequence **impacts of production are avoided**.

Finally, characteristic of stone material is the **chemical and toxicological safety**: it does not emit vapours, fumes, gases or other substances that could be dangerous for human beings or for the environment.

To sum up, stone materials present some good characteristics in terms of sustainability. Nevertheless their supply chain and waste management still need to be improved to mitigate the negative effects of this sector. To this aim a Life

Cycle approach can contribute to a more complete understanding of stone materials sustainability and to the identification of critical phases that could be enhanced.

Chapter 2

State-of-the-art and goals of the research project

2.1 State-of-the-art: Life Cycle approach in the ornamental stone sector

In the last decades, the issue of stone sector sustainability has been analysed with different approaches by research groups from the major ornamental stone production countries.

Some studies on ornamental stone supply chains were developed with a Life Cycle approach. In particular, as far as concern the **Italian stone sector**, one of the first Life Cycle studies (Nicoletti et al., 2002) was developed to compare ceramic and Carrara marble tiles. This study considered a functional unit of 1 m^2 of tile over a period of 40 years and the assessment of both the materials was mainly based on the consumption of water, electricity and fuel. Results of this study proved that the impact of ceramic tiles was significantly higher than the marble one. Some years later a research group of the University of Palermo focused on the Sicilian marble (Perlato di Sicilia) from the Custonaci basin. Through a LCA with from-cradle-to-gate boundaries, they quantified the environmental impacts caused by energy and water consumption necessary for producing 1 m^3 of both slabs and tiles of this material (Liguori et al., 2008; Traverso et al., 2010); subsequently this evaluation has been implemented with the economic and social sustainability, respectively through the LCC and SLCA assessments (Capitano et al., 2011). In Sardinia, the Orosei marble has been qualitatively analyzed focusing on environmental factors such as noise, vibration, fumes, dust, vehicle traffic with the aim of identifying land management guidelines able to improve the sustainability of the Orosei Marble industrial area (Careddu and Siotto, 2011). Other LCA studies have been developed for the Pietra Serena sandstone, quarried in the Tuscan districts of Firenzuola, Ascoli and Trasimeno (Torricelli and Palumbo, 2016). The mentioned Life Cycle studies were therefore mainly based on input flows of energy and water resources, while impacts related to cutting tools were scarcely taken into account because of unavailability of data. Moreover, these studies were conceived to assess specific stone supply chains, and, as a consequence, in general results can't be considered fully representative also of other stone production chains.

In the **international panorama** other research groups analysed the Life Cycle of stone products. In 2015, a further comparison between ceramic panels and other façade materials (marble, glass and aluminium) has been developed, in this case with reference to the Chinese production (Han et al., 2015). Results lead to different conclusions from the analogous study of Nicoletti previously cited, probably because of different technologies and energy carriers employed in Italy and China.

A comparison has also been the focus of a Swiss team (Ioannidou et al., 2014), which evaluated the environmental performances of different types of wall systems. To this aim they developed a LCA collecting data from two quarries and processing facilities in Switzerland, which respectively extract gneiss and sandstone.

At the same time, at the National Technical University of Athens, Taxiarchou and Kostopoulou (2007) compared the environmental sustainability of Greek marble and granite production according to an LCA based on energy and water consumption. In 2012, Gazi et al., carried out an energy assessment of a typical medium-sized marble quarry and processing plant in Northern Greece and proposed some measures to improve the overall sustainability.

The embodied energy and CO_2 of dimension stones have been the focus of a study carried out taking into account the fuel use and production of year 2008 in quarry and processing facilities located in Scotland, England, Northern Ireland and the Republic of Ireland (Crishna et al., 2011).

Finally, in Portugal, Catarino et al. (2016) have carried out a project aiming at quantifying the eco-efficiency of Portuguese marble companies. To this aim raw materials, water, energy, products, waste and noise emissions were taken into account.

While also in the international panorama, the main aim of the mentioned researches has been the evaluation of specific stone production chains, another, more global, approach has been followed by both research groups of United States and Brazil. In both cases a Life Cycle Inventory (LCI) has been developed with the aim of providing LC tools to allow enterprises and researchers developing their own assessments. In particular, the University of Tennessee worked at the LCI of products of four different lithotypes: granite (University of Tennessee - Center for Clean Products, 2009a), limestone (University of Tennessee - Center for Clean Products, 2008a), sandstone (University of Tennessee - Center for Clean Products, 2008b) and slate (University of Tennessee - Center for Clean Products, 2009b), basing their analyses on fifteen quarries and processing facilities located in the United States. Similarly, in Brazil, a research group of the CETEM (Centro de Tecnologia Mineral) of Rio de Janeiro (Castoldi Borlini Gadioli et al., 2012) collected primary data from three enterprises located in the state of Espírito Santo (main pole of ornamental stone Brazilian production) for years 2011-2012. More details on the Brazilian LCI are provided in next paragraph.

2.1.1 LCI datasets of Brazilian stone supply chain

The Brazilian research centre CETEM started working on dimension stones LCI in 2009, for the development of the project “Technology, Energy and Environmental Improvements of Dimension Stones Production Through Product Life-Cycle Assessment, LCI – Stones”. This project was part of the Brazilian Life-Cycle Assessment Program (PBACV, Programa Brasileiro de Avaliação do Ciclo de Vida) and the other partners were the Brazilian Institute of Information in Science and Technology (IBICT), Monte Líbano Environmental Association (AAMOL), National Institute of Metrology, Standardization and Industrial Quality (INMETRO) and the Federal Institute of Education, Science and Technology of the Espírito Santo (IFES).

The research project has been carried out in the Espírito Santo State, which is the main producer and exporter of Brazil, and it has been based on primary data collected in three enterprises. The functional unit of the inventory is 1 m^2 of polished granite slab and, as showed in Figures 7 and 8, the processes that have been considered are the quarrying of blocks (average dimensions of 2,90 x 1,90 x 1,80 m^3), their cutting into slabs and the polishing phase (average dimensions of 2,90 x 1,90 x 2-3 m^3).

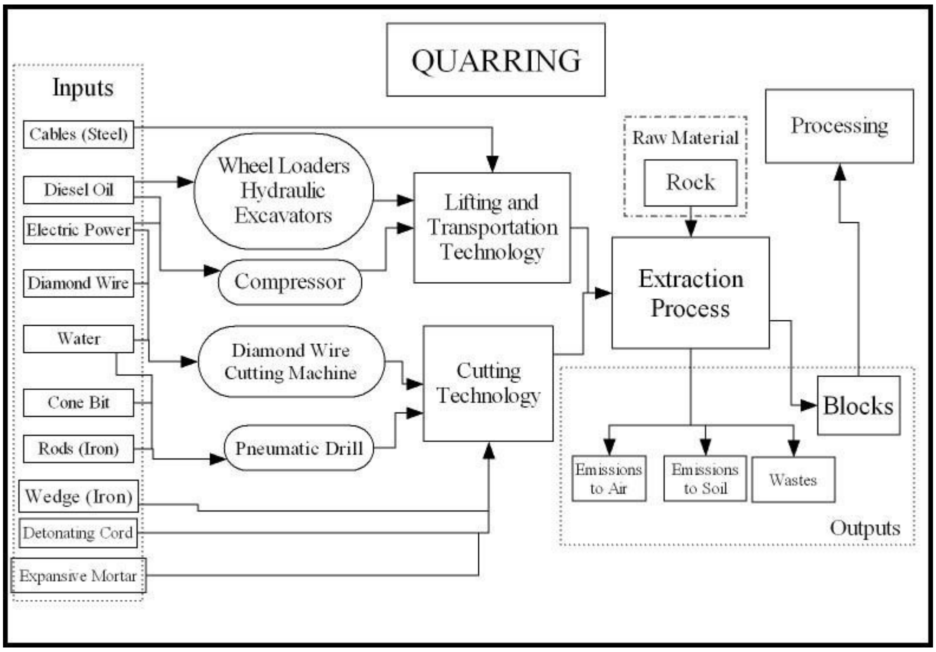


Figure 7: System boundaries of the quarrying phase for the development of LCI on Brazilian dimension stones (source: Castoldi Borlini Gadioli et al., 2012)

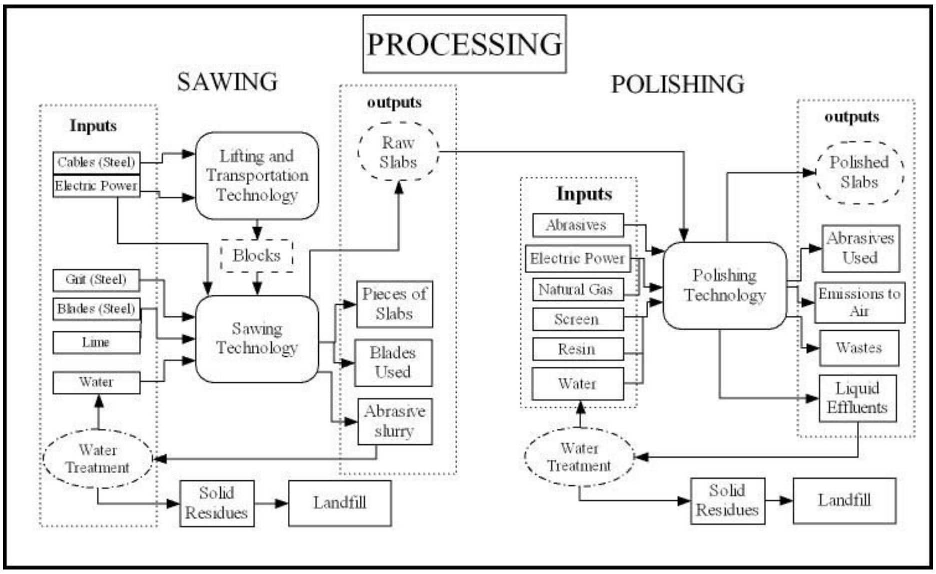


Figure 8: System boundaries of the processing phase for the development of LCI on Brazilian dimension stones (source: Castoldi Borlini Gadioli et al., 2012)

The inventory was referred to the average supply chain of Espírto Santo, where 80% of blocks were cut with multi-blade gang-saws and 20% with multi diamond wire technology. This inventory has been validated in 2014 by LCA experts.

Since in the last years the technology mix of the average Brazilian stone supply chain changed, the LCI is currently being updated. In this framework, a period of PhD has been spent at CETEM, with the aim of strengthening the cooperation in the field of dimension stones and enabling a mutual exchange of information and expertise. The main activities carried out during this period has been the collection of primary data in Brazilian stone quarries and processing plants and the update of Life Cycle models.

Differently from years 2011-2012, currently the technologies of multi-blade gang saws and diamond multi-wires are equally employed in Brazilian stone enterprises. The updated Brazilian stone LCI will consider the new technology mix and updated primary data.

As better explained in Paragraph 4.1.2, despite most part of the machineries for the stone sector are produced in Italy and exported worldwide, the average dimension stone production chains in Brazil and in Italy can be slightly different. For this reason, the LCI dataset of Brazilian granite slabs can’t be generally considered representative also of the Italian stone products.

2.2 Goals of the PhD research project

The goal of the PhD research has been defined in response to the scarce availability, in Life Cycle databases, of Life Cycle datasets on the most common processes in the ornamental stone supply chain. As emerges from the previous paragraphs, different research groups studied the stone sector with a Life Cycle approach. Nevertheless, in many cases these studies scarcely took into account the consumption of cutting tools and, above all, they were mainly referred to specific productions. As a consequence, results of these studies are not easily exploitable for other stone production chains. The lacking of LCI datasets of the most common stone processes is among the causes that hinder a systematic effort of stone enterprises toward sustainability issues. Moreover the availability of these

LCI databases

The efficiency of a Life Cycle Assessment is highly dependent on the quality of the data collected during the Life Cycle Inventory phase. Different databases, developed by both enterprises and researchers, provide data which cover the main industrial process. According to Sanfélix et al. (2013), more than 25 LCA databases and 40 LCA software are available.

In order to increase the interoperability and to boost the creation of a net of consistent, robust and quality assured data, the European Commission developed guidelines which have been published in the International Reference Life Cycle Data System (ILCD) Handbook. The ILCD Handbook is perfectly in line with the international ISO 14040-44 standards and it is composed by a set of documents: the “General guide for Life Cycle Assessment”, the “Specific guide for Life Cycle Inventory (LCI) data sets”, the Life Cycle Impact Assessment (LCIA) guides and the “Review schemes for Life Cycle Assessment”.

In 2014, the Life Cycle Data Network (**LCDN**) was officially launched in Brussels by Vladímir Šucha (DG JRC, European Commission) and Alan Seatter (DG Environment). Aim of the LCDN is providing a organized repository to host quality assured life cycle dataset (such as LCI datasets and LCIA method datasets). As shown in Figure 9 (Recchioni et al., 2015), the

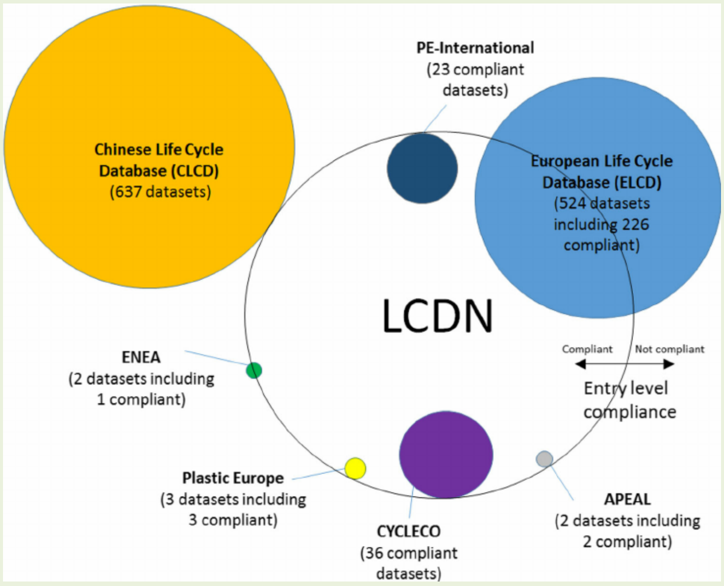


Figure 9: Overview of participants in the Life Cycle Data Network in 2015 (source: Recchioni et al., 2015)

LCDN has been launched with the involvement of 7 initial partners (currently grown to 12), but just part of the datasets were, at that time, compliant to the ILCD entry-level requirements. Nowadays 8 nodes have been approved and registered in the LCDN (European Founded Research Projects, European Life Cycle Database, PlasticsEurope, Gabi AG, SICV Brasil, Eco-systèmes WEEE LCI, Récylum WEEE LCI and APEAL), but activities of dataset reviewing against the ILCD entry-level requirements are still ongoing.

Hereafter are briefly explained three databases largely used by LCA practitioners in Europe.

European Life Cycle Database (ELCD)

This database has been developed by the Joint Research Centre (JRC) of the European Commission and it comprises the LCI data of key materials, energy carriers, transport and waste management. The first version of ELCD has been published in 2006, while with the second version, in 2009, the datasets reached a quantity over 300. The third version of ELCD has been published in 2013 with a higher number of datasets and with part of them verified as compliant to the ILCD entry level requirements.

Gabi Database

Thinkstep (formerly known as PE International) is a German company specialized in sustainability software and consulting. Beyond the development of Gabi software, Thinkstep also provided a database, which currently accounts over 10.000 LCI datasets, comprising all relevant sectors, including plastics, chemicals, construction, renewables, and electronics. In 2015, Thinkstep made freely available around 2000 datasets in the LCDN.

Ecoinvent

Ecoinvent has its roots in 1992, when a joint initiative of the ETH Domain and Swiss Federal Offices was established, while currently it is a not-for-profit association. The first version of the Ecoinvent life cycle database was launched in 2003, followed, in 2007, by the second version, which extended and reviewed the first one. The third version of the database has been releases in 2013 and the last update (version 3.3) has been in August 2016. Ecoinvent database provides over 10.000 datasets and covers many different sectors, such as agriculture, energy and manufacturing. Currently Ecoinvent is not part of the LCDN.

LCI datasets would benefit also parallel research fields which are developing technical solutions to enhance the stone supply chain sustainability (cf. Paragraph 1.5): in these cases more detailed Life Cycle assessments would therefore avoid the risk of shifting environmental impacts from one phase of the process (e.g. waste disposal) to another one (e.g. construction of recycling machineries and tools).

As previously mentioned, Brazilian researchers developed a LCI dataset related to the production granite slabs; nevertheless, because of differences in the production technology mix, the Brazilian dataset is not completely representative also of the Italian sector.

In light of these reasons, the **main goals of this research study** are the following:

1) the development of a well-defined methodology of Life Cycle Inventory in the ornamental stone supply chain. The PhD thesis aims therefore to implement the ISO 14040-44 standards and the ILCD Handbook guidelines for their specific application in the stone sector.

2) the creation of Life Cycle Inventory (LCI) data on the most common and widespread technologies of stone quarrying, cutting and polishing, with reference to the Italian dimension stone sector. The novelty is therefore the development of detailed LCI datasets which comprehend input data of both energy and materials consumed during the processes and which are representative of the Italian sector. Nevertheless, since Italian stone cutting technologies are exported worldwide, datasets could be considered significant also for foreign stone supply chains. This goal is in line with the international and European guidance, promoting the availability, accessibility and exchange of free of charge LCI data through the development of public, protected, transparent and accredited databases.

3) the realisation of a parameterized model of LCA comprising the phases of blocks quarrying, cutting into slabs/tiles and polishing. This LC model is developed with the LCI datasets previously developed and parameters are set in order to easily allow the model to be adapted to the production of specific enterprises. The LC model aims to encourage an active use of LCA tool among stone enterprises in order to both identify strategies to mitigate negative impacts of the stone production chain and to allow a transparent promotion of the most environmentally sustainable stone products.

Chapter 3

Methodology for developing a Life Cycle Inventory on techniques and technologies of the stone sector

The creation of Life Cycle datasets on processes of the ornamental stone supply chain followed the methodological guidelines given by the "Specific guide for Life Cycle Inventory data sets", component of the International Reference Life Cycle Data System (ILCD) Handbook. This guide, edited by the European Commission - Joint Research Centre (2010), is in line with the ISO 14040 and 14044 standards on Life Cycle Assessment and specifically *provides guidance for developing Life Cycle Inventory (LCI) data sets, which contain all emissions and resources that are associated with the life cycle of the analysed process or product*. The methodological steps followed during the PhD research project are showed in the next paragraphs.

3.1 Identification of LCI unit processes

Firstly, it has been necessary to identify the LCI unit processes to develop. To provide significant data to LCA practitioners and stone enterprises, the most common and significant technologies of the Italian stone supply chain have been detected. Different and complementary approaches have been used: on-site investigations, dialogue with experts of the stone sector and literature reviews.

Once identified the processes, it has been verified whether good quality datasets were available in existing LC databases to describe the relative input/output flows. When these latter were not available in LC databases (i.e., for example, for specific cutting tools such as the diamond wires), further investigations were carried out to obtain the necessary Life Cycle data. Also in these cases, the identification of the most significant processes has been developed through the collection of primary and secondary data.

3.1.1 Identification of processes through primary data

Since the technologies employed during the supply chain of dimension stones are different according to the hardness of the stone, Italian quarries and transformation plants of both hard stones (such as gneiss) and soft stones (such as marble) were analysed.

On-site investigations were carried out:

- in the basin of Carrara (Tuscany), in particular in the Gioia quarry (about 50.000 m^2) where marble is extracted and in 3 transformation plants where both marble and gneiss stones are cut and polished.
- in the Verbano-Cusio-Ossola province (Piedmont), with reference to 3 quarries (2 of gneiss, 1 of marble) and 3 transformation plants where both marbles and gneisses are cut and polished.
- in the Bagnolo-Luserna basin (Piedmont), with reference to 2 quarries and 2 transformation plants, all working with the hard Luserna gneiss stone.

Further information were also provided through the dialogue with public administrations connected with the stone sector, in particular:

- Carrara Municipality, marble sector.
- Regione Piemonte, mining activities sector.

Since, as explained before, Life Cycle datasets related to some of the most significant tools consumed in the dimension stone supply chains were not available in the LC databases, the production chains of these tools were investigated through visits in the following enterprises:

- Stein Varz (Crevoladossola), which produces diamond tools;
- Mega Diamant (Carrara), specialized in the production of diamond wires.

In other cases, when direct visits were not feasible, an useful exchange of information has been carried out with enterprises' owners or delegates. In particular with:

- Mimitalia (Genova), producing sintered diamond tools;
- Pravisani (Udine), producing explosives.

3.1.2 Identification of processes through secondary data

Since for technical and logistic reasons the primary investigation was developed in the north and centre of Italy, a deep literature review has been carried out to evaluate if the stone supply chain in other Italian regions is composed by the same technologies or by alternative ones. The most important sources for this state-of-the-art analysis have been Primavori (2011, 1999) and Careddu and Siotto (2011) for Sardinia; Giuffrida (2010), Traverso et al. (2010), Capitano et al. (2011) for Sicily; Langella et al. (2009) for Lazio; Alma (2009) and Masciullo (2016) for Apulia, Acocella (2004) for a general overview of the Italian stone sector technologies.

As a support and confirmation of the primary investigations, a literature review on the processes has also been carried out for stone production chains located in the north and centre of Italy. In particular, the main sources have been Cardu (2013, 2012, 2005, 2002), Crivello (2012), Dadalto Sahao (2013) Torricelli and Palumbo (2016), Vitali and Napoli (2011).

As far as concern the production chain of tools employed in the ornamental stone supply chain, papers, thesis, patents and technical sheets have been consulted and the specific references are mentioned within the datasets description in Chapter 5.

3.2 Data collection

The processes that from the previous investigations turned out to be the most common and widespread in the Italian dimension stone sector have been analysed in detail to build the correspondent LCI datasets. The data collection has been the

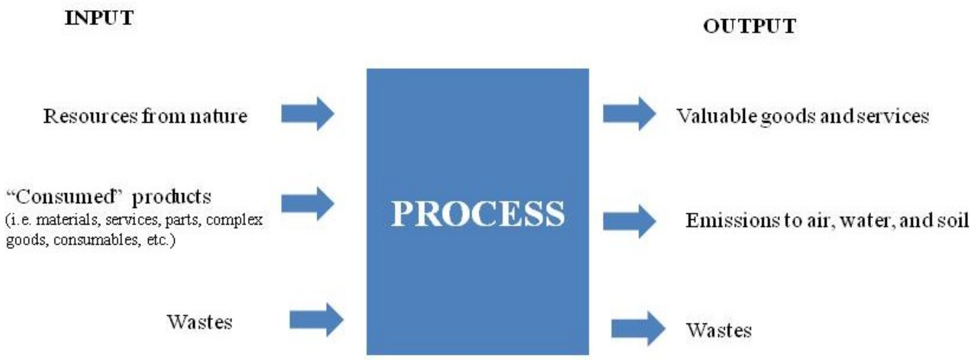


Figure 10: input and output flows to quantify for the creation of LCI datasets

phase that required the highest effort, resources and time. According to the ILCD Handbook, to obtain good quality datasets, *quantitative data of all relevant inputs and outputs that are associated with the unit process shall be collected/modelled, as far as possible*. Figure 10 summarizes the flows to be included in the modelled process.

To quantify the flows of stone supply chain processes, primary data have been preferred, while secondary data were employed to support and complete, when necessary, primary data.

Primary data were mainly obtained through direct measurements, interviews and questionnaires to managers and workers of quarries, processing plants and enterprises producing cutting tools. Annex 2 and Annex 3 show the questionnaires that were submitted to managers respectively of dimension stone quarries and processing plants. Another source of primary data has been the inventory that the Regione Piemonte public administration requires each year to owners of quarries located in Piedmont (Annex 4 shows an example of this document). Finally, bills and internal inventory documents have been employed to obtain useful data for the development of the LCI datasets. In particular, primary data were collected from: 4 marble quarries (of which, 2 located in the Carrara district and 2 in Piedmont); 10 gneiss quarries (located in Piedmont, both in Turin and Verbano-Cusio-Ossola provinces); 7 transformation plants (most of them generally cut and polish both marble and gneiss; 2 are located in Carrara basin, 3 in Verbano-Cusio-Ossola province, 2 in Turin province); 3 enterprises connected to the ornamental stone supply chain (1 located in Carrara district, producing diamond wires; 1 located in Verbano-Cusio-Ossola province, producing cutting tools, 1 located in Liguria, producing sinterized elements). The basis for the collected primary data were from 1 to 3 full years and all the data are referred to a period comprised between the beginning of 2014 and the end of 2016.

Secondary data were employed in order to cross-check the measured data and to fill the gaps when primary data were not available. Examples of secondary data are: technical sheets of machineries and tools commonly employed in the Italian dimension stone supply chain; specific scientific literature and patents concerning industrial processes of tools or tools components for cutting and polishing stone materials; formulations and stoichiometric models, employed especially for modeling LCI datasets of explosives. Finally, datasets from available Life Cycle databases were selected according to their completeness, precision and technological representativeness.

3.3 Modelling of LCI datasets

Data obtained from the previous phase were scaled according to the functional unit of the LCI dataset to be modelled. Subsequently, analogous data pertaining to different sources were averaged. The **average** has been calculated in order to obtain representative datasets of each technology analysed, without being referred to a specific enterprise production; moreover, the average allowed to protect confidential and proprietary information of quarries, transformation plants and companies collaborating to the project. **Data uncertainty** was then handed through the calculation of the standard deviation, to assess the value ranges around the mean values and to evaluate the consequent precision of the LCI datasets.

The **LCI datasets** of the stone supply chain processes were **modelled** through the Gabi software and the average values of input/output flows were inserted. The standard deviation previously calculated was also registered in the software in order to allow, in a subsequent stage, the calculation of uncertainty on the LCIA results. Since the quarrying processes bring to the production of different quality outputs, a market price **allocation** has been introduced when necessary. Moreover, **parameters** have been set through the integration of mathematical relations in order to provide LCI datasets easily adaptable to specific stone production chains.

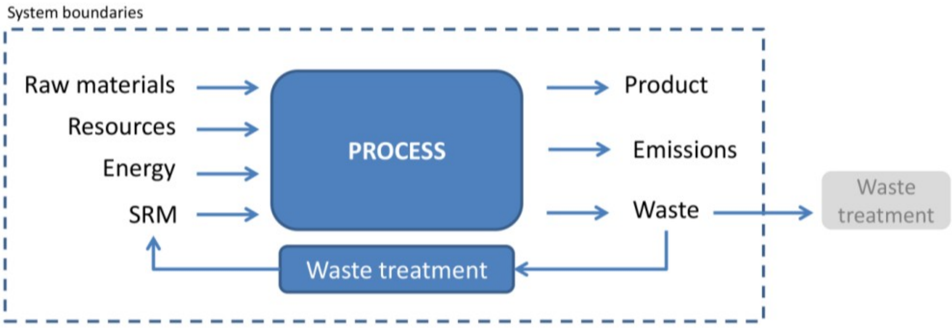


Figure 11: System boundaries of the developed LCI datasets

LCI datasets were developed for the single specific techniques/ technologies of the stone sector and for the related tools employed during the processes. As showed in Figure 11, the **system boundaries** of the datasets comprehend flows of energy, raw materials and resources necessary for the execution of the specific quarrying/cutting/finishing techniques or for tools production and output flows quantifying the product, the related by-product/waste and, when possible, the eventual direct emissions. LCI datasets do **not comprehend the treatment of waste** and do not include credits for by-products/waste which could be recycled or recovered in other production chains. The exclusion of waste treatments from the datasets is due to the high variety of possible End-of-Life scenarios for the waste produced throughout the stone production chain (cf. Paragraph 6.4) Nevertheless datasets comprehend the reuse of waste which are recovered in the same process (as it is the case, for example, of the steel core of the diamond disk, which is reused several times for the production of new diamond disks).

3.4 Quality control

LCI datasets whose input/output values were collected through primary data from different enterprises were submitted to an internal quality control in order to verify in which measure the uncertainty on these primary data could influence the final LCIA results. To this aim three LCIA methods (models and associated characterisation factors) of reference have been chosen. The choice has been based on the recommended methods listed by the European Commission (Annex 5 illustrates the tables from the ILCD Handbook summarising the recommended methods), choosing the methods of I level quality. This latter are respectively: the *Baseline model of 100 years of the IPCC* (for the assessment of the climate change impact category), the *Steady-state ODPs 1999 as in WMO assessment* (for the assessment of the ozone depletion impact category) and the *RiskPoll model (Rabl and Spadaro, 2004) and Greco et al 2007* (for the assessment of the

Particulate matter/Respiratory inorganics impact category). Therefore, aim of the analyses on LCIA is to assess the **magnitude of the uncertainty propagation from the primary data to the impact results** and not to evaluate the environmental consequences of the stone sector techniques and technologies. For this reason LCIA analyses have been developed just for the datasets whose inventory has been quantified as the average of primary data collected in stone quarries and enterprises, while they have not been developed for datasets resulting from secondary data. Uncertainty analyses on LCIA results have been performed through the calculation of standard deviation and Monte Carlo stochastic simulations. In particular, Monte Carlo simulations evaluate the stability of the impact results toward random parameters constellations; simulations have been based on the standard deviation of the inputs’ values, with a number of iteration in the amount of 1000.

Chapter 4

Techniques in the ornamental stone supply chain

This chapter illustrates the most common and widespread techniques in the Italian supply chain of dimension stones, while next Chapter will show how LCI datasets of these processes have been developed.

As explained in detail in Chapter 3, both primary and secondary data have been employed to identify the most widespread techniques and technologies. The collection of primary data mainly took place in quarries, transformation plants and enterprises of Piedmont and Tuscany, but, according to the secondary data investigation, it emerged that techniques and technologies of the dimension stone sector are basically the same also in the other Italian regions. As a consequence, the developed LCI datasets can be considered representative of the current Italian (but exported worldwide) stone supply chain technologies.

4.1 Italian ornamental stone supply chain

The ornamental stone supply chain can be divided into three macro-phases, as shown in Figure 12:

Quarrying phase: in this phase a primary cut is carried out to open a bench, which is subsequently tipped and divided into blocks of commercial dimensions for their transportation with trucks. In some quarries

Figure 12: macro-phases of the ornamental stone supply chain

machineries to square irregular blocks into regular ones are available. Aim of the dimension stone cultivation is the production of intact stone blocks of parallelepiped shape, generally having a volume variable between 2 and 15 m^3. According to the quality and the characteristics of the specific blocks (presence of fractures, colour, dimensions, etc.), they are classified and destined to different uses (and different selling prices). First-choice blocks are generally destined to be cut into slabs and/or tiles, while irregular or fractured blocks are used as cliff blocks or for producing minor stone products. Finally, irregular portion of stone material are crushed and can either be used as Secondary Raw Material or discarded. At the same time, some waste is produced, especially in presence of technologies requiring water (such as the cutting with diamond wire technology). In these cases, filter-press are more and more common in quarries to separate water from the solid fraction.

Cutting phase: stone blocks (generally quite heterogeneous because coming from different stone quarries) are transported to the processing plants, where machineries cut them into slabs and tiles of dimensions and thickness variable according to the market requests. When necessary, a previous squaring of the block is carried out.

Finishing phase: the stone semi-finished products can be submitted to different surface treatments according to the customer requests.

For each of these phases different techniques and technologies are available. The choice of the more suitable techniques and machineries to be used in stone supply chains mostly depends on the characteristics of the rock, and in particular on its abrasiveness. As a consequence, dimension stones are generally divided into two categories which are not strictly based on mineralogical and petrographical criteria, but that are useful to classify the stones according to their level of hardness. These two categories are commonly known with the improper names of:

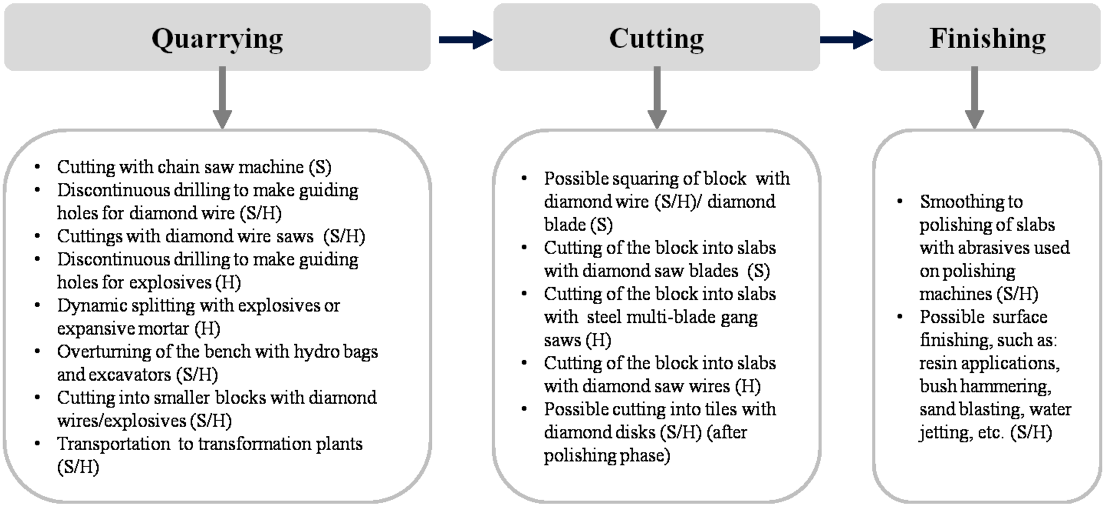


Figure 13: Scheme summarizing the most common techniques of the ornamental stone supply chain. Processes related to the production chain of soft and hard stones are respectively indicated with an S and H in brackets.

- “marbles” or “soft stones”; belong to this category all the stones with a hardness of about 3-4 in the Mohs scale. These stones are mostly carbonates, such as metamorphic marbles, dolomites, limestones, travertines, etc.
- “granites” or “hard stones”; belong to this category all the stones with a hardness of about 5-6 in the Mohs scale. These stones have a high presence of quartz, such as gneisses and granites.

Figure 13 resumes the techniques that were identified as the most diffused in the Italian territory. Paragraphs 4.3 to 4.5 describe these techniques.

4.2 Other ornamental stone supply chains: the case of Brazil

The Italian single technologies are exported worldwide, but the stone supply chain in other countries can be slightly different according to the available stone materials and other local variables, such as, for example, the climate conditions. It is here presented the case of Espírito Santo, the main producer of stone slabs in Brazil (cf. Paragraph 2.1.1), where the major production is of granite stones. The main differences among the current Italian and Brazilian dimension stone supply chains are hereafter explained.

Extraction of stone benches in Brazil is mainly carried out with the diamond wire cutting technique, and in lesser extent with dynamic splitting. On the other side, the chain cutting technique is almost never used in Brazilian quarries.

In Brazil, the **cutting** into slabs is the phase which has been majorly subjected to a progressive technology change in the last decade. According to the study developed by the CETEM Research center (Castoldi Borlini Gadioli et al., 2012), in years 2011-2012 about 80% of slabs where produced with multi-blade gang saws technology and 20% with multi diamond wire technology. Currently (2017), these two technologies are equally widespread. In particular, the multi-wire technology (whose machineries are mainly produced in Italy), in this moment, finds wider percentage use in Brazilian enterprises than in Italian ones. This can be due to the fact that in Brazil are mostly processed hard stones, while in Italy a significant production is also of soft stone, whose production chain does not widely employ the multi-wire technology. For the same reason, the use of diamond multi-blade technology is quite limited in Brazil, while in Italy it is the main technology employed for cutting soft stones.

The **surface treatment** of smoothing and polishing are basically the same in both the countries. Nevertheless, in Brazilian enterprises a larger quantity of slabs is treated with resin, which is employed to strengthen fragile stone slabs, to improve reflection properties of surfaces and to protect slabs against water penetration and hydrolysis. Moreover, the process of resin application in Espírito Santo has been, in some cases, adapted to take advantage of the local warm climate conditions. In fact, despite in most cases resin slabs are dried in ovens with the same procedure employed in Italy (cf. Paragraph 4.5), some Brazilian enterprises have started adapting the process by letting drying the slabs at open air and, when necessary, little heaters placed under conveyor rollers are turned on (Figure 14).

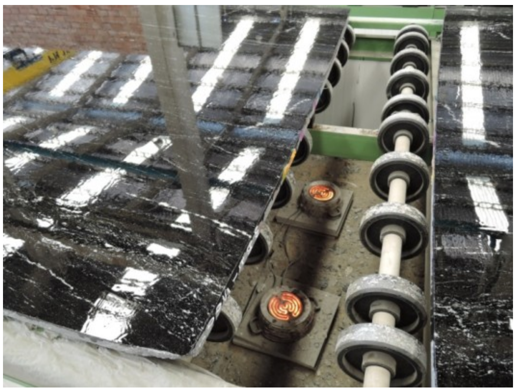


Figure 14: Drying of resined slabs in a Brazilian processing plant

4.3 Italian ornamental stone quarrying techniques

4.3.1 Dynamic splitting

The dynamic splitting is among the most traditional, well-known and economical quarrying techniques. Currently, this technique is largely diffused for the extraction of hard stones, while for soft stones are employed other, less invasive, techniques. The dynamic splitting is characterized by the use of explosives, generally black powder and detonating cords of penthrite. To perform this technique, parallel holes are drilled along the surface of splitting and black powder is placed at the bottom of the holes. Secondly, detonation cords are introduced and subsequently linked through knots. Holes are then filled with inert material and water (which will absorb the shock and cause the separation of the two rock surfaces). Finally the net of detonation cords is connected with a detonator, which is connected to a piece of slow burning fuse to trigger the dynamic splitting. The splitting is obtained by the strong tensile stress on the surfaces of the rock. Dynamic splitting can be used for both opening a bench and dividing benches into smaller blocks. The main disadvantages of this technique are the fractures that can be caused to the stone material during the splitting and the irregularity of the surfaces, which are responsible of the discard of higher quantity of material during the following phase of slabs and tiles production (in comparison to other techniques, such as the diamond wire cutting).

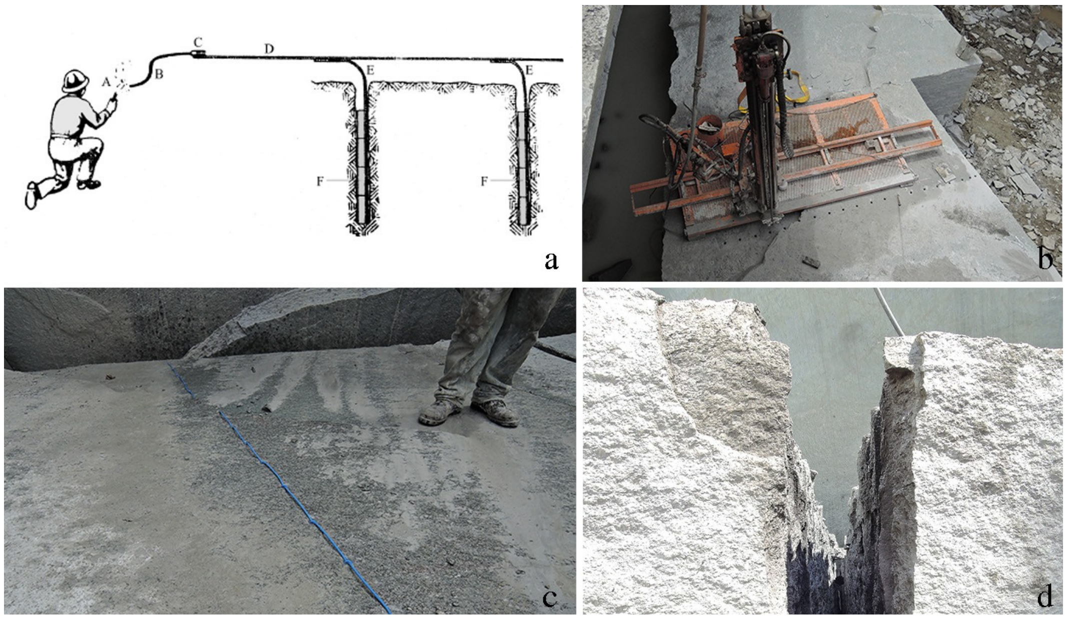


Figure 15: a) scheme of the dynamic splitting process (source: Selva and Nardin, 2013); b) holes drilling; c) detonation cords connected through knots; d) surfaces of stone block after the dynamic splitting

4.3.2 Stone cutting with diamond wire technology

The cutting with diamond wire technology has been developed in the ‘70s and it is nowadays employed in the majority of the Italian soft stone quarries. In the last decade, its use has grown also in hard stone quarries, using the diamond wire technology in some phases of the extraction. This technology is based on the diamond property of being the hardest mineral in the Mohr scale, and consequently able to cut all the other minerals. To perform this technology a close circuit is created, where a diamond wire is placed and made rotating at high speed (Figure 16). To this aim intersecting holes have to be previously drilled along the edges of the bench to be extracted. The cutting machine is composed by an electric engine connected to an aluminium pulley, which is able to rotate on its axis of 360°. Moreover, the machinery can be translated on apposite tracks. As a consequence, the diamond wire technology is highly flexible, allowing cutting in each direction and for (theoretically) infinite extensions. This technology is employed for both extracting the benches and cutting them into smaller blocks.

The use of water during the cutting is necessary to cool the wire. The diamond wire is composed by a steel wire of about 5 mm where diamond beads are placed at regular distance (generally between 28 and 40 beads per meter, according to the lithotype to cut) through the use of spacers and connectors; a rubber or plastic coating covers and protects the steel wire. Diamond beads are composed by cylindrical axle boxes, which are coated with a matrix composed of metallic and synthetic diamond powders.

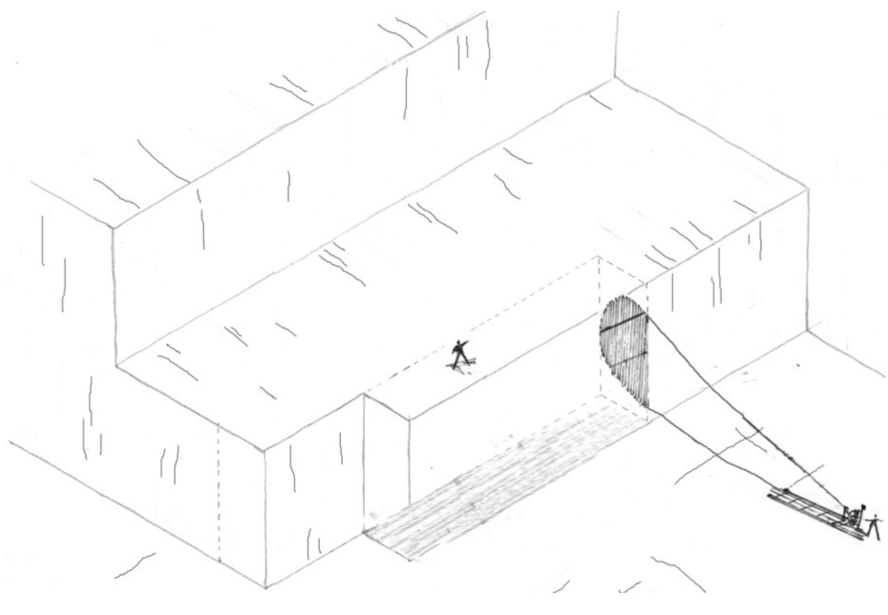


Figure 16: sketch of bench cutting with diamond wire technology

Figure 17: a) holes drilling ;b) marble bench with vertical cut made with diamond wire technology; c) quarryman preparing a block to be squared with diamond wire technology; a) electro-plated diamond wire; b) scheme summarizing the difference between sintered and electro-plated diamond beads (source: Tonshoff and Hillmann-Apmann, 2002)

Two main types of beads are currently available on the market (Figure 17e):

- Sintered diamond beads: the diamond powder is mixed with metallic powders to form a matrix which is sintered on the axle box. Through this production technology, the synthetic diamonds are homogenously distributed in the whole thickness of the matrix. As a consequence the diamonds consumption goes at the same time of the matrix consumption and beads maintain their abrasiveness till the total consumption of the matrix.

- Electroplated diamond beads: the synthetic diamonds are chemically electroplated on the surface of the axle box. This structure allows a faster cutting, but, since there is just a single external layer of diamonds, its performance decreases with the wear of the surface layer.

The performance of the diamond wire technology highly varies according to the stone mineral composition. In carbonate materials it provides a high productiveness and the cost of the wire is offset by its quite long lifetime; on the contrary with hard stones, the presence of large quantities of silicates decelerate the operation (cutting speed is 1/3 to half the speed obtained with carbonate minerals), and the wire has a shorter lifetime. This explain the reasons why the diamond wire cutting is highly widespread in soft stone quarries while for hard stones the most employed technique is still the dynamic splitting.

4.3.3 Stone cutting with chain saw technology

Chain saws are generally employed in soft stone quarries for bench cutting. These machineries are composed by an electric engine block responsible of the movement of an arm with a toothed chain moving along its perimeter. The chain is equipped with tipped cutting tools in tungsten carbide (also called widia) or polycrystalline diamond. The machinery can be moved along a track, while the arm is able to rotate of 360° on the axis linking the engine with the arm; finally the arm can be overturned of 90°. As a consequence, cuttings can be performed in each direction for a deep depending on the arm length (generally between 2 and 6-4 meters). The cutting can be performed dry (generally faster) or with cooling water (lowering the tools consumption). In any case a water jet is necessary to remove the stone waste produced during the cutting. The chain always need to be lubricated during the cutting.

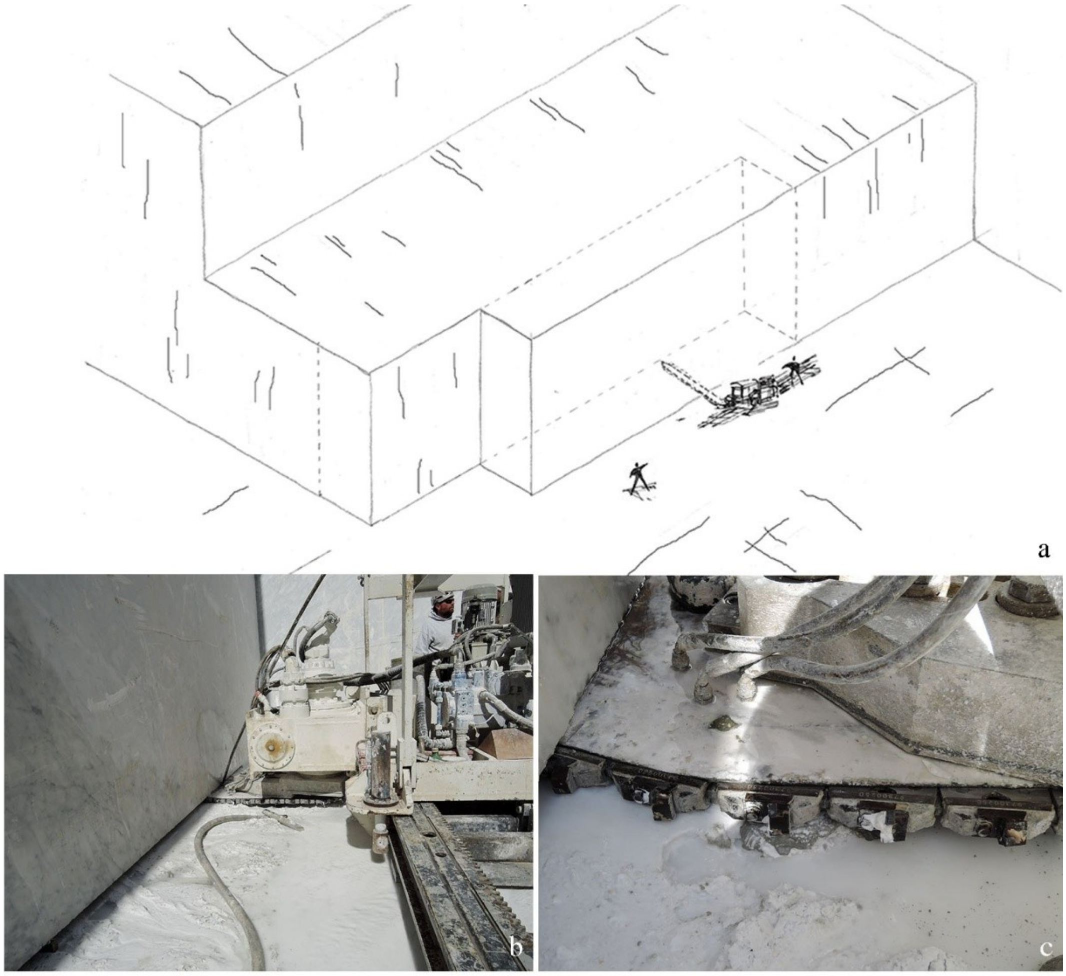


Figure 18: a) sketch of bench cutting with chain saw technology; b-c) chain saw cutting a Carrara marble bench

4.3.4 Benches overturning

After the complete separation from the quarry bedrock, the bench has to be laid down and, subsequently, divided into blocks of the desired dimensions for their transportation. In order to reduce the development of cracks, the bench is laid down on a bed of debris, previously prepared. The overturning technique can be carried out through the use of different technologies.

One of the most widespread technology is the use of hydro-bags (Figure 19a). These latter are thin steel bags which can be inserted directly in the space created by the splitting surfaces. Bags are then inflated with water by a junction box, till they reach a pressure of about 30 bar and the bench starts moving.

Figure 19: a) hydrobag (source: www.tecnocave.com/hydrobag/); b) bench overturning

The final overturning can be carried out by the action of an excavator bucket (Figure 19b). Alternatively, the bench can be laid down through the pressure given by hydraulic jacks. In this case, junction boxes activate a set of pistons which are able to overturn the bench. Hydraulic jacks are placed in the space created by the bags or in holes created with a pneumatic drill.

Finally, in particular cases, the bench can be laid down also by traction, with a steel cable or other tools. Since this technique is the most dangerous one, the previous methods are generally preferred.

4.4 Italian dimension stone cutting techniques

Regular blocks are transported to transformation plants, where they are generally cut into slabs or tiles. When blocks are irregulars, they are previously squared. Different technologies are currently available for both cutting and squaring and the choice of the technology mostly depends on the hardness of the stone block.

4.4.1 Stone squaring/cutting with diamond mono-wire technology

The diamond mono-wire technology consists of a stationary machine where a single diamond wire is installed in a close circuit (Figure 20). An engine makes move the wire along the circuit and progressively translate it in the vertical direction, while a water jet assure the correct cooling of the wire. This technology is largely employed for squaring both hard and soft stone blocks. It is also employed to obtain thick slabs or to divide blocks according to specific requests.

Figure 20: squaring/cutting of stone blocks with mono diamond wire technology

4.4.2 Stone squaring with diamond mono-blade technology

Alternatively to the diamond mono-wire, soft stone blocks can be squared with a steel blade to which a stationary machine gives an oscillating movement. The cutting action is provided by a set of diamond segments which are welded on the bottom edge of the blade. This technology is not employed with hard stone blocks because the rapid worn out of the diamond segment makes this technology inconvenient.

Figure 21: a) squaring of a marble block with mono diamond blade technology; b) worn out diamond blades

4.4.3 Stone squaring/cutting with giant disk saw technology

Giant disk saws are generally employed for both squaring irregular blocks and cutting slabs from regular blocks. This machine is composed by a frame where an horizontal beam (able to move vertically) supports a disk with a large diameter (up to 4000 mm). The giant disk has abrasive diamond sectors all along its perimeter, which are responsible of the cutting action. This technology is more often employed with hard stones, but can be employed also with soft stones.

Figure 22: a) giant disk cutting a hard stone block; b) detail of a giant disk

4.4.4 Stone cutting with steel grid gang saws technology

This technology is largely employed to cut hard stone blocks into slabs, while it is not employed for cutting soft stones. The machine is composed by a frame, where a set of steel blades are placed parallel, with a distance that can be regulated according to the market requests (slabs of 2-3 cm thickness are commonly produced). Blades oscillate with a pendular movement and their main function is the transportation of the cutting agent: an abrasive slurry composed by water, lime and steel (or cast iron) grit. The abrasive slurry is continuously pumped over the block, and the abrasiveness is maintained through periodic substitutions. A system continuously collects the water, which is then treated with a filter press and recirculated into the process. Blades have to be replaced quite frequently because of their fast consumption during the cutting process.

Figure 23: cutting of hard stone blocks with steel grid gang saw technology

4.4.5 Stone cutting with diamond multi-blade saw technology

To cut soft stone regular blocks diamond multi-blade saws are commonly employed in Italian processing plants. Similarly to the previous technology, a frame gives an oscillating movement to a set of blades, which are distanced according to the desired thickness of the slabs to be produced. In this case the responsible of the cutting action are the blades and, in particular, the diamond segments which are welded on an edge of the blade. This cutting technology requires the use of water in order to cool the tools; water is recycled in a closed loop: a filter-press collects the water, treats it and re-send it to the cutting machine. When the diamond segments are worn out but the blade still maintains its strength properties, new segment are welded on the same blade (this substitution is generally feasible for 2-3 times).

Figure 24: cutting of marble blocks with diamond multiblade saws technology

4.4.6 Stone cutting with diamond multi-wire saw technology

Another technology that can be used to cut both hard and soft stone blocks is the diamond multi-wire cutting. Currently, in Italy this technology has not a wide diffusion: processing plants cutting marbles generally prefer the diamond blade saws technology (mainly for economic reasons), while its application is slowly growing for the hard stone cutting, in substitution to the steel grid gang saw. This technology makes use of a frame where a set of diamond wires are spaced according to the desired thickness of the slabs to be produced. The diamond wire employed for this technology are similar to the ones used in quarries, but of smaller dimensions (6-7 mm diameter). In order to lower the wires fatigue, in the machine are installed drums and wire stretching pulleys, one for each wire. This technology requires the use of water to cool the diamond wires. Also in this case, water is collected, treated in a filter-press and reused in the same processing plant.

Figure 25: pulleys and diamond wires installed in a diamond multi-wire cutting machine

4.4.7 Stone cutting with diamond disk technologies

Different types of diamond disks machines are commonly employed for producing strips (*filagne*, in Italian) and tiles of both soft and hard stones. Steel disks of different diameters are provided of abrasive diamond segments on their perimeter (Figure 26a). The cutting action is obtained through the rotation and translation of diamond disks; during the cutting, water has to be provided to cool the tools. In particular, the main machines currently available are:

- bridge saws (Figure 26b-d). A single disk is supported by an horizontal beam, which vertically translates to transport the disk close to the stone slab to cut. The table where the slab is placed is, in some cases, able to turn and tilt to facilitate the cutting in different directions. The last models of these machines also allow operators to set automatic controlled cycles;
- disk cutting lines. These machines are equipped with a mobile trolley where stone slabs are placed. A cluster of disks is hold by an horizontal shaft for vertical cuttings. Generally there is also a vertical

shaft supporting a disk for horizontal cuttings. These machines usually have a good level of automation.

Figure 26: a) diamond disk; b-c) diamond disks with different diameters cutting stone strips (a) and slabs (b); d) worker programming the disk cutting machine

4.5 Italian dimension stone finishing techniques

After the cutting processes, slabs and tiles present not completely planar surfaces. According to the final use of the stone product, it can be necessary to carry out a surface treatment. The surface of slabs/tiles after the cutting phase is significantly influenced by the cutting technique that has been used. Hard stone slabs obtained from the steel grid gang saws cutting are often characterized by a high level of roughness with quite evident defects of flatness and grooves; on the contrary, soft stones cut with diamond saw blades are generally quite regular and the surface is almost smooth. Also after the diamond wire cutting stone surfaces are particularly regular; moreover the diamond wire could provide not only quite planar surfaces, but also other geometries such as concave and convex surfaces, as well as cylindrical, conical or helical forms. As far as concern the cutting with diamond disks, for both soft and hard stones, surfaces present poor roughness and good planarity. When very precise dimensions are required for the stone product or when particular effects are desired, different surface treatments can be carried out. It follows the main surface treatments.

4.5.1 Surface treatments: smoothing to polishing

Smoothing and polishing are the most common surface treatments for stone elements, particularly exalting aesthetic qualities, color and texture of stone materials. Smoothing is the process able to eliminate the surface irregularities of the cutting phase and improve the planarity, while the polishing process gives to the surface shiny properties. Beyond the brightness, this treatment is also useful to close the stone superficial pores in order to limit water infiltrations.

Smoothing and polishing are carried out through a mechanical process. The most common machineries (Figure 27a-b) are provided with a mobile trolley where slabs are transported, while, at the same time, mandrels provided with abrasive tools and supported by a bridge structure rotate on the stone slab surface. The abrasive located in the mandrels have progressively decreasing grain size, from metallic brushes (for the first smoothing step, Figure 27c) to very fine abrasives (able to polish the surface, Figure 27d). These machines generally have a high level of automation helping the improvement of the production rates.

Figure 27: a-b) smoothing/polishing machines; c) metal abrasive for smoothing; c) diamond resin abrasive for polishing

4.5.2 Other surface treatments

Other surface treatments are available in processing plants, to satisfy the specific requests of the market. In particular, the main surface finishing technologies are:

Bush hammering

This technology can be applied to both soft and hard stones, even if for hard stones it has been often replaced by the more convenient flaming technology. Bush hammering leaves the surface of the stone quite rough and with small indentations, providing the surface with a slide-preventing grip. Nevertheless, since this effect is obtained through the mechanical action of pneumatic hammers, the stone material can be damaged or weakened at the smaller scale.

Flaming

This technology is mostly used with hard stone materials, often as an alternative to bush-hammering. The surface effect is obtained by a flame fed by oxygen and propane, provoking a thermal shock.

Waterjet

This technology is particularly used (and studied) in Sardinia (Careddu et al., 2014; Ozcelik et al., 2011) and it consists in injecting water at high pressure on the stone surface. According to the water pressure and the nozzles position and speed, different effects of rough finishing can be obtained. Waterjet is currently employed also as cutting technique, generally to provide decorative designs (Figure 28)

Figure 28: a) waterjet cutting machine; b) marble slabs cut with waterjet cutting technology

Sand blasting

A high pressure jet of abrasive particles (such as silica sand, steel or pig iron grit, etc.) is applied on the stone surface. This treatment leaves the surface rough, but without sharp protrusions.

Resin application

The resin application is a technology generally applied to fragile or partially cracked stone slabs to consolidate and reinforce them, but it can be employed also to improve the reflection of stone surfaces and to protect them against water penetration. Polished slabs are firstly heated in ovens to completely dry them and facilitate the following chemical reaction with the resin. Secondly, epoxy resins or polyester resins are applied on one (or both) side of the slab (Figure 29a). When the stone slab is highly damaged, on its back side it is applied a fibreglass or nylon reinforcing net (Figure 29b). Then the slab pass through a second oven where it is dried again; finally, the front side of the slab is polished.

Despite this technology is currently not highly widespread among the Italian enterprises, it gives the possibility of taking advantage also of stone blocks with partial damages.

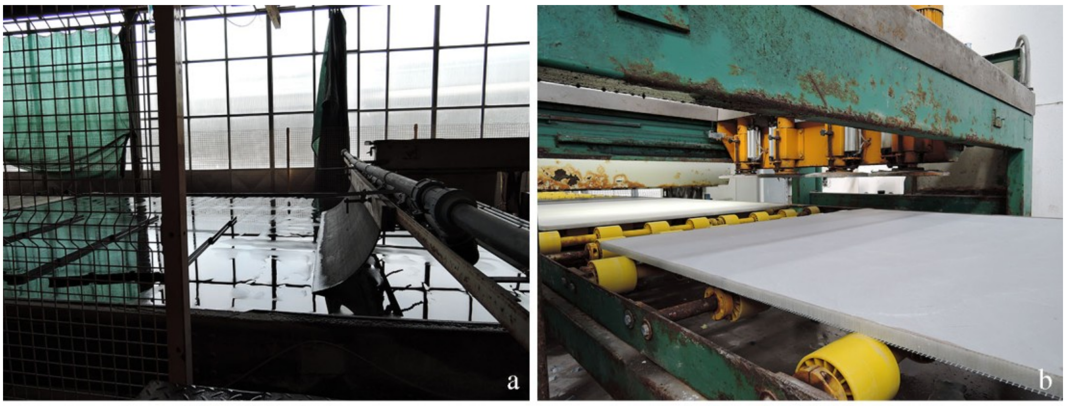


Figure 29: a) resin application on stone slabs; b) process of resin application to slabs with reinforcing net.

4.6 Extractive waste from stone supply chain

As introduced in Paragraph 1.5, during the processes of quarrying, cutting and finishing of ornamental stones, waste are produced. The global efficiency of the stone production chain is variable, but it is often quite low: a ratio of 0,3 between the quantity of finished stone products and the total quantity of extracted material is common. During the quarrying phase, the low efficiency is mainly due to the difficulty of predicting the quality of the stone before starting the primary cutting: the presence of discontinuities or not homogeneous areas can compromise both the mechanical characteristics and the aesthetical value of the stone product. Moreover, the loss of material can also be due to damages caused by the technologies themselves (such as, in particular, the dynamic splitting and the overturning of benches). Even if in minor measure, also the cutting and finishing of stone blocks into final products (such as slabs, tiles, etc.) are responsible of losses of material, which generally vary between the 5% and the 30%.

According to the Extractive Waste Directive (2006/21/EC), the waste from extractive industries should be managed by plans aiming to: i) prevent or reduce the waste production; ii) recovery the extractive waste through the recycling, reuse or reclaiming the waste; iii) ensure the safety of short and long-term disposal of the extractive waste.

Extractive waste from ornamental stone supply chain are quite heterogeneous, depending on the mineralogical characteristics of the stone, on the quarrying/cutting/finishing technique and on the specific tools employed.

The **quarrying activity** of both hard and soft stones produces solid extractive waste of irregular shape or small dimensions, which are not suitable for the production of slabs. This waste can be employed as cliff blocks, or for the production of paving stones or artworks; stone waste of smaller dimensions can be crushed as aggregated and used in the construction sector. Beyond the solid extractive waste, the quarrying activity is often responsible of other types of waste. As far as concern marble quarries, where drilling, diamond wire and chain cutting are the main technologies, waste water is generally produced. This latter is composed by water employed during the cutting, marble dust (mainly calcium carbonate), elements coming from the wear of cutting tools and in some cases residues of lubricants. In particular, since lubricants are employed just in the chain cutting process, in some quarries, waste water from this technology is treated separately. Waste water is collected within the quarry and then, through a pump, it is transferred to filter bags (Figure 30a) in order to reduce the humidity to the 40-50%. The filtered water is generally reused within the same quarry. Filter bags with marble waste are stocked for at least 30 days; the slurried extractive waste is then in part reused within the quarry (e.g. for overturning beds) and in part sent to authorised companies for the waste treatment. Some enterprises are currently

Figure 30: a) filter bag in a soft stone quarry; b) waste water from a hard stone quarry.

introducing in quarries also filter-press machineries to reduce the humidity more efficiently. As far as concern hard stone quarries where dynamic splitting technique is used, waste water (Figure 30b) is produced mainly as a consequence of the drilling and of water introduced in drilling holes (cf. Paragraph 4.3.1). In this waste water stone dust and elements from cutting and explosive tools are present. Generally, waste water from dynamic splitting is reintroduced in rivers without any treatments.

The **cutting and finishing processes** produce slurried waste, which is mainly composed by powder of the cut stone and by elements coming from the wear of the cutting and polishing tools employed. As a consequence, the chemical composition of the waste highly varies from enterprise to enterprise. Also the quantity is not constant, depending on the characteristics of the stone material, on the geometry of the product to realise and on the consequent technologies employed. Nevertheless, according to data collected in Carrara transformation plants, approximately the 30% of stone blocks used to produce 3 cm thick slabs, turns into waste during the cutting and polishing processes. In particular, about the 25% is lost during the cutting process, the 3% during the smoothing process and the 2% during the finishing process.

Waste water from the different cutting and finishing processes are, in most cases, gathered together and pumped (Figure 31a) in a silos where flocculants are added in the amount of about 2-3 g per m^3 of water. Flocculants are based on polyacrylamides and are necessary to separate particulate matter from the water (this latter is recovered and reused in cutting processes); the sludge part is then sent to a filter press machine (Figure 31b), where the humidity of the slurried

Figure 31: a) pumps sending waste water of stone cutting/finishing processes to the filter-press plant; b) filter-press plant; c) slurried extractive waste after the treatment.

waste reaches a water content of the 20-22% (Figure 31c) and other water is recovered. Considering the usage of filter presses and a final content of water of 22%, the approximate density of filter-pressed waste is 1,97 t/m^3. It results that cutting 1 m^2 of slab produces averagely about 38 kg of filter-pressed slurried waste and consumes 0,095 g of flocculants, while the surface treatments of smoothing and polishing of 1 m^2 of slab respectively produce about 5 kg and 3 kg of waste (for a related flocculant consumption of approximately 0,013 g and 0,0075 g). Often processing plants work in the same establishment with both soft and hard stones and for this reason the above mentioned quantities of slurried waste after the filter-press treatment are averages of soft and hard stone productions. Nevertheless, soft and hard stone processes could produce similar amounts of slurried waste since the quantity of stone dust deriving from the cutting of blocks into slabs probably not differ substantially and since the humidity rate reached by slurried waste through filter-presses is the same independently from the origin of the stone waste. Moreover, since the slurried waste from the cutting and polishing machineries in processing plants are generally collected and treated together, there is no availability of data on the specific quantities of slurried waste produced by each cutting technique.

In order to identify the possible treatments on the slurried extractive waste, this latter has to be characterized (Zichella et al., 2018). In Italy, chemical analyses on solid fractions in unaltered state (in accordance with Italian D.M. 04/05/2006 n. 186) and leaching test on eluate (in accordance with Italian D.M. 05/02/1998) are performed to determine the concentration of metals. The Italian Regulation D. Lgs. 152/06 establishes specific limits for the concentration of metals in the extractive waste. In case limits are exceeded, the waste has to be sent to specific disposals. When values are lower than the limits, the waste can be recovered. According to the European Waste Catalogue and Hazardous Waste

List (Environmental Protection Agency, 2002), the CER code of stone extractive waste is 01 04 13 (*wastes from stone cutting and sawing other than those mentioned in 01 04 07*), and according to EU Waste Framework Directive 2008/98, the recovery codes associated to this type of waste are R5 (*Recycling/reclamation of other inorganic materials*) and R13 (*Storage of wastes pending any of the operations numbered R1 to R12 (excluding temporary storage, pending collection, on the site where it is produced) through recycling/reclamation*). Different recovery treatments can be performed to slurried extractive waste; some of the most common recovery treatments are addressed to:

- the placement of waste into excavation voids
- the production of construction materials (such as cement)
- the production of calcium nitrate, employed in granular and liquid fertilizers (for carbonate waste);
- the neutralization of acid residues (e.g. neutralization of the residues of sulfuric acid from industries) (for carbonate waste)
- the desulfurization of combustion fumes (for carbonate waste)
- the paper production chain, as charge (calcium carbonate)
- the production of water paints (for carbonate waste)

Moreover, as explained in Paragraph 1.5, different research groups have proposed new or improved recovery treatments for stone slurried extractive waste, such as the usage for producing different types of concrete (Medina et al., 2017; Rana et al., 2016; Singh et al., 2016; Sogancioglu et al., 2016), as additives for the stabilisation of clayey soil (Sivrikaya et al., 2014) as fillers for asphalt pavements (Santagata et al., 2017), for structural geopolymer composites (Roper et al., 2015) and for glazed ceramic (Hastenreiter et al., 2017).

Therefore, the recovery of extractive waste can lead to many different solutions, which vary according to the specific physical and chemical characteristics of the specific slurried extractive waste.

Chapter 5

Life Cycle Inventory of techniques and technologies in the ornamental stone supply chain

This chapter provides details on the Life Cycle Inventory of techniques (Paragraph 5.1) and technologies/tools (Paragraph 5.2) commonly employed in quarries and processing plants of the ornamental stone supply chain. Table 1 summarizes the techniques and technologies that have been analysed and indicates the respective Paragraph of reference. To protect confidential and proprietary information of the enterprises that collaborated to the project, the flow values published in this thesis are the average of all the data collected. Minimum and maximum values are also showed, as well as the standard deviation, able to quantify the data uncertainty. Datasets have been modelled with Gabi software and secondary data from Gabi, Ecoinvent and ELCD databases were employed.

Note that LCI datasets often do not comprehend direct emissions to air/water/soil from the quarrying/cutting/finishing techniques because of scarce availability of data. Energy employed by filter-presses is as well not included in the inventory because of unavailability of information to correlate the quantity of waste water to the related consumption of electricity. Nevertheless, according to the stone enterprises which collaborated to the project, the energy consumption is limited to the use of pumps, requiring a low amount of energy in comparison to cutting machineries.

Table 1: List of the developed LCI datasets, with reference to the corresponding Paragraph where they are described.

LCI DATASET		PARAGRAPH
TECHNIQUES	Dynamic splitting	5.1.1
	Soft stone cutting with diamond wire technology	5.1.2
	Stone cutting with chain saw technology	5.1.3
	Soft stone quarrying	5.1.4
	Stone squaring/cutting with diamond mono-wire technology	5.1.5
	Stone cutting with diamond multi-wire technology	5.1.6
	Stone squaring/cutting with giant disk saw technology	5.1.7
	Stone cutting with bridge diamond disk saw technology	5.1.8
	Stone squaring with diamond mono-blade technology	5.1.9
	Stone cutting with diamond multi-blade saw technology	5.1.10
	Stone cutting with steel grit gang saws technology	5.1.11
	Surface treatment: smoothing to polishing	5.1.12
TECHNOLOGIES/TOOLS	Black powder	5.2.1
	Slow-burning fuses	5.2.2
	Detonators	5.2.3
	Detonation cords	5.2.4
	Drilling rods and bits	5.2.5
	Tungsten and tungsten carbide	5.2.6
	Sintered diamond wire	5.2.7
	Sintered diamond beads	5.2.8
	Diamond powder	5.2.9
	Grease	5.2.10
	Diamond disks	5.2.11
	Diamond sectors	5.2.12
	Metal matrix for cutting tools	5.2.13
	Diamond blade	5.2.14
	Metal abrasives	5.2.15
	Resin diamond abrasives	5.2.16
	Magnesite abrasives	5.2.17

5.1 LCI datasets of techniques in the ornamental stone supply chain

5.1.1 LCI of dynamic splitting

The reference unit of the dynamic splitting dataset is 1 m^3 of quarried hard stone block. Input data are the average of 10 Italian hard stone quarries and quantities of input flows have been calculated with reference to the total volume of stone extracted by each enterprise (and not to the commercial output yield).

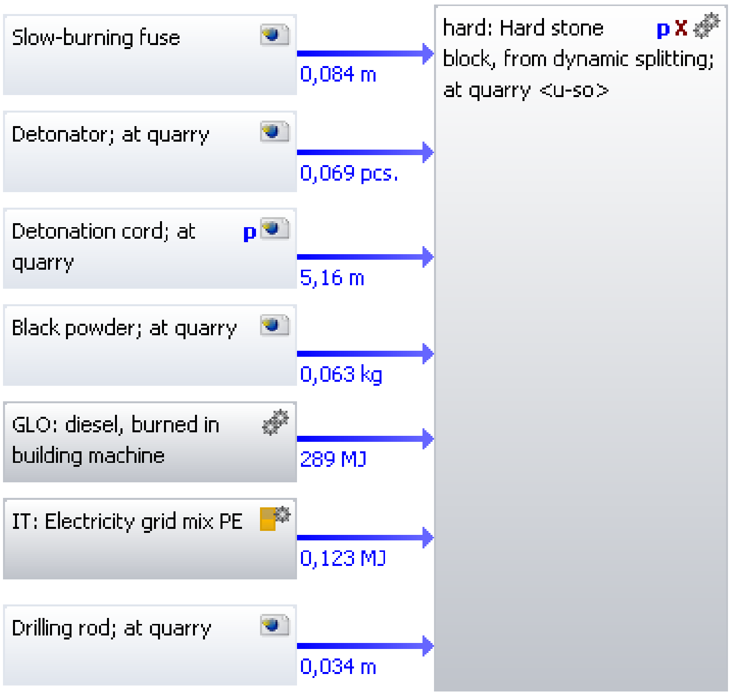
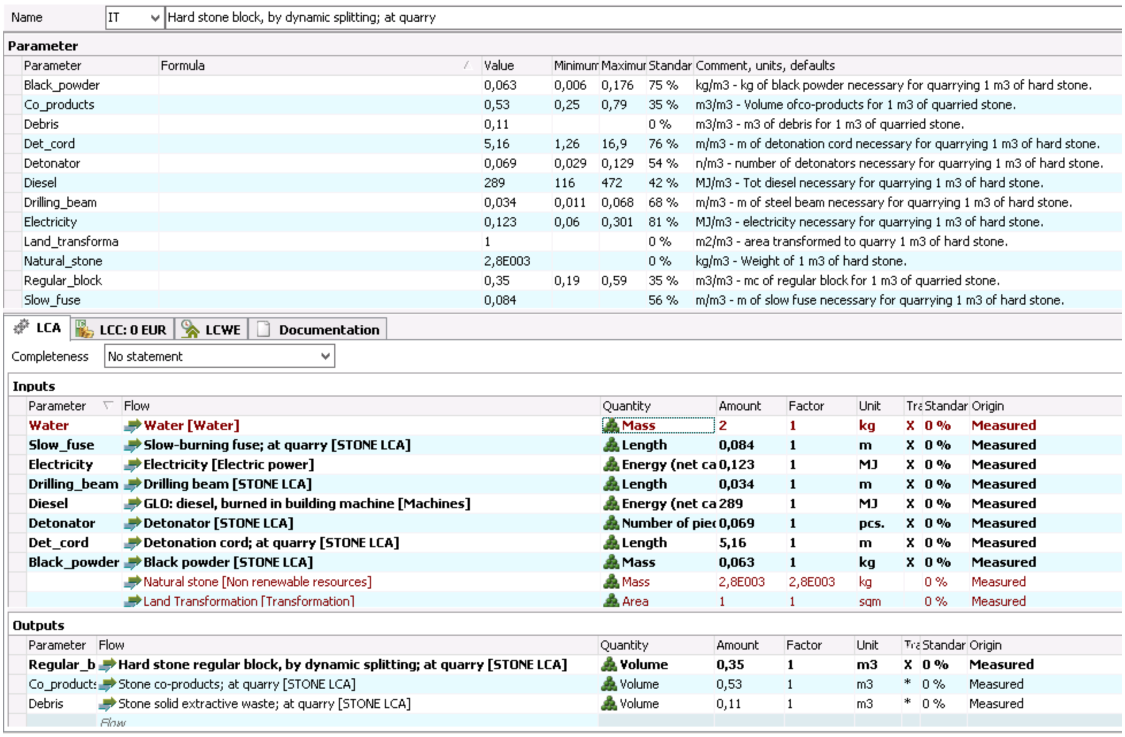


Figure 32: LCI dataset of 1 m^3 of hard stone quarried through dynamic splitting



Name: IT — Hard stone block, by dynamic splitting; at quarry

Parameter

Parameter	Formula	Value	Minimum	Maximum	Standar	Comment, units, defaults
Black_powder		0,063	0,006	0,176	75 %	kg/m3 - kg of black powder necessary for quarrying 1 m3 of hard stone.
Co_products		0,53	0,25	0,79	35 %	m3/m3 - Volume ofco-products for 1 m3 of quarried stone.
Debris		0,11			0 %	m3/m3 - m3 of debris for 1 m3 of quarried stone.
Det_cord		5,16	1,26	16,9	76 %	m/m3 - m of detonation cord necessary for quarrying 1 m3 of hard stone.
Detonator		0,069	0,029	0,129	54 %	n/m3 - number of detonators necessary for quarrying 1 m3 of hard stone.
Diesel		289	116	472	42 %	MJ/m3 - Tot diesel necessary for quarrying 1 m3 of hard stone.
Drilling_beam		0,034	0,011	0,068	68 %	m/m3 - m of steel beam necessary for quarrying 1 m3 of hard stone.
Electricity		0,123	0,06	0,301	81 %	MJ/m3 - electricity necessary for quarrying 1 m3 of hard stone.
Land_transforma		1			0 %	m2/m3 - area transformed to quarry 1 m3 of hard stone.
Natural_stone		2,8E003			0 %	kg/m3 - Weight of 1 m3 of hard stone.
Regular_block		0,35	0,19	0,59	35 %	m3/m3 - mc of regular block for 1 m3 of quarried stone.
Slow_fuse		0,084			56 %	m/m3 - m of slow fuse necessary for quarrying 1 m3 of hard stone.

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Completeness: No statement

Inputs

Parameter	Flow	Quantity	Amount	Factor	Unit	Tra	Standar	Origin
Water	Water [Water]	Mass	2	1	kg	X	0 %	Measured
Slow_fuse	Slow-burning fuse; at quarry [STONE LCA]	Length	0,084	1	m	X	0 %	Measured
Electricity	Electricity [Electric power]	Energy (net ca	0,123	1	MJ	X	0 %	Measured
Drilling_beam	Drilling beam [STONE LCA]	Length	0,034	1	m	X	0 %	Measured
Diesel	GLO: diesel, burned in building machine [Machines]	Energy (net ca	289	1	MJ	X	0 %	Measured
Detonator	Detonator [STONE LCA]	Number of piec	0,069	1	pcs.	X	0 %	Measured
Det_cord	Detonation cord; at quarry [STONE LCA]	Length	5,16	1	m	X	0 %	Measured
Black_powder	Black powder [STONE LCA]	Mass	0,063	1	kg	X	0 %	Measured
	Natural stone [Non renewable resources]	Mass	2,8E003	2,8E003	kg		0 %	Measured
	Land Transformation [Transformation]	Area	1	1	sqm		0 %	Measured

Outputs

Parameter	Flow	Quantity	Amount	Factor	Unit	Tra	Standar	Origin
Regular_b	Hard stone regular block, by dynamic splitting; at quarry [STONE LCA]	Volume	0,35	1	m3	X	0 %	Measured
Co_product:	Stone co-products; at quarry [STONE LCA]	Volume	0,53	1	m3	*	0 %	Measured
Debris	Stone solid extractive waste; at quarry [STONE LCA]	Volume	0,11	1	m3	*	0 %	Measured
	Flow							

Figure 33: setting of parameters, inputs and outputs for the LCI dataset of stone quarrying with dynamic splitting

This because the yield can highly vary from quarry to quarry and even within the same quarry. As a consequence this dataset has three outputs: gneiss regular blocks (which generally have a high commercial value), co-products (such as irregular blocks, having a lower commercial value) and solid extractive waste (not commercialized but with possibility to be employed in other production chains). The quantities set to each output flow are an average of all the data collected. Nevertheless the percentage of commercial blocks over the total extracted volume can edited through process parameters (Figure 33). The potential environmental impact of these output flows is managed through an economic allocation: according to primary data of 7 gneiss quarries, the allocation has been set with the values of 265 euro/m^3 for regular stone blocks, 7,14 euro/m^3 for irregular blocks and 0 euro/m^3 for solid extractive waste. Since these values are highly variable according to market trends and stone characteristics, also these economic values can be changed within the dataset model.

The system boundaries of this dataset comprehend: the holes drilling, the use of slow-burning fuses, detonators, detonation cords, black powder, diesel for machineries, electricity and water. Data on direct air emissions and on the quantity and characteristics of waste water were not available and consequently are not included in this LCI dataset. Information on specific quarries waste water may be found in the related permits for emission to surface water. Table 2 summarizes the inventory.

Table 2: Inventory of the dataset of stone quarrying with dynamic splitting, source of the flow values and the proposed correspondent reference processes.

	FLOW NAME	VALUE	DATA SOURCE	REFERENCE PROCESS
INPUTS	Electricity, IT grid mix [MJ]	0,123	-Hard stone quarries	Gabi: IT Electricity grid mix
	Diesel [MJ]	288,921	-Hard stone quarries	Ecoinvent: diesel, burned in building machine
	Drilling beam [m]	0,034	-Hard stone quarries	Created (cf. Par. 5.2.5): Drilling beam
	Black powder [kg]	0,063	-Hard stone quarries	Created (cf. Par. 5.2.1): Black powder

	Detonation cord [m]	5,156	-Hard stone quarries	Created (cf. Par. 5.2.4): Detonation cord
	Detonator [pcs]	0,069	-Hard stone quarries	Created (cf. Par. 5.2.3): Detonator
	Slow-burning fuse [m]	0,084	-Hard stone quarries	Created (cf. 5.2.2): Slow-burning fuse
	Water [kg]	2	-Calculated from hard stone quarries	Gabi: Water (Elementary flow)
	Natural stone [kg]	2800	Calculated	Gabi: Natural stone (Elementary flow)
	Land transformation [m^2]	1	Calculated	Gabi: Land transformation (Elementary flow)
OUTPUTS	Hard stone regular block, from dynamic splitting; at quarry [m^3]	0,35	-Hard stone quarries	-
	Stone co-products; at quarry [m^3]	0,53	-Hard stone quarries	-
	Stone solid extractive waste; at quarry [m^3]	0,11	Calculated	-

Table 3 shows the standard deviation of the primary data collected in quarries and the minimum and maximum values for each flow. As it can be noticed, the standard deviation is quite high, even in comparison with other techniques of the dimension stone supply chain. This is reasonably due to the different possible combinations of explosives that can be employed to perform the dynamic splitting: some quarries mostly employ black powder, some have higher consumes of penthrite (detonation cords, detonators, etc.), while in most cases the use is balanced between black powder and penthrite, with sporadic cases of usage of diamond wire cutting technology.

Table 3: Average value, standard deviation, minimum and maximum values of primary data employed in the dataset of stone quarrying with dynamic splitting technique.

	FLOW NAME	Average	St. deviation	% St. deviation	Min	Max
INPUTS	Electricity, IT grid mix [MJ]	0,123	0,1	81%	0,06	0,301
	Diesel [MJ]	288,921	122,177	42%	116,331	472,388
	Drilling beam [m]	0,034	0,023	68 %	0,011	0,068
	Black powder [kg]	0,063	0,047	75 %	0,006	0,176
	Detonation cord [m]	5,156	3,925	76 %	1,26	16,94
	Detonator [pcs]	0,069	0,037	54 %	0,029	0,129
	Slow burning fuse [m]	0,084	n.a.	n.a.	0,084	0,084
OUTPUTS	Hard stone regular block, from dynamic splitting; at quarry [m^3]	0,35	0,12	35%	0,19	0,59
	Co-products; at quarry [m^3]	0,53	0,19	35%	0,25	0,79

As explained in Paragraph 3.4, a Monte Carlo simulation has been run to evaluate in which measure the uncertainty on collected primary data could influence the related impact results. To this specific aim, a LCIA of the hard stone quarrying process has been carried out. The most recommended assessment methods (according to ILCD Handbook) have been chosen to respectively assess the potential climate change, ozone depletion and particulate matter/respiratory inorganics. To obtain robust results, the Monte Carlo simulation has been run with 1000 random parameter constellations. Table 4 lists the impact values obtained with the basis scenario, the mean value of the parameter constellations, the related standard deviation (in percentage) and the impact results at 10th and 95th percentiles. As it can be noticed, even if the primary inventory data had a quite large diffusion, the standard deviation on the impacts is generally lower, standing around 30% for all the three impact categories analysed.

Table 4: Uncertainty on LCIA results for the process of 1 m^3 of hard stone quarried with dynamic splitting. Results obtained with Monte Carlo simulation.

Impact category	Unit	Basis scenario	Mean value	Standard dev.	Percentile	
					10th	90th
IPCC global warming, incl. biogenic carbon	kg CO_2-eq.	27,7	28,2	28,6%	17,4	39
Ozone depletion, WMO model, ReCiPe	kg CFC-11 eq.	3,33E-6	3,38E-6	29,6%	2,03E-6	4,73E-6
Particulate matter/Respiratory inorganics, RiskPoll	kg PM2,5-eq.	0,0315	0,0319	29,8%	0,0192	0,0447

Figure 34 shows the distribution of the results obtained with Monte Carlo simulation. The three analysed impact categories show similar distributions: the form of the graph can be approximated to a Gaussian curve, which indicates a stable dataset, but, as expected from the standard deviation values reported in the previous table, the precision around the mean is not very high. This is due, as explained before, to the significant variability of resources and materials employed in the quarrying phase. For this reason, enterprises or researches wanting to carry out a specific stone supply chain LCA are encouraged to edit the dataset parameters to obtain more precise impact results.

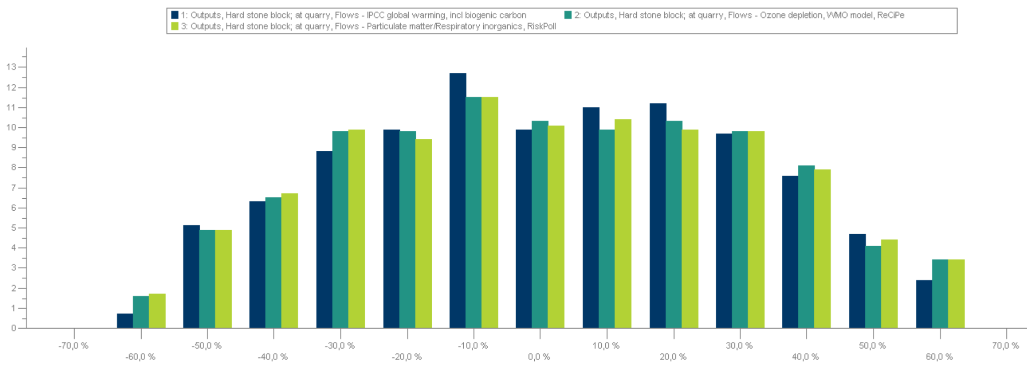


Figure 34: Distribution of LCIA results around the mean value for the process of quarrying 1 m^3 of hard stone with dynamic splitting.

5.1.2 LCI of soft stone cutting with diamond wire technology

This dataset describes this cutting technique with reference to Italian soft stone quarries. The boundaries of the dataset comprise energy and materials that are

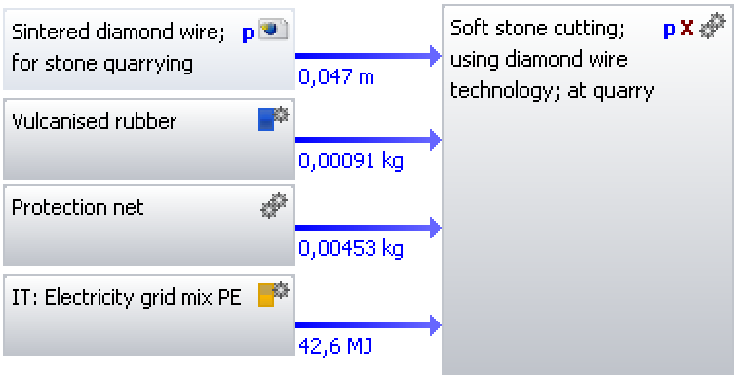


Figure 35: LCI dataset related to the cutting 1 m^2 of soft stone through the diamond wire technology

averagely consumed to cut 1 m^2 of marble, but do not include the previous drilling of holes (modelled as a separate dataset) and transportation of blocks within the quarry. Because of unavailability of data, direct emissions to air, water and soil produced by this technology are not included in the LCI dataset. Figure 35 shows the dataset model. As it can be noticed, the model includes inputs of diamond wires, vulcanised rubber, protection net and electricity. In particular, the **diamond wire** input refers to sintered diamond wires (cf. Paragraph 5.2.7), commonly employed in Italian quarries to separate benches from the quarry bedrock and divide them into blocks; the seal in **vulcanised rubber** (or polyurethane) is commonly employed to create a bearing between metallic pulleys and diamond wires, while a **protection net**, in Kevlar and Teflon, is placed along the entire length of the wire in order to stop wire elements in case of brakeage and whiplashes. The protection net is generally commercialized in rolls and, before starting the cutting, it is placed in a roller allowing its elongation at the same time of the machine moving. The outputs of this dataset are two: the cutting of 1 m^2 of soft stone and the slurried extractive waste produced during the process (considering the reduction of humidity at 45% with filter bags).

Table 5 lists the average value of each flow, the sources where these data have been collected (enterprise names are not declared for confidential reasons) and the reference processes used for modelling the dataset. In relation to the average value of the input flows, Table 6 lists the correspondent standard deviation (in absolute value and in percentage) and the minimum and maximum values.

Table 5: Inventory of the dataset of stone cutting with diamond wire technology, source of the flow values and the proposed correspondent reference processes.

	FLOW NAME	VALUE	DATA SOURCE	DATABASE PROCESS
INPUTS	Sintered diamond wire; for stone quarrying [m]	0,047	-Soft stone quarries	Created (cf. Par. 5.2.7): Sintered diamond wire; for stone quarrying
	Vulcanised rubber [kg]	0,0009	-Soft stone quarries	Gabi: Styrene-Butadiene Rubber (SBR) Mix
	Protection net [kg]	0,004	-Soft stone quarries	Ecoinvent: tetrafluoroethylene, at plant
	Electricity, IT grid mix [MJ]	42,63	-Soft stone quarries	Gabi: IT Electricity grid mix
OUTPUTS	Soft stone cutting; using diamond wire technology; at quarry [m^2]	1	-Soft stone quarries	-
	Slurried extractive waste; from stone quarrying [kg]	47	-Soft stone quarries -Literature	-

Table 6: Average value, standard deviation, minimum and maximum values of primary data employed in the dataset of stone cutting with diamond wire technology.

	FLOW NAME	Average	St. deviation	% St. dev.	Min	Max
INPUTS	Sintered diamond wire; for stone quarry	0,047	0,059	32%	0,11	0,25
	Vulcanised rubber	0,009	0,00013	14%	0,00081	0,00099
	Protection net	0,004	n.a.	n.a.	0,004	0,004
	Electricity, IT grid mix	42,63	7,63	18%	33,72	52,27

A Monte Carlo simulation has been run to evaluate in which measure the primary data uncertainty influences the related environmental impact results. To this aim, the LCIA of the diamond wire technology has been developed, using the two assessment methods of I level quality (according to the ILCD Handbook), which are respectively related to the impact categories of climate change and particulate matter/respiratory inorganics. Monte Carlo simulation has been run with 1000 random parameter constellations and in Table 7 are listed the main results. As it can be noticed from the table and from Figure 36, the distribution for both the impact categories is quite narrow, and the standard deviation stands around 10%. Nevertheless, impact categories majorly depending on protection net process (such as the Ozone depletion) could be interested by higher distributions. Therefore, the uncertainty on the protection net is not available because just 1 quarry declared the consumption of this material.

Table 7: Uncertainty on LCIA results for the process of cutting 1 m^2 of soft stone with diamond wire technology. Results obtained with Monte Carlo simulation.

Impact category	**Unit**	**Basis scenario**	**Mean value**	**Standard dev.**	**Percentile**	
					10th	**90th**
IPCC global warming, incl biogenic carbon	kg CO_2-eq.	8,33	8,37	9,1%	7,34	9,43
Ozone depletion, WMO model, ReCiPe	kg CFC-11 eq.	4,27E-05	4,27E-05	0,0004%	4,27E-05	4,27E-05
Particulate matter/Respiratory inorganics, RiskPoll	kg $PM_{2,5}$-eq.	0,000882	0,000885	10,4%	0,000761	0,00101

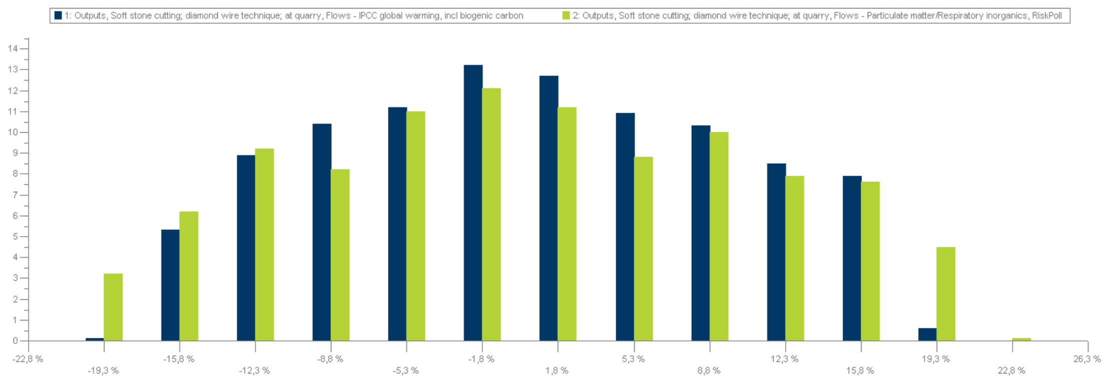


Figure 36: Distribution of LCIA results around the mean value for the process of cutting 1 m^2 of soft stone with diamond wire technology.

5.1.3 LCI of soft stone cutting with chain saw technology

The cutting technique with chain saw is often complementary to the technique with diamond wire (cf. Paragraph 4.3.3). The related LC inventory dataset was modeled according to primary data from Gioia quarry (Carrara), with the integration of secondary data from technical sheets. During the execution of this technique, abrasive inserts, grease, electricity and water are consumed. Nevertheless, since the water is recycled from the drilling process, it has not been inserted among the input flows. Because of unavailability of data, direct emissions to air, water and soil are not included in the LCI dataset. Table 8 shows the inventory of this dataset and Figure 37 shows the related model.

Table 8: Inventory of the dataset of soft stone bench cutting with chain technology, source of the flow values and the proposed correspondent reference processes.

	FLOW NAME	VALUE	DATA SOURCE	REFERENCE PROCESS
INPUTS	Electricity, IT grid mix [MJ]	22,3	-Soft stone quarry -Technical sheets	Gabi: IT Electricity grid mix
	Grease [kg]	0,36	-Soft stone quarry	Literature
	Abrasive insert [kg]	0,00463	-Soft stone quarry	Created (cf. Par. 5.2.6): Tungsten carbide
OUTPUTS	Soft stone cutting; using chain technology; at quarry [m^2]	1	-Soft stone quarry	-
	Slurried extractive waste; from stone quarrying [kg]	47	-Soft stone quarries -Literature	-

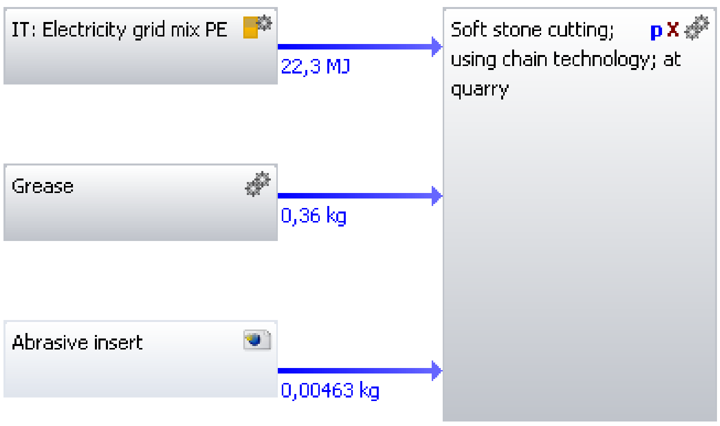


Figure 37: LCI dataset related to the cutting 1 m^2 of soft stone through the chain saw technology

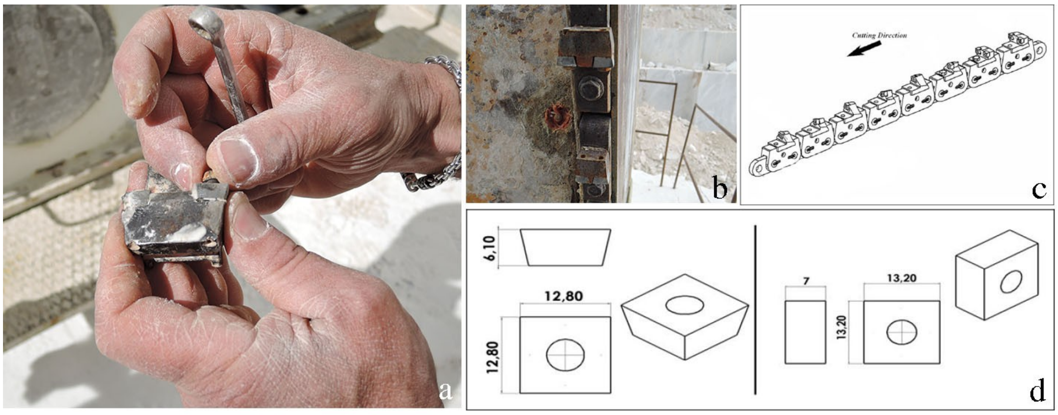


Figure 38: a-b) chain bars with four-edges inserts; c) draw of a chain body with single and paired inserts (source: Sariisik and Sariisik, 2013); d) geometries of a four-edges insert (left) and eight-edges insert (right) (source: Sariisik and Sariisik, 2013)

Abrasive inserts, assembled on the rotating chain, are made of tungsten carbide (widia) or, for harder stones, in polycrystalline diamond. Two types of inserts are available on the market: four-edges inserts and eight-edges inserts, as showed in Figure 38. When an edge is worn, inserts are rotated to expose another cutting edge and when all the edges are worn out inserts are replaced with new ones. The weight of four- and eight-edges inserts is respectively of 10 and 15 g. Inserts are assembled on the chain with specific sequences to maximize the cutting efficiency. The LC dataset is referred to a chain cutter having a 3 meters long arm, where 9 sequences with the same cutting pattern are repeated. Each sequence is composed by 6 bars for a single insert + 3 bars for paired inserts, for a total of 12 inserts for each sequence and 9x12 = 108 inserts along all the chain. Since both 4-edges and 8-edges inserts are common in quarries, the input flow has been calculated considering average inserts of the weight of 12,5 g. Since the available databases did not contain the LC dataset on tungsten carbide, this latter has been modeled from secondary data (cf. Paragraph 5.2.6).

Grease is employed to assure a proper lubrication to the chain during the cutting. Problems connected to emissions of mineral oils and greases into the environment, lead to the development and use of biodegradable lubricants in order to minimize the risk of aquifer contamination. The grease LCI dataset has been modeled on the basis of the European Addnano project (https://sites.google.com/site/addnanoeu/) (cf. Paragraph 5.2.10).

5.1.4 LCI of soft stone quarrying

Life Cycle Datasets of soft stone cutting techniques have been combined to create a LC model of soft stone quarrying. The Functional Unit of this dataset is 1 m^3 of soft stone detached from the quarry bedrock and cut into a commercial block of average dimension 3x2x2 m^3. The dataset has been developed with reference to a stone bench measuring 17x3x8 m^3, where it is assumed that the primary cut is carried out with the chain cutting technology (for the base of the bench) and with the drilling + diamond wire cutting technology (for the other sides of the bench). The secondary cut into commercial blocks is assumed to be obtained through the diamond wire cutting technology. These assumptions have been based on primary data collected in Gioia quarry (Carrara). Figure 39 illustrates the dataset model and Table 9 shows the related inventory.

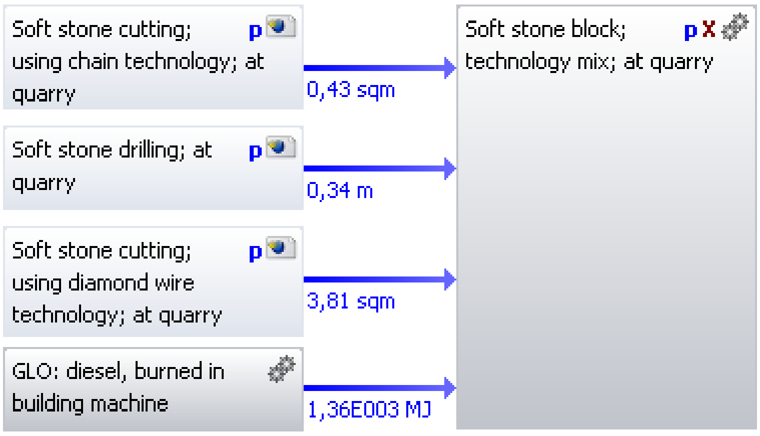


Figure 39: LCI dataset of 1 m^3 of soft stone quarried through chain saw + diamond wire technologies

Table 9: Inventory of the dataset of soft stone quarrying, source of the flow values and the proposed correspondent reference processes.

	FLOW NAME	VALUE	DATA SOURCE	REFERENCE PROCESS
INPUTS	Soft stone cutting; using chain technology; at quarry [m^2]	0,43	-Calculated from soft stone quarry data	Created (cf. Par. 5.1.3): Soft stone cutting; using chain technology; at quarry
INPUTS	Soft stone drilling; at quarry [m]	0,34	-Calculated from soft	Created: Soft stone drilling; at

			stone quarry data	quarry
	Soft stone cutting; using diamond wire technology; at quarry [m^2]	3,81	-Calculated from soft stone quarry data	Created (cf. Par. 5.1.2.): Soft stone cutting; using diamond wire technology; at quarry
	Water [kg]	2,84	-Soft stone quarry	Gabi: Water (Elementary flow)
	Diesel, burned [MJ]	1360	-Soft stone quarries	Ecoinvent: diesel, burned in building machine
	Natural stone [kg]	9530	-Calculated (d=2800 kg/m^3)	Gabi: Natural stone (non-renewable resources)
	Land transformation [m^2]	4,25	-Calculated	Gabi: Land Transformation (Transformation)
OUTPUTS	Soft stone block; technology mix; at quarry [m^3]	1	-Soft stone quarries	-
	Stone co-products; at quarry [m^3]	1,7	-Calculated from soft stone quarry data	-
	Stone solid extractive waste; at quarry [m^3]	0,67	-Calculated from soft stone quarry data	-

The value of diesel burned in quarrying machineries is the average from 4 marble quarries (with standard deviation of 49%), while the input value of water is affected by the highest uncertainty. This because the water consumption is generally not registered in quarries, and the value has been provided by a single marble enterprise.

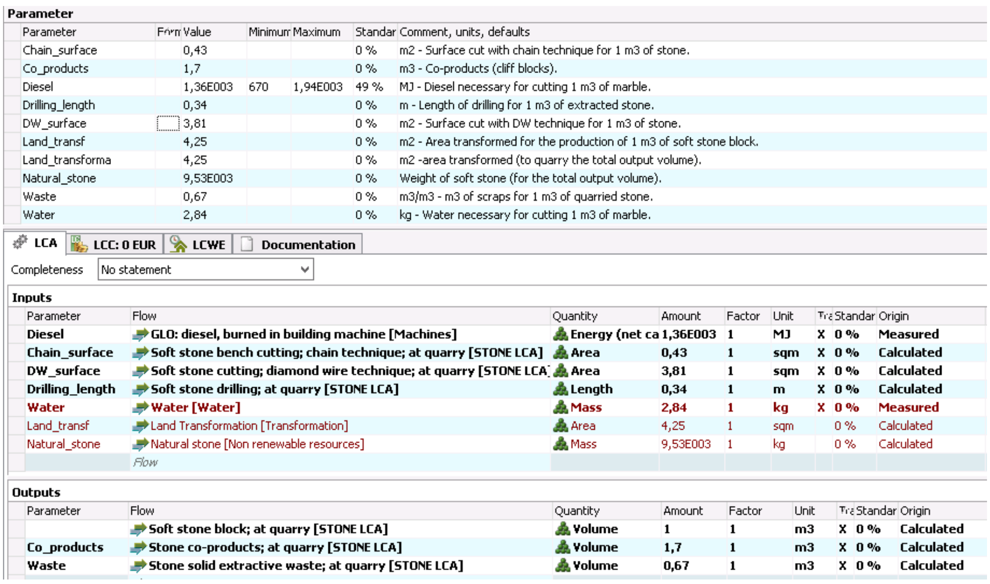
According to data provided by 3 marble quarries, the average outputs consist in: 29% of good quality stone blocks, 51% of stone co-products (such as cliff blocks) and 20% of stone solid extractive waste. To deal with these multiple outputs, it has been necessary to allocate the impacts to the different outputs.

Since all the outputs are made of the same material, but have very different economic values, the allocation has been based on a price criteria. In particular, the following price values have been set in the correspondent output flows:

- good quality blocks = 1680 euro/m^3
- irregular blocks = 7 euro/m^3;
- stone solid extractive waste = 0 euro/m^3;

These average selling prices have been declared by a marble enterprise that collaborated to the project. They are highly variable (depending on the material quarried and on the market), but, in any case, the value of good quality blocks is always much higher than the value of the other two outputs, and as a consequence almost all the impacts of the quarrying processes will be connected to the production of good quality blocks. Despite stone extractive waste (especially from marble quarries) are sometimes reemployed in other production chains (cf. Paragraph 1.5), in the current situation their economic value is generally null. The quantities of slurry waste produced by cutting techniques have been inserted in the LC model of the corresponding technologies (cf. Paragraph 5.1.2-5.1.3).

All the values are set through the use of parameters which can be easily modified to adapt the dataset to specific supply chains (Figure 40).


Parameter

Parameter	Form	Value	Minimum	Maximum	Standar	Comment, units, defaults
Chain_surface		0,43			0 %	m2 - Surface cut with chain technique for 1 m3 of stone.
Co_products		1,7			0 %	m3 - Co-products (cliff blocks).
Diesel		1,36E003	670	1,94E003	49 %	MJ - Diesel necessary for cutting 1 m3 of marble.
Drilling_length		0,34			0 %	m - Length of drilling for 1 m3 of extracted stone.
DW_surface		3,81			0 %	m2 - Surface cut with DW technique for 1 m3 of stone.
Land_transf		4,25			0 %	m2 - Area transformed for the production of 1 m3 of soft stone block.
Land_transforma		4,25			0 %	m2 -area transformed (to quarry the total output volume).
Natural_stone		9,53E003			0 %	Weight of soft stone (for the total output volume).
Waste		0,67			0 %	m3/m3 - m3 of scraps for 1 m3 of quarried stone.
Water		2,84			0 %	kg - Water necessary for cutting 1 m3 of marble.

LCA | LCC: 0 EUR | LCWE | Documentation

Completeness: No statement

Inputs

Parameter	Flow	Quantity	Amount	Factor	Unit	Tra	Standar	Origin
Diesel	GLO: diesel, burned in building machine [Machines]	Energy (net ca	1,36E003	1	MJ	X	0 %	Measured
Chain_surface	Soft stone bench cutting; chain technique; at quarry [STONE LCA]	Area	0,43	1	sqm	X	0 %	Calculated
DW_surface	Soft stone cutting; diamond wire technique; at quarry [STONE LCA	Area	3,81	1	sqm	X	0 %	Calculated
Drilling_length	Soft stone drilling; at quarry [STONE LCA]	Length	0,34	1	m	X	0 %	Calculated
Water	Water [Water]	Mass	2,84	1	kg	X	0 %	Measured
Land_transf	Land Transformation [Transformation]	Area	4,25	1	sqm		0 %	Calculated
Natural_stone	Natural stone [Non renewable resources]	Mass	9,53E003	1	kg		0 %	Calculated
	Flow							

Outputs

Parameter	Flow	Quantity	Amount	Factor	Unit	Tra	Standar	Origin
	Soft stone block; at quarry [STONE LCA]	Volume	1	1	m3	X	0 %	Calculated
Co_products	Stone co-products; at quarry [STONE LCA]	Volume	1,7	1	m3	X	0 %	Calculated
Waste	Stone solid extractive waste; at quarry [STONE LCA]	Volume	0,67	1	m3	X	0 %	Calculated

Figure 40: setting of parameters, inputs and outputs for the LCI dataset of soft stone quarrying

5.1.5 LCI of stone squaring/cutting with diamond mono-wire technology

Mono diamond wire machineries are used to square and cut soft and hard stone blocks (cf. Paragraph 4.4.1). Since the resources necessary to cut 1 m^2 with this technology highly vary according to the hardness of the stone, two datasets were created. Table 10 shows the respective inventories, while Table 11 and Table 12 are respectively related to the uncertainty of squaring/cutting datasets of soft and hard stones. These datasets have been modeled on the basis of primary data from three enterprises (located in Verbano Cusio Ossola province and in Carrara district) and of secondary data from technical sheets (Pedrini, Cofiplast, Diamond board, Breton, SimecWire). Because of unavailability of data, this dataset does not contain information on direct emissions to air, water, soil.

Table 10:Inventory of the dataset of stone squaring/cutting with diamond mono-wire technology, source of the flow values and the proposed correspondent reference processes.

	FLOW NAME	VALUE		DATA SOURCE	DATABASE PROCESS
		Soft stones	Hard stones		
INPUTS	Electricity [MJ]	21,87	91,68	-Hard stone transformation plants	Gabi: IT Electricity grid mix
	Diamond wire [m]	0,015	0,072	-Hard stone transformation plants	Created (cf. Par. 5.2.7): Sintered diamond wire
	Water [kg]	4,34	44,93	-Hard stone transformation plants	Gabi: Tap water
	Flocculant [kg]	9,5 E-5	9,5 E-5	-Calculated from transformation plants and literature data	Ecoinvent: polyacrylamide production, cut-off, S

OUTPUTS	Stone block squaring/cutting; by diamond mono-wire [m^2]	1	1	-	-
	Slurried extractive waste; from stone cutting/polishing [kg]	38	38	-Calculated from transformation plants and literature data	-

Table 11: Average value, standard deviation, minimum and maximum values of primary data for the dataset of soft stone squaring/cutting with diamond mono-wire.

	FLOW NAME	Average	St. deviation	% St. deviation	Min	Max
INPUTS	Electricity [MJ]	21,87	11,00	50%	15,12	34,56
	Diamond wire [m]	0,015	0,0004	28%	0,01	0,02
	Water [kg]	4,34	1,90	44%	3,00	5,68
OUTPUTS	Soft stone block squaring/cutting; using diamond mono-wire technology; at plant [m^2]	1	-	-	-	-

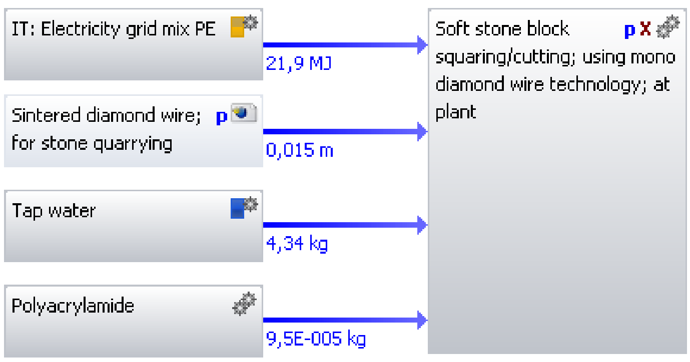


Figure 41: LCI dataset of 1 m^2 of soft stone cut with diamond mono-wire technology

Table 12: Average value, standard deviation, minimum and maximum values of data employed in the dataset of hard stone squaring/cutting with mono diamond wire.

	FLOW NAME	Average	St. deviation	% St. deviation	Min	Max
INPUTS	Electricity [MJ]	91,68	19,22	21%	69,12	115,20
	Diamond wire [m]	0,072	0,0051	7%	0,0668	0,0769
	Water [kg]	44,93	17,46	39%	24	64
OUTPUT	Hard stone block squaring/cutting; using diamond mono-wire technology; at plant [m^2]	1	-	-	-	-

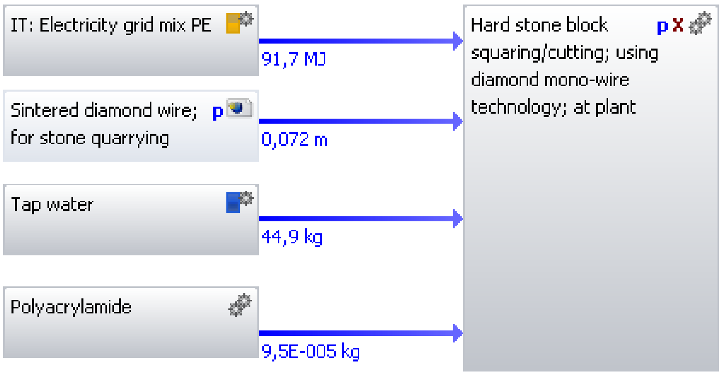


Figure 42: LCI dataset of 1 m^2 of hard stone cut with mono-diamond wire technology

As explained in Paragraph 3.4, Monte Carlo simulations have been run to evaluate the stability of impact results of the two described datasets. The impact categories that were analyzed are the climate change, ozone depletion and particulate matter/respiratory inorganics, since the related impact assessment methods have been classified as the most reliable by the European Commission (ILCD Handbook). Monte Carlo simulations have been run with 1000 random parameter constellations. Table 13/Figure 43 and Table 14/Figure 44 are related to the datasets of squaring with mono diamond wire respectively of soft and hard stones. As it can be noticed, the LCI dataset of hard stone squaring/cutting has a minor distribution of the LCIA impacts; nevertheless, also for the soft stone dataset, the distribution on impact results is not particularly high. In both cases the ozone depletion category is the least affected by the primary data uncertainty.

Table 13: Uncertainty on LCIA results for the process of squaring/cutting 1 m^2 of soft stone with mono diamond wire technology. Results obtained with Monte Carlo simulation.

Impact category	**Unit**	**Basis scenario**	**Mean value**	**Standard dev.**	**Percentile**	
					10th	**90th**
IPCC global warming, incl biogenic carbon	kg CO_2-eq.	3,5	3,87	21,5%	2,76	5,03
Ozone depletion, WMO model, ReCiPe	kg CFC-11 eq.	7,18E-10	7,75E-10	17,3%	6,05E-10	9,60E-10
Particulate matter/Respiratory inorganics,RiskPoll	kg $PM_{2,5}$-eq.	0,000428	0,000472	21,2%	0,000338	0,000613

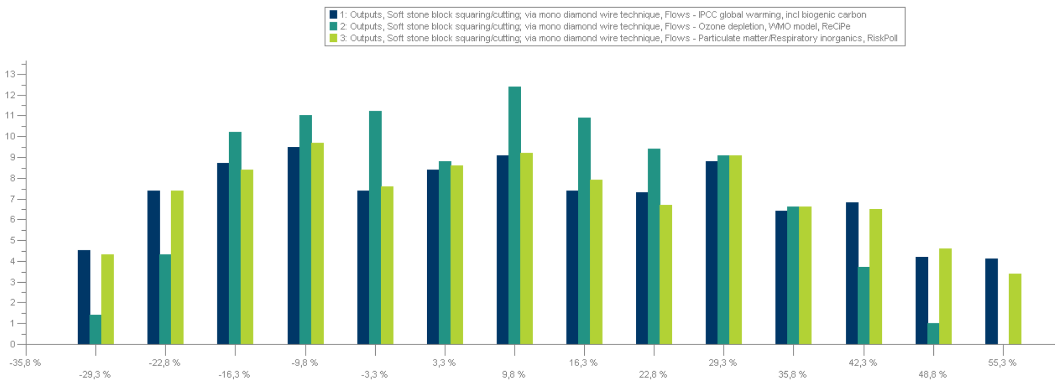


Figure 43: Distribution of LCIA results around the mean value for the process of soft stone squaring/cutting with the mono diamond wire technology.

Table 14: Uncertainty on LCIA results for the process of squaring/cutting 1 m^2 of hard stone with diamond mono-wire technology. Obtained with Monte Carlo simulation.

Impact category	**Unit**	**Basis scenario**	**Mean value**	**Standard dev.**	**Percentile**	
					10th	**90th**
IPCC global warming, incl biogenic carbon	kg CO_2-Equiv.	14,7	14,8	12,9%	12,2	17,5
Ozone depletion, WMO model, ReCiPe	kg CFC-11 eq	3,12E-09	3,14E-09	9,5%	2,74E-09	3,56E-09
Particulate matter/Respiratory inorganics, RiskPoll	kg $PM_{2,5}$-Equiv.	0,0018	0,00181	12,7%	0,0015	0,00214

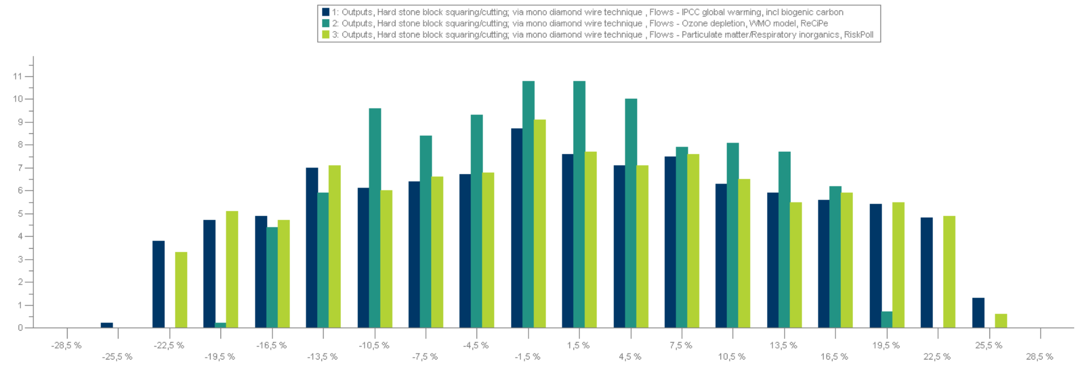


Figure 44: Distribution of LCIA results around the mean value for the process of hard stone squaring/cutting with diamond mono-wire technology.

5.1.6 LCI of hard stone cutting with diamond multi-wire technology

The multi-wire technology makes use of a set of diamond wires to cut stone blocks into slabs (cf. Paragraph 4.4.6). In Italy this technology is mostly used to cut hard stones and even if its diffusion is currently quite low, in the next future it could be more and more employed as an alternative to the steel grit multi-blade technology. The LCI dataset has been calculated basing on primary data provided by a transformation plant in Carrara district and by Mega Diamant enterprise and on secondary data from Breton technical sheets (in particular related to the GS220 F64-P93 multiwire machine model). This dataset is referred to an average cutting of 33 slabs/m of block thickness, with cutting speed of each wire of 1 m^2/h and a wire performance of 12m^2/m. A water re-circulation system is generally employed in transformation plants and the cooling water integration has been assumed to be the 2% of the total volume of cooling water. During the process slurry waste is produced. Data on direct emissions of this process were not available and are consequently not included in the dataset. Table 15 lists the inventory, while Figure 45 shows the LC model of the dataset. The flow values are regulated by parameters, which can eventually be edited for adapting the dataset to specific production chains.

Table 15: Inventory of the dataset of stone cutting with diamond multi-wire technology, source of the flow values and the proposed correspondent reference processes.

	FLOW NAME	VALUE	DATA SOURCE	REFERENCE PROCESS
IN	Electricity [MJ]	18	-Transformation	Gabi:

			plant -Tool producer -Technical sheet	IT Electricity grid mix
	Diamond wire [m]	0,083	-Transformation plant -Tool producer -Technical sheet	Created (cf. Par. 5.2.7): Sintered diamond wire
	Water [kg]	50,4	-Transformation plant -Tool producer -Technical sheet	Gabi: Tap water
	Flocculant [kg]	9,5 E-5	Calculated from transformation plants and literature data	Ecoinvent: polyacrylamide production, cut-off, S
OUTPUTS	Stone block squaring/cutting; using diamond multi-wire technology; at plant [m^2]	1	-	-
	Slurried extractive waste; from stone cutting/polishing [kg]	38	-Calculated from transformation plants and literature data	-

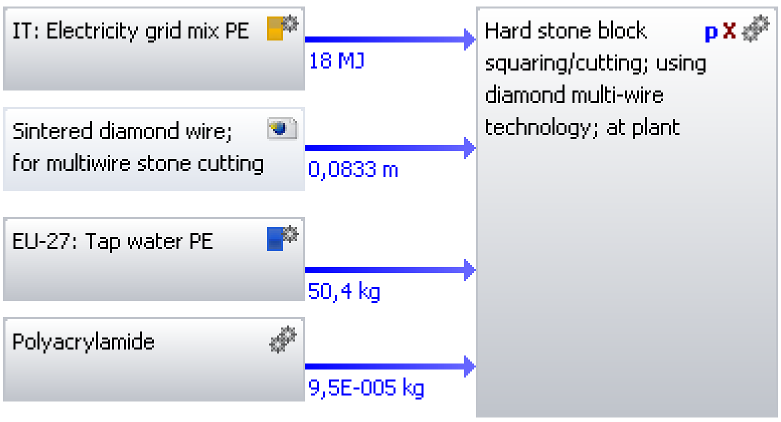


Figure 45: LCI dataset of 1 m^2 of hard stone cut with diamond multi-wire technology

5.1.7 LCI of stone squaring/cutting with giant disk saw technology

Giant disks are commonly used in hard stone transformation plants to square irregular blocks or to cut thick slabs according to the requests of customers. The corresponding dataset is referred to primary data collected from transformation plants of Chiri (Santena), Rinaudo (Scarnafigi) and Agifin (Piedimulera), and to secondary data collected in technical sheets of GMM (Gravellona Macchine Marmo), Pedrini, Winterstone and Dellas.

Table 16 and 17 respectively show the inventory of giant disk cutting and the uncertainty on collected data.

Table 16: Inventory of the dataset of squaring/cutting with giant disks, source of the flow values and the proposed correspondent reference processes.

	FLOW NAME	VALUE	DATA SOURCE	REFERENCE PROCESS
INPUTS	Electricity [MJ]	178	-Transformation plants	Gabi: IT Electricity grid mix
	Giant diamond disk [pcs]	0,00167	-Transformation plants	Created (cf. Par. 5.211) Giant diamond disk
	Water [kg]	35	-Transformation plants -Technical sheets	Gabi: Water (Elementary flow)
	Flocculant [kg]	9,5 E-5	Calculated from transformation plants and literature data	Ecoinvent: polyacrylamide production, cut-off, S
OUTPUTS	Hard stone cutting; using giant disk technology; at plant [m^2]	1	-	-
	Steel scrap [kg]	0,021	Calculated	-

	Slurried extractive waste; from stone cutting/polishing [kg]	38	-Calculated from transformation plants and literature data	-

Table 17: Average value, standard deviation, minimum and maximum values of primary data employed in the dataset of stone cutting with diamond wire technology.

	FLOW NAME	Average	St. dev.	% St. dev.	Min	Max
INPUTS	Electricity [MJ]	178	68	39%	120	254
	Giant diamond disk [pcs]	0,00167	0,00047	28%	0,0013	0,002
	Water [kg]	34,9	6,4	18%	30,4	39,4
	Hard stone cutting; using giant disk technology; at plant [m^2]	1	-	-	-	-

To evaluate the influence of dataset uncertainty on impact results, a Monte Carlo simulation has been run with 1000 random iterations. The analysis is based on the impact categories of climate change, ozone depletion and particulate matter/respiratory inorganics, assessed through the methods defined of I level quality in the ILCD Handbook. Table 18 lists the impact values obtained with the basis scenario, the mean value of the parameter constellations, the related standard deviation (in percentage) and the impact results at 10^{th} and 90^{th} percentiles. From these data and from the graph showed in Figure 46 it can be deduced that the dataset causes limited dispersions of impact results. In particular, the Ozone depletion results are the less affected by the data uncertainty, with a standard deviation of 10%, while the most affected impact category is the climate change, showing a wider diffusion and a standard deviation of 18%.

Table 18: Uncertainty on LCIA results for the process of cutting 1 m^2 of hard stone with giant disk technology. Results obtained with Monte Carlo simulation.

Impact category	Unit	Basis scenario	Mean value	Standard dev.	Percentile	
					10^{th}	90^{th}
IPCC global warming, incl biogenic carbon	kg CO_2-Equiv.	29,4	30,3	18,4%	22,7	38,3

Ozone depletion, WMO model, ReCiPe	kg CFC-11 eq	1,61E-08	1,61E-08	10,1%	1,40E-08	1,83E-08
Particulate matter/ Respiratory inorganics, RiskPoll	kg PM2,5-Equiv.	0,00396	0,00406	16,6%	0,00315	0,00502

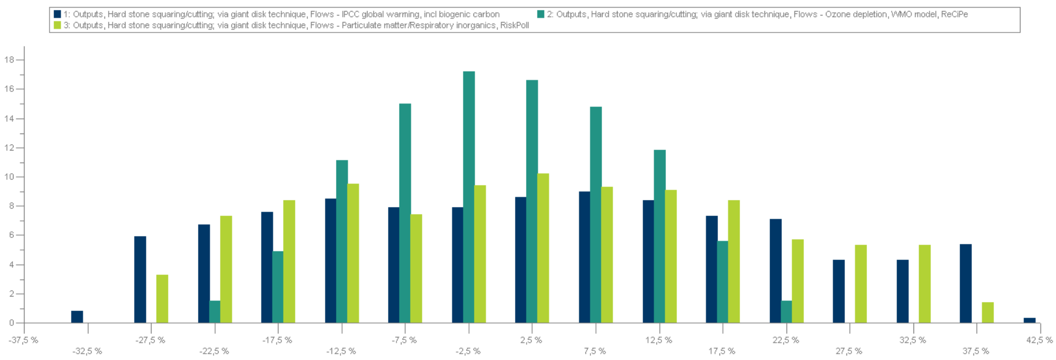


Figure 46: Distribution of LCIA results around the mean value for the process of cutting 1 m^2 of hard stone with giant disk technology.

5.1.8 LCI of stone cutting with bridge diamond disk saw technology

The bridge diamond disk saw technology is commonly employed for cutting stone slabs into smaller parts. Despite the process is the same for both hard and soft stones, four separate datasets have been created in order to partly take into account the high variability of disks wear, cutting speed and disks dimensions.

To cut hard stones, disks abrade a stone layer of 2-4 mm for each stroke, while with softer stones the disk is able to directly cut several centimeters of material (about 10 cm). According to Stein Varz enterprise, the average cutting speed [m^2/h] of disks in soft stones is about 2-3 times higher than in hard materials and the life time of diamond sectors (in terms of total cut area) is about 10 times higher.

Table 19 resumes the average values of diamond sectors geometry, cutting speed and disk lifetime in reference to disks of different size employed with hard stones (primary data from Stein Varz enterprise).

Table 19: average disks characteristics in relation to their diameter

Disk diameter [mm]	**500**	**1000**	**1500**	**2000**	**3500**
Thickness steel core [mm]	2,8	5	7	8	9,5
Sector thickness [mm]	3,8	6,5	9	10,5	13
Sector height [mm]	10-20	15-20	20-30	20-30	30
% of disk perimeter covered by diamond sectors	60%	70%	70%	70%	70%
Diamond sectors lifetime (for granite) [m²]	100	200	500	800	1200
Average speed (for granite) [m²/ h]	3-4	3	2,5-3	2,5-3	3

The disk dimension is chosen according to the thickness of the slab to cut: for low thicknesses (about 2-12 cm) disks with diameter <600 mm are employed; for cutting 10-15 cm slabs a disk of about 600 mm diameter is required, while to cut 30 cm slabs are employed disks with diameter of about 1000 mm.

The datasets that have been modeled are the following ones:

- Hard stone cutting; with diamond disk; d<600mm
- Soft stone cutting; with diamond disk; d<600mm
- Hard stone cutting; with diamond disk; d≥600mm
- Soft stone cutting; with diamond disk; d≥600mm

Table 20 shows the input flows common to all the four datasets, while table 21 shows the relative flow values. Data on direct emissions to air, water and soil were not available and are not included in these datasets.

Table 20: Input/output flows of the dataset of cutting with bridge diamond disk saw, source of collected data and the proposed correspondent reference processes.

	FLOW NAME	**DATA SOURCE**	**REFERENCE PROCESS**
INPUTS	Electricity [MJ]	-Transformation plants - Tool producer	Gabi: IT Electricity grid mix

	Diamond disk [pcs]	-Transformation plants - Tool producer	Created (cf. Par. 5.2.11): -Diamond disk; d=400mm -Diamond disk; for soft stones cutting; d=600mm -Diamond disk; for hard stones cutting; d=600mm
	Water [kg]	-Transformation plants -Technical sheets	Gabi: Water (Elementary flow)
	Flocculant [kg]	-Calculated from transformation plants and literature data	Ecoinvent: polyacrylamide production, cut-off, S
OUTPUTS	Stone cutting; with diamond disk [m^2]	-Transformation plants -Technical sheets	-
	Stainless steel scrap [kg]	-Transformation plants - Tool producer	-
	Sludge; from stone cutting [kg]	-Calculated from transformation plants and literature data	-

Table 21: Inventory of the dataset of cutting with bridge diamond disk saw, in relation to the disk diameter and the hardness of the stone slab to cut.

	FLOW NAME	**disk diam. =400 mm**		**disk diam. = 600 mm**	
		Soft stones	**Hard stones**	**Soft stones**	**Hard stones**
INPUTS	Electricity [MJ]	44	71,3	44	71,3
	Diamond disk [pcs]	0,034	0,0034	0,00114	0,0114
	Water [kg]	50	70,6	50	70,6
	Flocculant [kg]	9,5 E-5	9,5 E-5	9,5 E-5	9,5 E-5
OUTPUTS	Stone cutting; with diamond disk [m^2]	1	1	1	1
	Stainless steel scrap [kg]	0,00473	0,0473	0,00285	0,0122

	Slurried extractive waste; from stone cutting [kg]	38	38	38	38

Uncertainty data are showed in table 22 for the dataset of “Hard stone cutting; with diamond disk; d<600mm”.

Table 22: Average value, standard deviation, minimum and maximum values of data employed in the dataset of hard stone cutting with diamond disk (d<600 mm).

Variables	**Average**	**St. deviation**	**% St. deviation**	**Min**	**Max**
Electricity, IT grid mix [MJ]	71,3	12,41	17%	60	84,6
Diamond disk performance [m^2]	29,4	122,177	50%	17,5	50
Water [kg]	70,6	13,3	19 %	61	80

Figure 47 shows the models of the four LCI datasets related to the process of cutting hard/soft stones with diamond disks of different diameters.

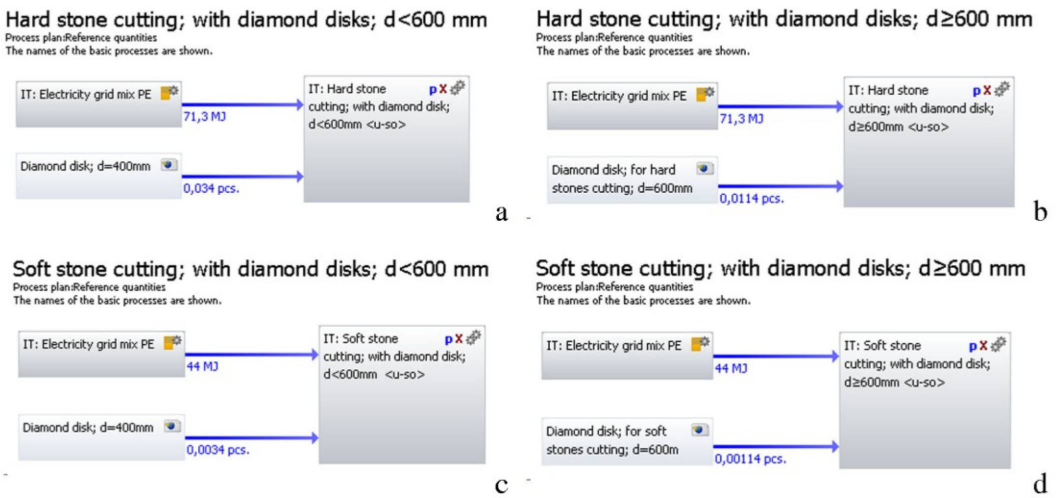


Figure 47: LCI dataset of 1 m^2 of hard stone cut with diamond disk of diameter d<600mm (a)/d≥600mm (b); LCI dataset of 1 m^2 of soft stone cut with diamond disk of diameter d<600mm (c)/d≥600mm (d)

As explained in Paragraph 3.4, a Monte Carlo simulation with 1000 iterations has been developed in order to evaluate in which measure the dataset uncertainty spreads on impact results. As in the previous cases, the analysis is carried out on the impact categories of climate change, ozone depletion and particulate matter/respiratory inorganics, which have been assessed through the methods recommended by the ILCD Handbook. Table 23 lists the impact values obtained with the basis scenario, the mean value of the parameter constellations, the related standard deviation (in percentage) and the impact results at 10^{th} and 90^{th} percentiles. These data and the related graph of Figure 48 shows that the primary data uncertainty slightly affects the climate change results (the graph shows a narrow Gaussian curve and the standard deviation is 8,5%). Similar results have been obtained for the particulate matter impact category, while for the ozone depletion the dispersion is higher (standard deviation of 30%). The quantity of steel employed for disks (and, as a consequence, the disk performance) is the major responsible of the ozone depletion for the process under study; to obtain more precise results on the ozone depletion impacts it is suggested to edit the dataset parameters according to the specific inventory of the supply chain of reference.

Table 23: Uncertainty on LCIA results for the process of cutting 1 m^2 of hard stone with a diamond disk of diameter <600mm. Results obtained with Monte Carlo simulation.

Impact category	**Unit**	**Basis scenario**	**Mean value**	**Standard dev.**	**Percentile**	
					10^{th}	**90^{th}**
IPCC global warming, incl biogenic carbon	kg CO_2-eq.	12,9	13	8,5%	11,6	14,5
Ozone depletion, WMO model, ReCiPe	kg CFC-11 eq.	1,87E-08	1,84E-08	25,9%	1,31E-08	2,60E-08
Particulate matter/Respiratory inorganics, RiskPoll	kg $PM_{2,5}$-eq.	0,00197	0,00198	10,5%	0,00171	0,00226

Figure 48: Distribution of LCIA results around the mean value for the process of cutting 1 m^2 of hard stone with a diamond disk of diameter <600mm.

5.1.9 LCI of soft stone squaring with diamond mono-blade technology

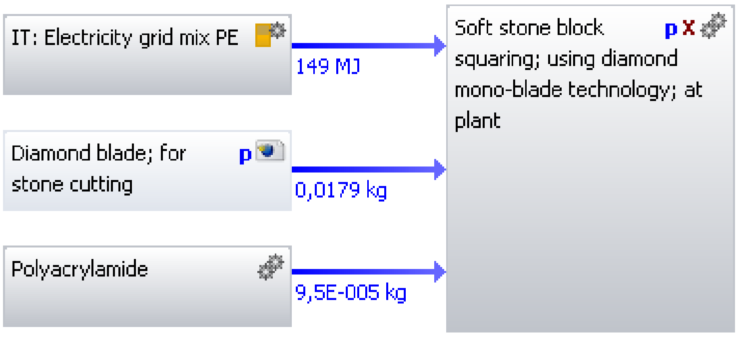


Figure 49: LCI dataset of 1 m^2 of soft stone cut with diamond mono-blade technology.

Irregular blocks of soft stones can be cut with the technology of diamond mono-blade. Since scarce primary data were available for this technology, the LC dataset has been modelled mainly on the basis of technical sheets from BM (www.bmofficine.it). In particular, it has been estimated an energy consumption of 112 MJ/h for cutting a 3 m length block and with a lowering speed of the diamond blade of 0,25 m/h; this latter is assumed to last 800 m^2 of cutting. Direct emissions are not included in this dataset because of unavailability of data. Table 24 resume the inventory of this dataset.

Table 24: Inventory of the dataset of soft stone squaring with diamond mono-blade saw, source of the flow values and the proposed correspondent reference processes.

	FLOW NAME	VALUE	DATA SOURCE	REFERENCE PROCESS
INPUTS	Diamond blade; for stone cutting [kg]	0,018	-Tool producer -Technical sheets	Created (cf. Par. 5.2.13): Diamond blade
INPUTS	Electricity [MJ]	149	-Technical sheets	Gabi: IT Electricity grid mix
INPUTS	Flocculant [kg]	9,5 E-5	Calculated from transformation plants and literature data	Ecoinvent: polyacrylamide production, cut-off, S

OUTPUTS	Soft stone block squaring; using diamond mono-blade technology; at plant [m^2]	1	-	-
	Steel scrap [kg]	0,018	-Tool producer -Technical sheets	-
	Slurried extractive waste; from stone cutting [kg]	38	-Calculated from transformation plants and literature data	-

5.1.10 LCI of stone cutting with diamond multi-blade saw technology

Regular blocks of soft stones can be cut into slabs through diamond multi-blade saws (cf. Paragraph 4.4.5). This t technology makes use the same type of diamond blades employed for the squaring technique described in previous paragraph. Primary data were collected in two transformation plants of Carrara district, secondary data were collected in technical sheets (Pedrini, BM, Diamond Board). Direct emissions to air, water and soil produced by this process are not included in this dataset because of unavailability of data.

Figure 50 illustrates LCI model of the dataset, while Table 25 and Table 26 respectively show the related inventory of the dataset and the uncertainty on primary data.

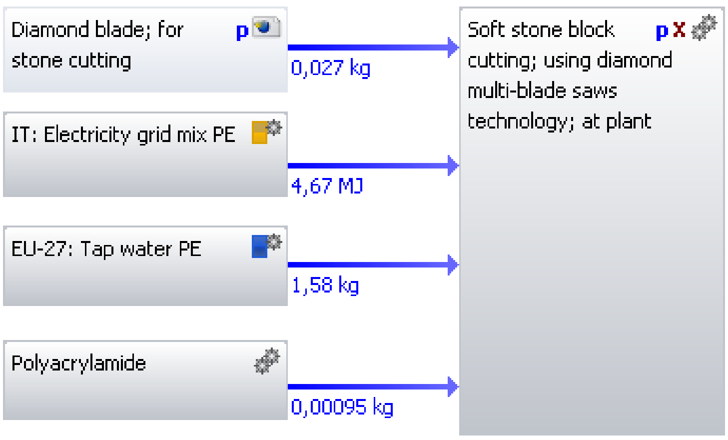


Figure 50: LCI dataset of 1 m^2 of soft stone cut with diamond multi-blade saws

Table 25: Inventory of the dataset of soft stone cutting with diamond multi-blade saws, source of the flow values and the proposed correspondent reference processes.

	FLOW NAME	VALUE	DATA SOURCE	REFERENCE PROCESS
INPUTS	Diamond blade; for stone cutting [kg]	0,027	-Transformation plants -Technical sheets	Created (cf. Par. 5.2.13): Diamond blade; for stone cutting
	Water [kg]	1,58	-Transformation plant	Gabi: Tap water
	Electricity [MJ]	4,67	-Transformation plants -Technical sheets	Gabi: IT Electricity grid mix
	Flocculant [kg]	9,5 E-5	-Calculated from transformation plants and literature data	Ecoinvent: polyacrylamide production, cut-off, S
OUTPUTS	Soft stone block squaring; using diamond multi-blade technology; at plant [m^2]	1	-	-
	Steel scrap [kg]	0,025	-Transformation plants -Technical sheets	-
	Slurried extractive waste; from stone cutting [kg]	38	-Calculated from transformation plants and literature data	-

Table 26: Average value, standard deviation, minimum and maximum values of data employed in the dataset of soft stone cutting with diamond multi-blade saws.

	FLOW NAME	Average	St. deviation	% St. deviation	Min	Max
INPUTS	Diamond blades [kg]	0,027	0,008	32%	0,021	0,036
	Water [kg]	1,58	n.a.	n.a.	1,58	1,58

	Electricity [MJ]	4,67	1,27	27%	3,41	5,83
OUPUTS	Soft stone block squaring; using diamond multi-blade technology; at plant [m^2]	1	-	-	-	-
	Steel scrap [kg]	0,025	0,01	39%	0,019	0,036

As explained in Paragraph 3.4, a Monte Carlo simulation has been run to evaluate how uncertainty on collected data affects the stability of impact results. To this aim, the impact assessment of this cutting technique has been developed, selecting the I level quality methods (according to ILCD Handbook recommendations), which are respectively related to the impact categories of climate change, ozone depletion and particulate matter/respiratory inorganics. To obtain robust results, the Monte Carlo simulation has been run with 1000 random parameter constellations. Table 27 lists the impact values obtained with the basis scenario, the mean value resulting from the parameter constellation, the related standard deviation (in percentage) and the results at 10^{th} and 90^{th} percentiles. As it can be noticed the standard deviation of the constellation mean value from the basis scenario value is reasonably low (about 10% for all the impact categories analysed).

Table 27: Uncertainty on LCIA results for the process of cutting 1 m^2 of soft stone with a diamond multi-blade saws. Results obtained with Monte Carlo simulation.

Impact category	Unit	Basis scenario	Mean value	Standard dev.	Percentile	
					10^{th}	**90^{th}**
IPCC global warming, incl biogenic carbon	kg CO_2-eq.	0,673	0,793	10,8%	0,69	0,918
Ozone depletion, WMO model, ReCiPe	kg CFC-11 eq.	4,64E-09	5,95E-09	10,8%	5,24E-09	6,86E-09
Particulate matter/Respiratory inorganics, RiskPoll	kg $PM_{2,5}$-eq.	1,38E-04	1,68 E-04	8,4%	1,51 E-04	1,87 E-04

Figure 51 shows the distribution of the results obtained with Monte Carlo simulation. Among the analyzed impact categories, the ozone depletion is the one with the major distribution, while the climate change is the most stable.

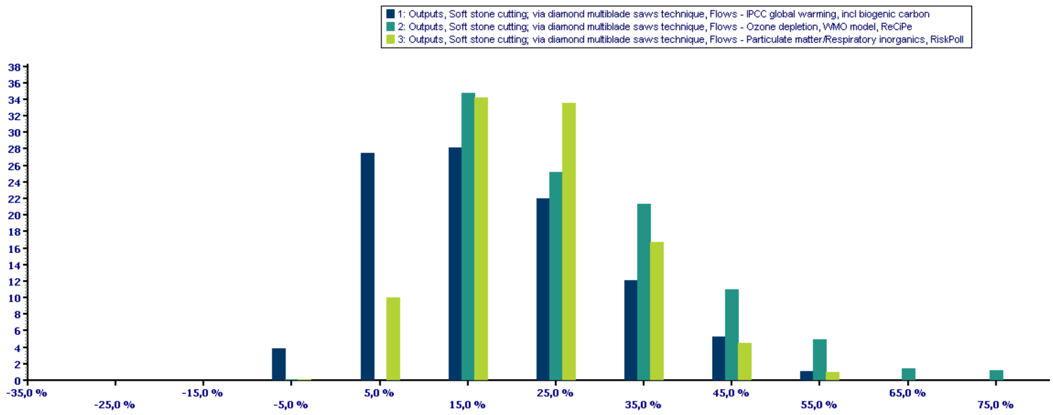


Figure 51: Distribution of LCIA results around the mean value for the process of soft stone cutting with a diamond multi-blade saws.

5.1.11 LCI of stone cutting with steel grit gang saws technology

The steel grit gang saw technology is largely employed for cutting slabs from regular hard stone blocks (cf. Paragraph 4.4.4). To create the related dataset, primary data were collected in three enterprises (two located in Verbano-Cusio-Ossola province one in Carrara district). Secondary data from technical sheets were also employed. Table 28 and Figure 52 show the inventory and the related LC model of this cutting process, while Table 29 illustrates the uncertainty on primary data. Direct emissions to air, water and soil produced by this process are not included in this dataset because of unavailability of data.

Table 28: Inventory of the dataset of hard stone cutting with steel grit gang saw technology, source of the flow values and the proposed correspondent reference processes.

	FLOW NAME	VALUE	DATA SOURCE	REFERENCE PROCESS
INPUTS	Steel blades [kg]	2,20	Hard stone transformation plants	Gabi: Steel hot rolled section
	Grit [kg]	1,67	Hard stone transformation	Gabi: Cast iron part

			plants	
	Limestone [kg]	1,34	Hard stone transformation plants	Gabi: Lime (CaO; quicklime lumpy)
	Water [kg]	3,79	Hard stone transformation plants	Gabi: Tap water
	Electricity [MJ]	6,56	Hard stone transformation plants	Gabi: IT Electricity grid mix
	Flocculant [kg]	9,5 E-5	Calculated from transformation plants and literature data	Ecoinvent: polyacrylamide production, cut-off, S
OUTPUTS	Cutting of hard stones; using steel grit gang saw technology [m^2]	1	-	-
	Steel scrap [kg]	1,75	Hard stone transformation plants	-
	Hard stone block cutting; using steel grit gang saw technology; at plant [kg]	38	-Calculated from transformation plants and literature data	-

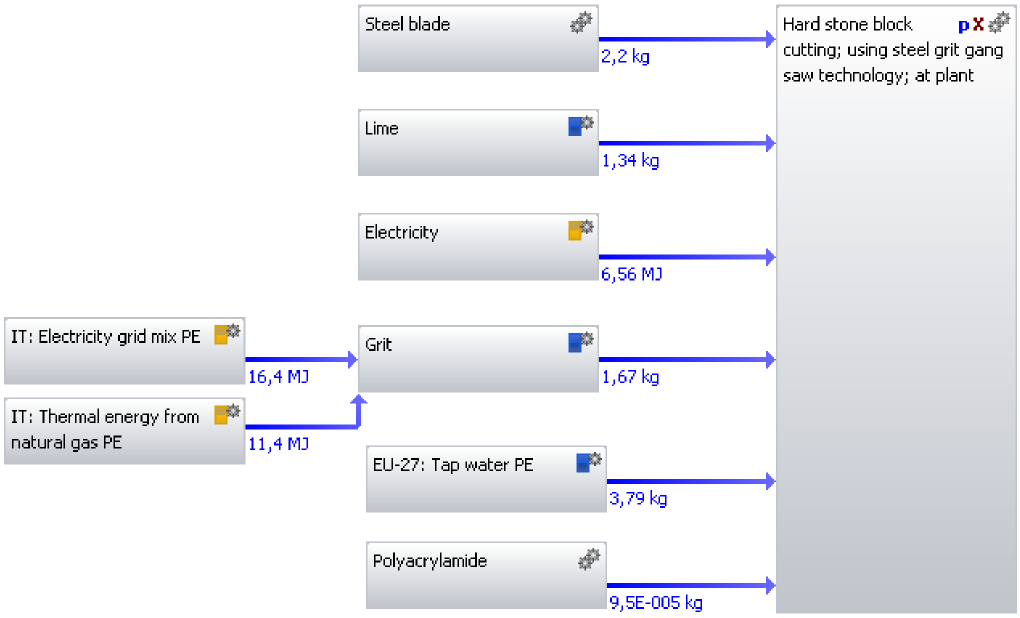


Figure 52: LCI dataset of 1 m^2 of soft stone cut with diamond multiblade saws

Table 29: Average value, standard deviation, minimum and maximum values of data employed in the dataset of hard stone cutting with steel grit gang saw technology.

	FLOW NAME	Average	St. deviation	% St. deviation	Min	Max
INPUTS	Steel blades [kg]	2,20	1,37	63%	0,63	3,20
	Steel grit [kg]	1,67	0,38	23%	1,32	2,08
	Limestone [kg]	1,34	0,83	62%	0,76	1,93
	Water [kg]	3,79	n.a.	n.a.	3,79	3,79
	Electricity [MJ]	6,56	1,44	22%	5,54	7,57
	Flocculant [kg]	9,5 E-5	n.a.	n.a.	9,5 E-5	9,5 E-5

As explained in Paragraph 3.4, a Monte Carlo simulation with 1000 random parameter constellations has been run to evaluate how uncertainty on collected data affects the stability of the related impact results. As for the previous datasets, the LCIA of the steel grit gang saw technology has been developed with the most recommended assessment methods (ILCD Handbook), which are respectively related to the impact categories of climate change, ozone depletion and particulate matter/respiratory inorganics. Table 30 lists the impact values obtained with the basis scenario, the mean value resulting from the parameter constellation, the related standard deviation (in percentage) and the impact results at 10th and 90th percentiles. As it can be noticed the deviation of the Monte Carlo mean value from the basis scenario value is around 10% for all the three impact categories.

Table 30: Uncertainty on LCIA results for the process of cutting 1 m^2 of hard stone with the steel grit gang saw technology. Results obtained with Monte Carlo simulation.

Impact category	**Unit**	**Basis scenario**	**Mean value**	**Standard dev.**	**Percentile**	
					10th	**90th**
IPCC global warming, incl biogenic carbon	kg CO_2-eq.	9,91	8,73	11,7%	7,4	10
Ozone depletion, WMO model, ReCiPe	kg CFC-11 eq.	6,05E-10	5,79E-10	8,8%	5,07E-10	6,44E-10
Particulate matter/Respiratory inorganics, RiskPoll	kg $PM_{2,5}$-eq.	0,00634	0,00621	11,1%	0,00523	0,00715

Figure 53 shows the distribution of the results obtained with Monte Carlo simulation. Among the analysed impact categories, the ozone depletion shows the minor distribution; as far as concern the climate change, the graph shows a significant number of constellations whose result is lower than the basis scenario, meaning that the LCI dataset could lead to a slightly overestimated impact on climate change.

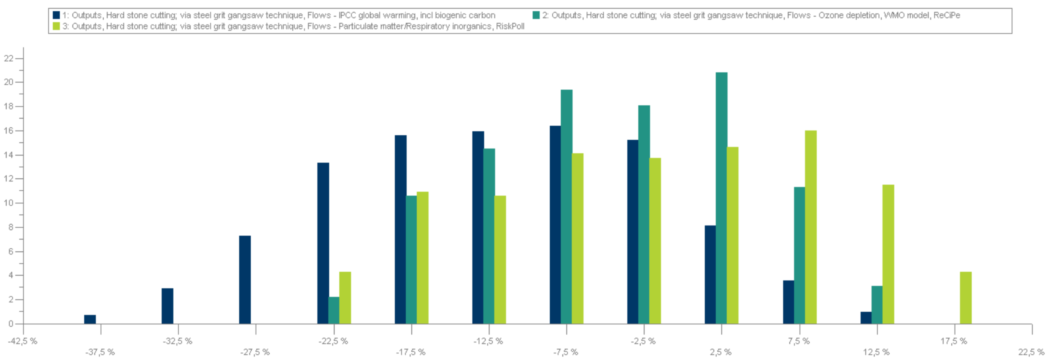


Figure 53: Distribution of LCIA results around the mean value for the process of hard stone cutting with the steel grit gang saw technology.

5.1.12 LCI of stone surface treatment: smoothing to polishing

The most common surface treatments for both soft and hard stones are the smoothing and polishing processes (cf. Paragraph 4.5.1). They are performed, in succession, by the same machine and the level of roughness depends on the set of abrasives used during the treatment. The machinery is composed by a set of heads, where 6-8 abrasives are mounted on rotating plates. Generally the treatment starts with metallic brushes and continues with resin, magnesite or synthetic abrasives of progressively decreasing grits till the use of polishing wheels, with the finest grits.

Two separate LC datasets have been developed for the processes of smoothing and polishing. More precisely, since the polishing treatment is the prosecution of the smoothing one, its correspondent LC dataset has been modeled comprehending the smoothing dataset. Data were collected in 3 transformation plants (respectively located in Carrara district, Santena (Turin province) and Domodossola (Verbano Cusio Ossola province). Secondary data were collected on technical sheets of the main polishing lines producers (Pedrini, Breton, Simec). Data of direct emissions from the surface treatment were not available and are consequently not included in the datasets. Table 31 and 32 respectively show the inventories of the smoothing and polishing processes datasets.

These datasets are referred to a polishing line with 14 heads, each one having 6 abrasives and divided as follows:

- heads 1-6 : metal abrasives
- heads 7-13: resin diamond abrasives
- head 14: polishing abrasives

Table 31: Inventory of the dataset of stone slab smoothing technique, source of the flow values and the proposed correspondent reference processes.

	FLOW NAME	VALUE	DATA SOURCE	REFERENCE PROCESS
INPUTS	Electricity [MJ]	8,25	-Transformation plants -Technical sheets	Gabi: IT Electricity grid mix
	Metal abrasive; for stone surface treatment [pcs]	0,39	-Transformation plants	Created (cf. Par. 5.2.14):

			-Technical sheets	Metal abrasive
	Water [kg]	11,72	-Transformation plants -Technical sheets	Gabi: Tap water
	Flocculant [kg]	1,3 E-5	-Calculated from transformation plants and literature data	Ecoinvent: polyacrylamide production, cut-off, S
OUTPUTS	Stone slab surface treatment; Smoothing; at plant [m^2]	1	-	-
	Slurried extractive waste; from stone finishing [kg]	5	-Calculated from transformation plants and literature data	-

Table 32: Inventory of the dataset of stone slab polishing technique, source of the flow values and the proposed correspondent reference processes.

	FLOW NAME	VALUE	DATA SOURCE	REFERENCE PROCESS
INPUTS	Electricity [MJ]	0,63	-Transformation plants -Technical sheets	Gabi: IT Electricity grid mix
	Resin diamond abrasive; for stone polishing [pcs]	0,052	-Transformation plants -Technical sheets	Created (cf. Par. 5.2.15): Resin diamond abrasive ; for stone polishing
	Water [kg]	0,76	-Transformation plants -Technical sheets	Gabi: Tap water
	Stone slab surface treatment; Smoothing [m^2]	1	-Transformation plants	Created: Stone slab surface treatment; Smoothing
	Flocculant [kg]	7,5 E-6	-Calculated from transformation plants and literature data	Ecoinvent: polyacrylamide production, cut-off, S
OUTPUTS	Stone slab surface treatment; Polishing; at plant [m^2]	1	-	-
	Slurried extractive waste; from stone finishing [kg]	3	-Calculated from transformation plants and literature data	-

Table 33: Average value, standard deviation, minimum and maximum values of data employed in the dataset of stone slab smoothing.

	FLOW NAME	Average	St. deviation	% St. deviation	Min	Max
INPUTS	Electricity [MJ]	8,25	3,072033	37%	6,08	10,43
	Metal abrasive [pcs]	0,39	0,020951	5%	0,37	0,40

	Water [kg]	11,72	2,427733	21%	10,00	13,43
OUTPUTS	Stone slab surface treatment; Smoothing [m^2]	1	-	-	-	-

Table 34: Average value, standard deviation, minimum and maximum values of data employed in the dataset of stone slab polishing.

	FLOW NAME	Average	St. deviation	% St. deviation	Min	Max
INPUTS	Electricity [MJ]	0,63	0,24	37%	0,47	0,80
INPUTS	Resin diamond abrasive [pcs]	0,052	0,02	40%	0,037	0,067
INPUTS	Water [kg]	0,76	0,39	52%	0,48	1,03
INPUTS	Stone slab surface treatment; Smoothing; at plant [m^2]	1	-	-	-	-
OUTPUTS	Stone slab surface treatment; Polishing; at plant [m^2]	1	-	-	-	-

As explained in Paragraph 3.4, starting from the standard deviation on collected data, Monte Carlo simulations have been run to evaluate how this uncertainty is reflected on impact assessment results. Simulations have been run with 1000 iterations and for the impact categories of climate change, ozone depletion and particulate matter/respiratory inorganics. These impact categories have been chosen since they are assessed with the most recommended methods according to the ILCD Handbook.

Table 35 and Figure 54 show the results for the smoothing process dataset. As it can be noticed, the uncertainty for the impact categories analysed is quite low. For the climate change, the distribution is more frequent for positive values, meaning that with the basis scenario the climate change impact could be slightly underestimated; the opposite for the ozone depletion and particulate matter/respiratory inorganics impact categories.

Table 35: Uncertainty on LCIA results for the process of smoothing 1 m^2 of stone slab. Results obtained with Monte Carlo simulation.

Impact category	**Unit**	**Basis scenario**	**Mean value**	**Standard dev.**	**Percentile**	
					10th	**90th**
IPCC global warming, incl biogenic carbon	kg CO_2-eq.	5,22	5,6	2,5%	5,42	5,77
Ozone depletion, WMO model, ReCiPe	kg CFC-11 eq.	1,86E-08	1,85E-08	2,2%	1,79E-08	1,91E-08
Particulate matter/Respiratory inorganics, RiskPoll	kg $PM_{2,5}$-eq.	0,00156	0,0016	2,1%	0,00155	0,00164

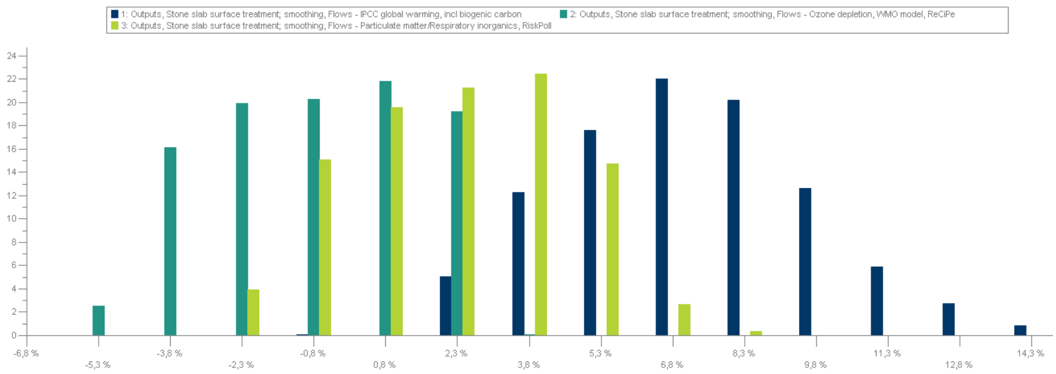


Figure 54: Distribution of LCIA results around the mean value for the process of stone slab smoothing.

Table 36 and Figure 55 show the results for the polishing process dataset. Also in this case, the standard deviation on impact results is low, especially for the climate change impact category, whose distribution also indicates a good accurateness of the basis scenario results.

Table 36: Uncertainty on LCIA results for the process of polishing 1 m^2 of stone slab. Results obtained with Monte Carlo simulation.

Impact category	**Unit**	**Basis scenario**	**Mean value**	**Standard dev.**	**Percentile**	
					10th	**90th**
IPCC global warming, incl biogenic carbon	kg CO_2-eq.	5,94	5,94	1,7%	5,81	6,08
Ozone depletion, WMO model, ReCiPe	kg CFC-11 eq.	2,54E-08	2,54E-08	4,2%	2,39E-08	2,69E-08
Particulate matter/Respiratory inorganics, RiskPoll	kg $PM_{2,5}$-eq.	0,00213	0,00213	4,1%	0,00201	0,00225

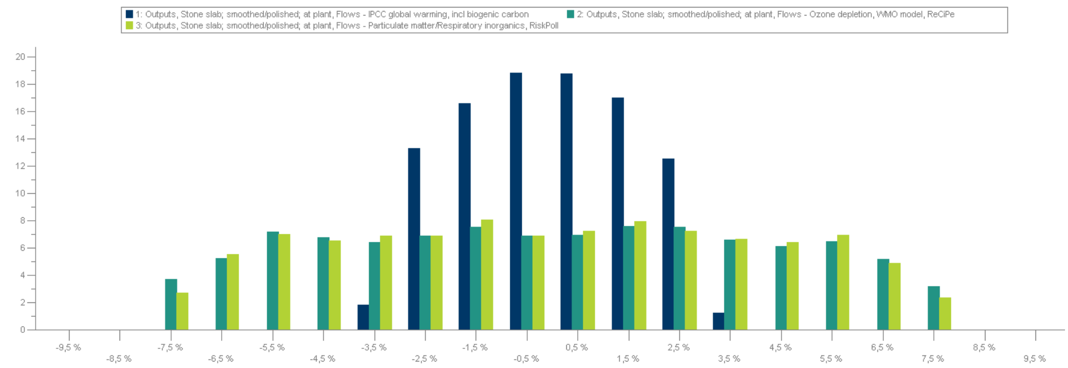


Figure 55: Distribution of LCIA results around the mean value for the process of stone slab polishing.

5.2 LCI datasets of technologies and tools in the ornamental stone supply chain

5.2.1 LCI of black powder

Black powder is generally composed by (Bacci, 2005; Selva and Nardin, 2013; von Maltitz, 2003):

- Potassium nitrate: 75%
- Charcoal 12,5 - 15%
- Sulphur 10 - 12%

As explained in detail by von Maltitz (2003) and Reza et al. (2014), the industrial process of black powder production is made of the phases showed in Figure 56.

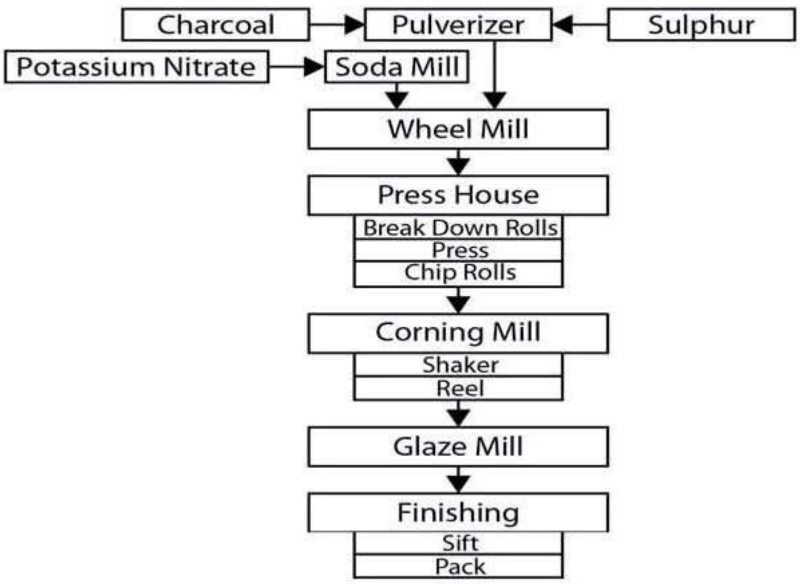


Figure 56: Black powder production chain (source: Reza et al., 2014)

At first, sulphur, charcoal and then potassium nitrate are mixed in wheel mills, whit a controlled amount of water to avoid accidental ignition of the explosive mixture. Then the mixture is compacted through an hydraulic press and the material is chipped up in a set of bronze rollers. Subsequently, the product is moved to a corning mill, where it is reduced in granular dimensions. Grains are then screened and transported to the glaze mill where granules are coated by graphite through rotating drums. Finally the black powder is weighted and packaged.

In order to build the LC dataset, the amount of electricity necessary for the processes of black powder production has been estimated on the basis of machineries technical sheets. Table 37 summarize the estimation for each phase of the process for the production of 1 t of black powder and the reference machines.

Table 37: Energy estimation for the processes of the black powder production chain.

PROCESS	ENERGY	DATA SOURCE
Pulverizing with ball mill	40 MJ	Model: Energy-Saving Ball Mill (900×3000). Producer: Henan Hongji Mine machinery Co., Henan (China) https://hnhongji.en.alibaba.com/product/236052265-213253684/Energy_Saving_Ball_Mill_Machine_Hot_Sale_.html?spm=a2700.8304367.prewdfa4cf.4.2c636ced2AVCAA
Milling	28 MJ	Model:DY-SS Producer: HeZhengzhou Diying Machinery Co., Henan (China) http://diying617.en.hisupplier.com/product-1361724-Advanced-best-seller-wheel-mill-charcoal-powder-crushing-machine-coal-grinding-machine.html
Pressing	67 MJ	Model: ZKHD530 Producer: Zhengzhou Kehua Industrial Equipment Co., Henan (China) https://www.alibaba.com/product-detail/Hydraulic-dry-coal-powder-charcoal-powder_60434031223.html?spm=a2700.7724838.0.0.l1ocH8&s=p
Corning	3 MJ	Model: DZSF520 Producer: Xinxiang Yongqing Screen Machine Co., Henan (China) https://www.alibaba.com/product-detail/High-frequency-vibrating-screen-sieve-shakers_1994503708.html?spm=a2700.7724838.20171

		15.94.650af1e3AAXvFz
Glazing/drying	14 MJ	Model: Φ1.2×8.0 Henan Hongxing Mining Machinery Co., Henan (China) https://www.alibaba.com/product-detail/ISO-belt-tumbler-dryer-machine-for_1453983881.html?spm=a2700.7724838.0.0.LGsiF1&s=p
TOTAL	**152 MJ/t**	

The final total value of energy consumption has been inserted as input flows in the black powder dataset.

The combustion of black powder causes emissions into air. The commonly cited chemical equation of Debus for the combustion of black powder is:

$$10\ KNO_3 + 3\ S + 8\ C \rightarrow 2\ K_2CO_3 + 3\ K_2SO_4 + 6\ CO_2 + 5\ N_2$$

From this chemical equation it emerges that the outputs are potassium carbonate (K_2CO_3), potassium sulphate (K_2SO_4), carbon dioxide (CO_2) and nitrogen (N_2).

Through the atomic number, it has been obtained the mass for the combustion of 1 kg of black powder:

Black powder	**K_2CO_3**	**K_2SO_4**	**CO_2**	**N_2**
1 kg	0,230 kg	0,434 kg	0,219 kg	0,058 kg

Commercial Life Cycle databases do not have availability of datasets to describe the emission into air of neither potassium carbonate nor potassium sulphate, which, as a consequence, were not added into the Black powder dataset. Nevertheless, according to Evonik Industries (2014) potassium and carbonate ions are naturally found widely in the environment and potassium carbonate has a low hazard on the environment. As far as concern the potassium sulphate, it has been approximated with the elementary flow dataset of Sulphuric acid. Moreover, according to Davis (1943), 1 g of black powder produce 718,1 calories while burning, that means that for 1 kg are produced 3 MJ of waste heat, as inserted in the dataset.

Finally a transportation has been added to the dataset. The distance (1000 km) has been calculated considering a round-trip with a lorry with reference to the gneiss quarries of Piedmont, which mostly purchase explosives produced by Pravisani enterprise in Udine (Italy).

The following table resumes the input/output flows.

Table 38: Inventory of the black powder dataset, source of the flow values and the proposed correspondent reference processes.

	FLOW NAME	VALUE	DATA SOURCE	REFERENCE PROCESS
INPUTS	Potassium nitrate [kg]	0,75	-Literature	Ecoinvent: potassium nitrate, as N, at regional storehouse
	Charcoal [kg]	0,14	-Literature	Ecoinvent: charcoal, at plant
	Sulphur [kg]	0,11	-Literature	Gabi: Sulphur (elemental) at refinery
	Electricity, IT grid mix [MJ]	0,152	-Calculated from technical sheets	Gabi: IT Electricity grid mix
	Transport [kg*km]	1000	-Calculated	Gabi: Lorry transport
OUTPUTS	Black powder [kg]	1	-	-
	Carbon dioxide	0,219	-Literature	Gabi: Carbon dioxide [Inorganic emission into air]
	Nitrogen	0,058	-Literature	Gabi: Nitrogen (atmospheric nitrogen) [Inorganic emission into air]

	Sulphuric acid	0,434	-Literature	Gabi: Sulphuric acid [Inorganic emission into air]
	Waste heat	3	-Literature	Gabi: Waste heat [Other emission to air]

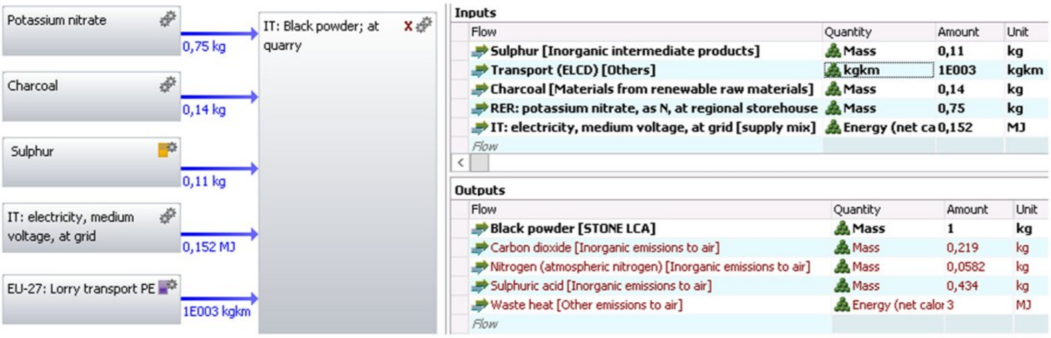


Figure 57: Model of the LCI dataset of 1 kg of burned black powder

5.2.2 LCI of slow-burning fuses

Slow burning fuse is employed to bring the explosive charge to detonation or the black powder to deflagration.

As showed in Figure 58 (based on Monetti and S.E.I. technical sheets), slow-burning fuses are composed by a core of black powder protected by layers of cotton/juta impregnated with special oils. An external layer of polyethylene protects the fuse from water.

With reference to Monetti technical sheet (Annex 6), the dataset of a slow-burning fuse with diameter of 6 mm has been modeled. The inventory is showed in Table 39, while Figure 59 illustrates the related LC model.

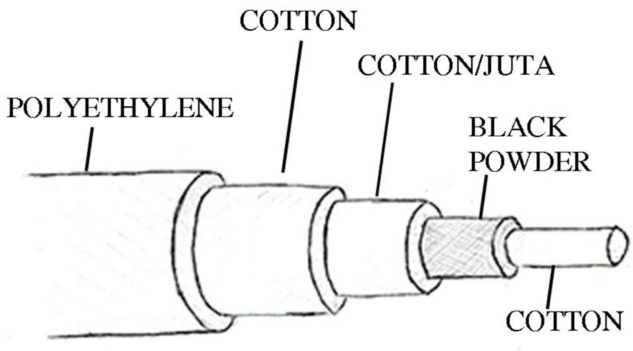


Figure 58: typical composition of slow-burning fuses

Table 39: Inventory of the slow-burning fuse dataset, source of the flow values and the proposed correspondent reference processes.

	FLOW NAME	VALUE	DATA SOURCE	REFERENCE PROCESS
INPUTS	Black powder [kg]	0,011	Literature	Ecoinvent: potassium nitrate, as N, at regional storehouse
	Cotton [kg]	0,001	Literature	Ecoinvent: charcoal, at plant
	PVC [kg]	0,016	Literature	Gabi: Sulphur (elemental) at refinery
	Transport [kg*km]	28	Calculated	Gabi: Small lorry (7.5t) incl. fuel
	Oil [kg]	0,002	Literature	Ecoinvent: lubricating oil, at plant
OUTP	Slow burning fuse [m]	1	-	-

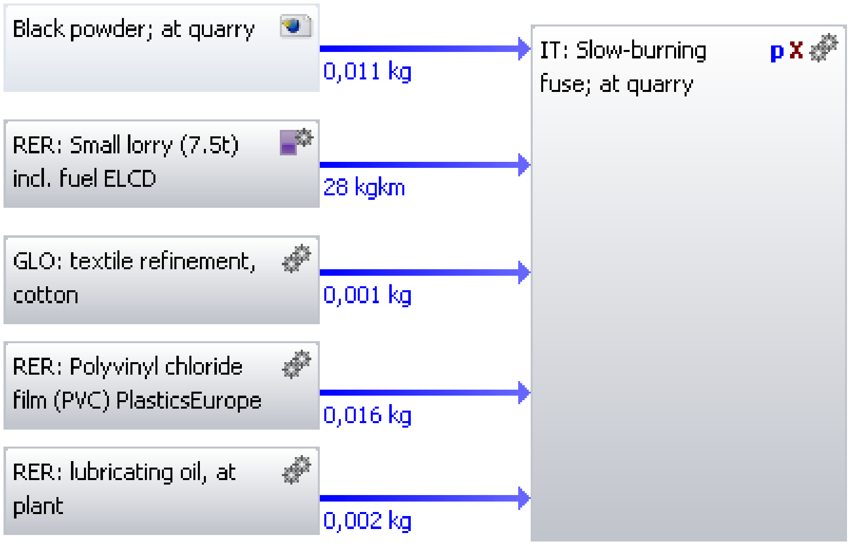


Figure 59: LCI dataset of 1 m of slow-burning fuse

5.2.3 LCI of detonators

Detonators (also called blasting caps) are employed to transfer the explosive charge from the slow-burning fuse to the detonation cord. Ordinary detonators are composed by an aluminum cylindrical capsule, having an open edge for inserting the slow-burning fuse (Figure 60). This latter activates a chain of explosives located in the opposite side of the capsule. These explosives have growing power and decreasing sensibility: the first charge is generally a primary explosive (such as lead azide, and mercury fulminate), while the following one is a secondary explosive (such as penthrite). Nevertheless, since the total amount of explosive in detonators is very low (about 1 g) and since in commercial LC databases the correspondent datasets of those explosives are not available, they were not included in the model. The detonator dataset is based on the Pravisani technical sheet (Annex 7) and it includes the production of the capsule and the transportation till the quarry (Table 40 shows the related inventory).

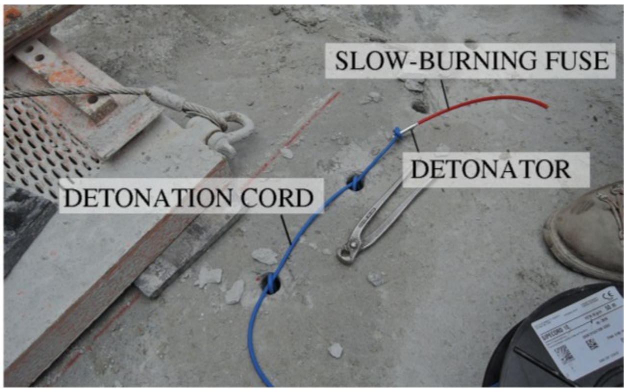


Figure 60: A common configuration for trigging the stone dynamic splitting

Table 40: Inventory of the detonator dataset, source of the flow values and the proposed correspondent reference processes.

	FLOW NAME	VALUE	DATA SOURCE	REFERENCE PROCESS
INPUTS	Aluminium [kg]	0,001	-Technical sheet	Gabi: Aluminium extrusion profile mix
	Transport [kg*km]	2	-Calculated	Gabi: Small lorry (7.5t) incl. fuel
OUTP	Detonator [pcs]	1	-	-

5.2.4 LCI of detonation cords

Detonation cords are used to trigger explosive charges which are connected to them. They are generally composed by a core of pentaerythritol tetranitrate (also known as penthrite or PETN) protected by multi-layers of textile materials (such as propylene or polyester) and an external waterproof layer of PVC. In quarries, the pieces of detonation cord that at the end of the working day have not been employed have to be burned in open air.

The dataset has been modeled for 1 m of detonation cord, with reference to detonation cords with 10 g/m of PETN and an external diameter of 5,2 mm, as indicated by Pravisani technical sheet (Annex 7). Data from Literature (Palma Rojas et al., 2013) have also been employed to quantify input flows related to the PETN production, which is produced through the nitration of pentaerythritol using concentrated nitric acid at 25 - 30 °C. This dataset do not include the energy for the detonation cord production because of unavailability of data. Table 41 shows the inventory of the dataset.

Table 41: Inventory of the detonation cord dataset, source of the flow values and the proposed correspondent reference processes.

	FLOW NAME	VALUE	DATA SOURCE	REFERENCE PROCESS
INPUTS	Pentaerythritol [kg]	0,0017	-Literature	Ecoinvent: penta-erythritol, at plant
	Nitric acid [kg]	0,0067	-Literature	Gabi: Nitric acid (98%)
	Toluene [kg]	0,0016	-Literature	Gabi: Toluene
	Polypropilene [kg]	0,018	-Technical sheet	Gabi: Polypropylene / Ethylene Propylene Diene Elastomer Granulate (PP/EPDM, TPE-O) Mix
	Transport [kg*km]	14	Calculated	Gabi: Small lorry (7.5t) incl. fuel
OUTP	Detonation cord; at quarry [m]	1	-	-

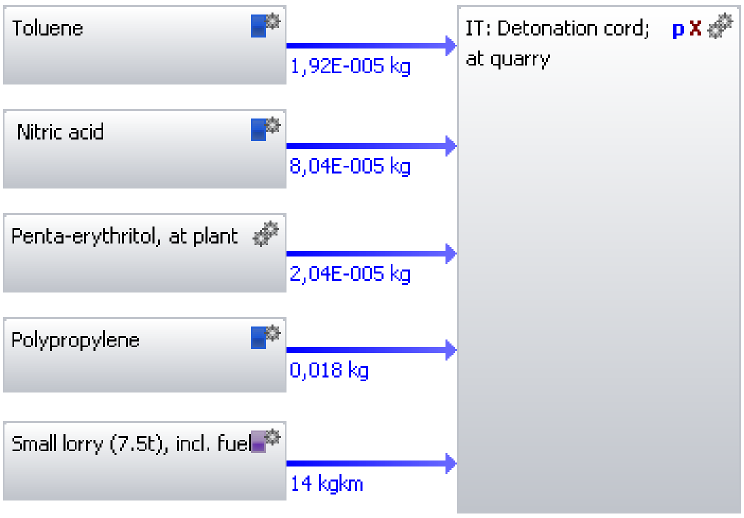


Figure 61: LCI dataset of 1 m of detonation cord

5.2.5 LCI of drilling rods and bits

Drilling rods are employed in quarries to create the holes to place explosive charges or for the passage of diamond wire. Generally holes for the dynamic splitting measures from 30 to 45 mm, while holes for the diamond wire saw have bigger diameters (50-100 mm). To create holes, a combined mechanism of roto-percussion is transmitted to a drilling rod. Generally, for small diameters are employed hollow steel rods having fixed length (normally multiples of 80 cm) with an abrasive insert integrated at its edge; for bigger diameters it is employed a set of connected rods with a separate interchangeable abrasive bit (Figure 62). In the first case, when the drilling rod is worn out it is sent to the iron recycling and it is completely replaced by a new one, while, in the second case, rods are employed for a longer time and just drilling bits are replaced.

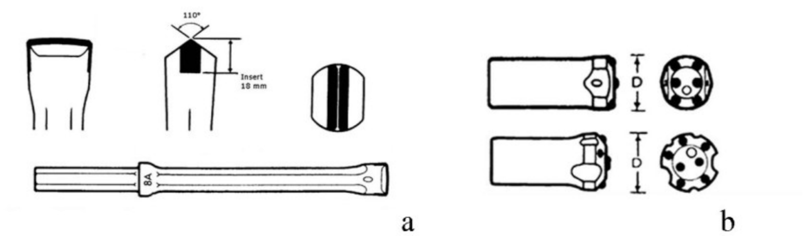


Figure 62: a) steel rod with fix abrasive insert; b) interchangeable abrasive bit (source: Geocom Srl technical sheet)

The two types of drilling rod have been modeled, mainly on the basis of technical sheets from Geocom and Tenir Italian enterprises.

1) Drilling rod with hexagonal body and tungsten carbide insert (Figure 62a). The dataset is modeled with reference to a drilling rod of length L = 3200 mm, diameter d= 31 mm and insert width W = 35 mm. Table 42 lists input/output flows and Figure 63 shows the related dataset model.

2) Drilling bit with 7 buttons (Figure 62b). A bit with diameter d = 76 mm has been chosen for modeling the dataset. Table 43 lists input/output flows and Figure 64 shows the related dataset model.

Table 42: Inventory of the drilling rod dataset, source of the flow values and the proposed correspondent reference processes.

	FLOW NAME	VALUE	DATA SOURCE	DATABASE PROCESS
INPUTS	Steel rod [kg]	10,5	-Technical sheets	Gabi: Steel rebar
INPUTS	Tungsten carbide [kg]	0,086	-Technical sheets	Created (cf. Par. 5.2.6): Tungsten carbide
INPUTS	Transport [kg*km]	525	-Calculated	Gabi: Lorry (22t) incl. fuel
OUTPUTS	Drilling rod; at quarry [m]	3,20	-	-
OUTPUTS	Iron scrap [kg]	10,5	-Technical sheets	-

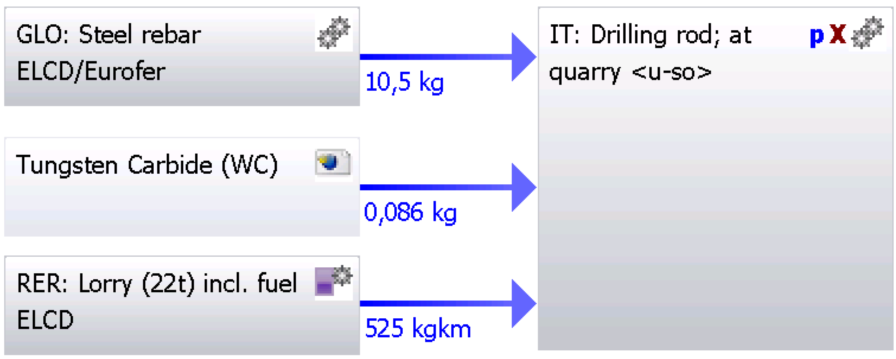


Figure 63: LCI dataset of 1 drilling rod of length 3,20 m

Table 43: Inventory of the drilling bit dataset, source of the flow values and the proposed correspondent reference processes.

	FLOW NAME	VALUE	DATA SOURCE	REFERENCE PROCESS
INPUTS	Steel [kg]	2,2	-Technical sheets	Gabi: Steel rebar
INPUTS	Tungsten carbide [kg]	0,0058	-Technical sheets	Created (cf. Par. 5.2.6): Tungsten carbide

	Transport [kg*km]	110	Calculated	Gabi: Lorry (22t) incl. fuel
OUTPUTS	Drilling bit; at quarry [pcs]	1	-	-
	Iron scrap [kg]	2,2	-Technical sheets	-

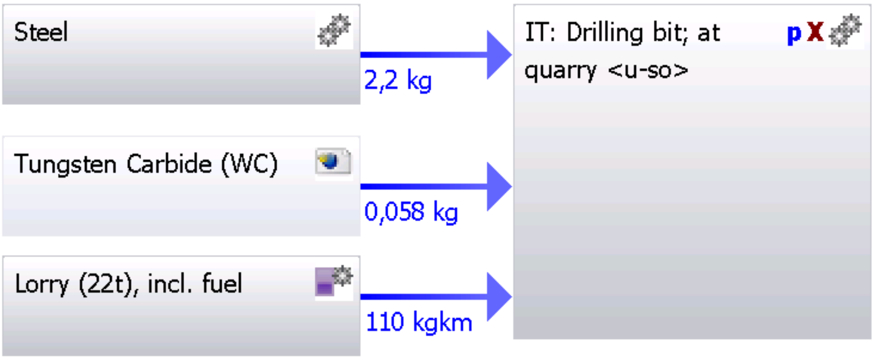


Figure 64: LCI dataset of 1 drilling bit

5.2.6 LCI of tungsten and tungsten carbide

Tungsten Carbide (WC) is produced with industrial technologies that can depend on the desired size of the particles and the end application. Among the most common technologies there is the processes summarized in Figure 65. As explained by Archer et al. (2003) and Wolfe et al. (2014), from tungsten ore and tungsten scraps it is produced Ammonium paratungstate (ATP) through hydrometallurgical methods. Tungsten trioxide (WO_3) is then produced by calcinations of ATP in the air (generally in rotary furnaces at 500-700°C). To convert WO_3 into tungsten metal (W), the predominant industrial method is the hydrogen reduction in apposite furnaces, where the reduction sequence is WO_3 -> WO_2 -> W. Subsequently, the carburization of W to form WC consists in pushing a graphite boat of blended tungsten metal and carbon powders through a furnace (at 1200 - 2000° C), in a reducing atmosphere.

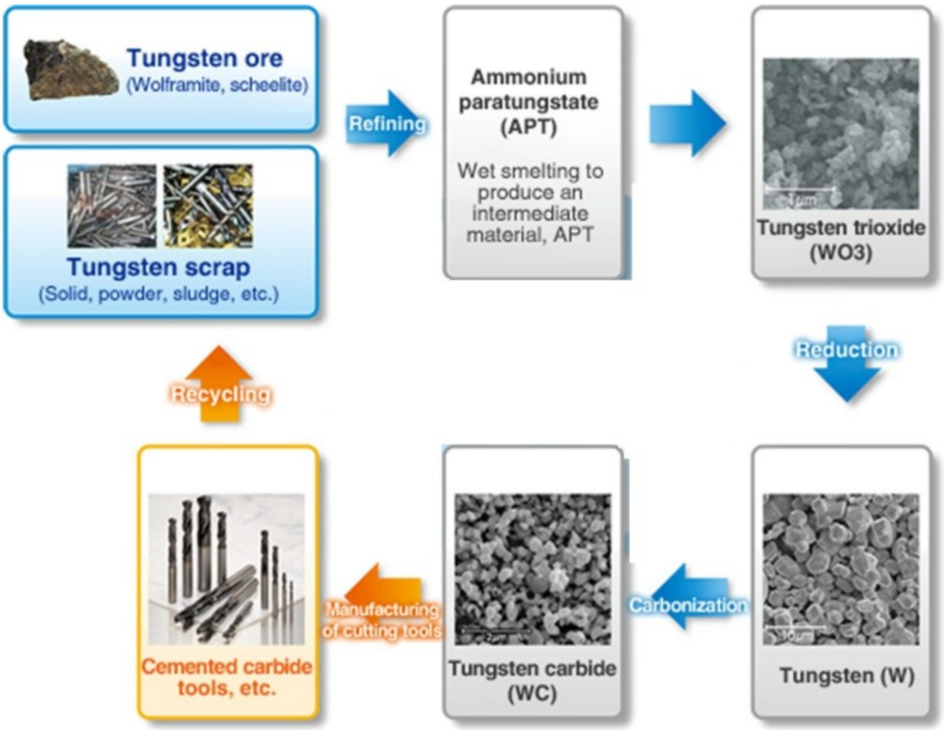


Figure 65: Tungsten carbide production chain (source: http://global-sei.com/sn/2013/435/3a.html)

The LC dataset of tungsten carbide (WC) has been modeled on the basis of literature data. Data from Novak et al., (2004); Syrrakou et al., (2005) and Bobba et al. (2016) were the basis for modelling the production of WO_3 (Table 44).

Table 44: Inventory of raw materials used for the WO_3 unit process (all the quantities are referred to 1 kg/WO_3) (Novak et al., 2004; Syrrakou et al., 2005; Bobba et al., 2016)

Denomination	**Quantity**	**Proposed correspondence with database Ecoinvent v2.2**
NaOH	1,03 kg	Sodium hydroxide, 50% in H_2O, production mix, at plant/RER
Al2(SO4)3e18H2O	0,08 kg	Aluminium sulphate, powder, at plant/RER
Sodium sulfide	0,05 kg	Sodium sulphide nanohydrate
Mg(SO4)e7H2O	0,03 kg	Magnesium sulphate, at plant/RER
Ammonium hydroxide	0,12 kg	Ammonia, liquid, at regional storehouse/CH
Soda ash	1,37 kg	Soda, powder, at plant/RER
Sulphuric acid	1,40 kg	Sulphuric acid, liquid, at plant/RER
Electricity	50 kWh	Electricity, medium voltage, production RER, at grid/RER

The conversion from WO_3 to W has been modeled on the basis of the LCA developed by Bobba et al. (2016), considering the processes to obtain W and WS_2 comparable (Table 45).

Table 45: Inventory of raw materials for producing 74,5 kg of WS_2 (Bobba et al., 2016).

Function	Denomination	Quantity	Proposed correspondence with database Ecoinvent v2.2
Raw material	WO_3	70 kg	-
Mixture gas	H_2 compressed gas	8,6 m3	Hydrogen sulphide, H2S, at plant/RER
	N_2 compressed gas	110 m3	Nitrogen, liquid, at plant/RER
	H_2S liquefied gas	25 kg	Hydrogen, liquid, at plant/RER
Energy	Electricity	1700 kWh	Electricity, medium voltage, production UCTE, at grid
Scrubbing solution	NaOH	46 kg	Sodium hydroxide, 50% in H2O, production mix, at plant/RER
	Water	225 l	cooling water

Finally, the carbonization process to produce WC from W has been modeled adding the carbon unit process. Since the atomic number of W is 184 and the atomic number of C is 12, in order to obtain a 1:1 ratio of W:C, the correct mass amounts are:

$$\text{Mass of carbon in WC} = \frac{12 \cdot 100}{184+12} = 6\%$$

$$\text{Mass of tungsten in WC} = \frac{184 \cdot 100}{184+12} = 94\%$$

Nevertheless, as explained by Archer (2004), enterprises generally add a 3 to 10% excess of carbon. An excess of 6% has been added in the model. Energy for this last process has been estimated starting from data of Dahmus and Gutowski (2004), saying that the embodied energy of tungsten carbide is about 400 MJ/kg. Subtracting the energy employed for the W production, it has been obtained a remaining energy of 164 MJ/kg, value that has been inserted in the model.

Table 46 summarizes the inventory for 1 kg of tungsten carbide production and Figure 66 illustrates the related LC model.

Table 46: Inventory of 1 kg of tungsten carbide and the proposed correspondent reference processes.

		FLOW NAME	VALUE	REFERENCE PROCESS
INPUTS	WO_3	NaOH [kg]	0,91	Sodium hydroxide, 50% in H_2O, production mix, at plant/RER
		Al2(SO4)3e18H2O [kg]	0,071	Aluminium sulphate, powder, at plant/RER
		Sodium sulfide [kg]	0,044	Sodium sulphide nanohydrate
		Mg(SO4)e7H2O [kg]	0,027	Magnesium sulphate, at plant/RER
		Ammonium hydroxide [kg]	0,106	Ammonia, liquid, at regional storehouse/CH
		Soda ash [kg]	1,21	Soda, powder, at plant/RER
		Sulphuric acid [kg]	1,24	Sulphuric acid, liquid, at plant/RER
		Electricity [MJ]	159	Electricity, medium voltage, production RER, at grid/RER
	W	H2 compressed gas [kg]	0,0076	Hydrogen sulphide, H2S, at plant/RER
		N2 compressed gas [kg]	1,65	Nitrogen, liquid, at plant/RER
		H2S liquefied gas [kg]	0,32	Hydrogen, liquid, at plant/RER
		Electricity [MJ]	77,2	Electricity, medium voltage, production UCTE, at grid
		NaOH [kg]	0,58	Sodium hydroxide, 50% in H2O, production mix, at plant/RER
		Water [kg]	2,84	cooling water
	WC	Carbon black [kg]	0,13	carbon black, at plant
		Electricity [MJ]	164	Electricity, medium voltage, production UCTE, at grid

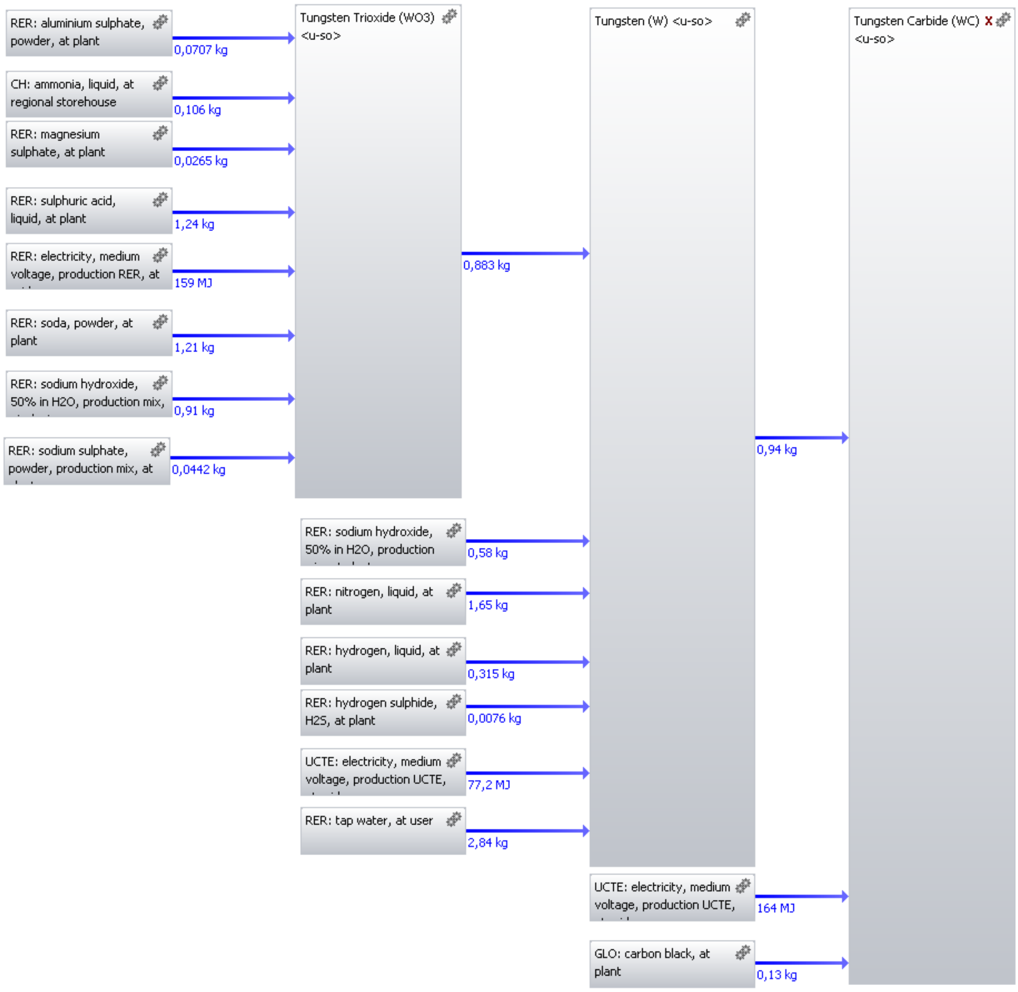


Figure 66: LCI dataset of 1 kg of tungsten carbide

5.2.7 LCI of sintered diamond wire

The diamond wire is a cutting tool highly widespread in the dimension stone sector. Nevertheless, studies on its environmental impact are scarce and there is no availability of datasets on this tool in Life Cycle databases. As a consequence, since purpose of this study is to provide datasets of processes in the dimension stone supply chain, the diamond wires production has been investigated.

As showed in Figure 67, diamond wires mainly consist of a steel rope, a set of diamond beads and a covering. Nevertheless, different kinds of diamond wires are

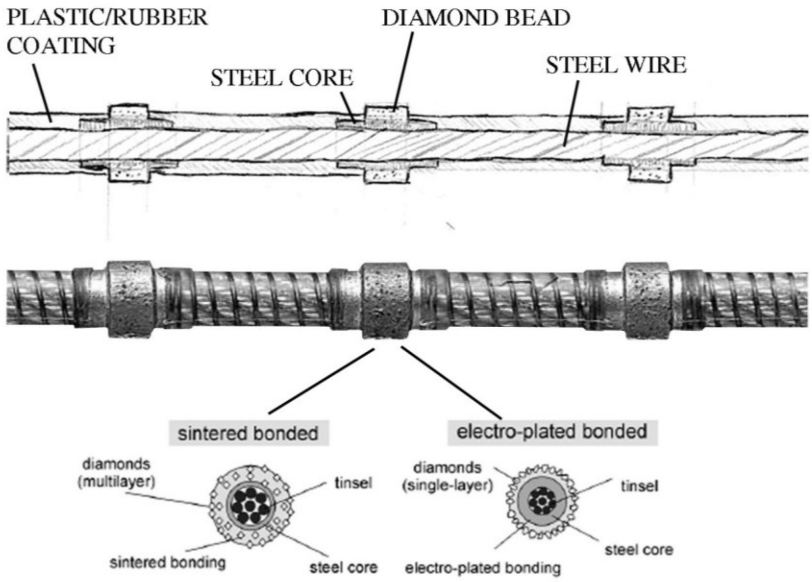


Figure 67: diamond wire composition (source of the central image: CO.FI.PLAST technical sheet) and difference between sintered and electroplated diamond beads (source of the bottom image: Tonshoff and Hillmann-Apmann, 2002)

currently available on the market, to satisfy different needs of the stone supply chain. The cutting element of the diamond wire is the bead, which is generally electroplated or sintered (Figure 67). Electroplated diamond beads have been the first to be introduced in the market and they are produced through an electrochemical process able to create a layer of diamonds on a steel core. In reason of this production process, the cutting agent (the diamond powder) is exclusively concentrated on the external side of the bead and the wearing of the bonding layer causes a rapid loose of the cutting efficacy. Nevertheless, the electroplated beads generally reach the highest cutting speeds. Sintered diamond beads are produced through a sintering process of metal and diamond powders on a steel core. In this case diamonds are concentrated on the entire thickness of the matrix, and the bead wearing always enable the release of new diamonds. As a consequence, the lifetime of sintered beads is generally longer than the electroplated ones.

Other differences can be find in the coating material. The most common coatings are made of plastic (mainly for hard stones), rubber (mainly for soft stones) or springs covered by a plastic layer. Finally, diamond wires of different dimensions are available: diamond wires with average bead diameter of 10,5 mm

Figure 68: a) diamond wire employed for cutting stone benches or squaring blocks; b) diamond wire employed for producing slabs with multiwire machineries.

are generally used to cut stone benches or to square blocks (Figure 68a), while thinner diamond wires (average bead diameter of 6,5 mm) are employed in multi-wire machineries to cut blocks into slabs (Figure 68b). Both these latter types of diamond wires have been investigated to create the correspondent LCI datasets, with reference, in both cases, to sintered beads and plastic coating. Electroplated diamond beads have not been modelled because of unavailability of data: the electroplating process is provided by few enterprises and it is covered by industrial secret.

Data were collected in the Italian enterprise Mega Diamant, located in Carrara and specialized in the production of sintered diamond wires. Secondary data from patents and papers were also collected to complement primary data.

The production of sintered diamond beads is explained in next Paragraph (5.2.8). To produce the diamond wire, beads are inserted in a steel rope with a semi-automatic system. Subsequently, the steel rope has to be covered with a protecting layer (Figure 69a). In the case of plastic coatings, a pre-adhesion liquid is applied for some minutes on the steel rope in order to facilitate the welding between steel and rubber. Then, thermoplastic granules (Figure 69b) are melted and injected at 300° C in a mould (Figure 69c), which hosts, at the same time the part of the steel rope to be covered. During this process, plastic residues are produced.

When the diamond wire reaches the end-of-life (usually due to the wear of the coating), the entire diamond wire is generally sent back to the producer. The wire is here placed into an oven which vaporizes the plastic/rubber covering and filters it. The waste here produced is disposed as a special waste. Residuals of plastic

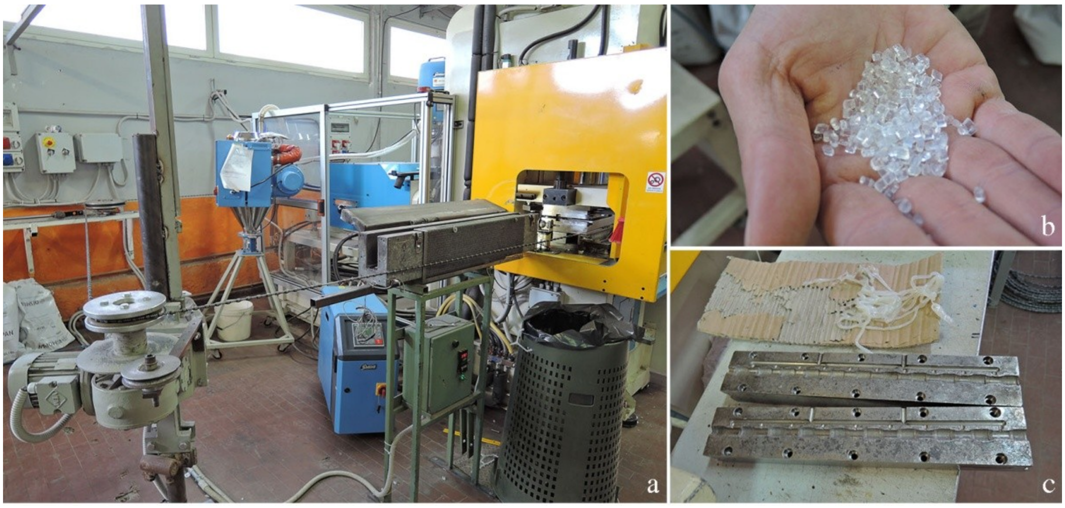


Figure 69: a) machinery for coating diamond wires; b) thermoplastic granules; c) mold employed for coating diamond wires with plastic.

combustion are completely removed through the washing of the wire in ultrasound solutions, followed by a centrifuge process. When the wire is clean, a machine separates the rope (then recycled as iron) from the beads and these latter are manually selected to be eventually reassembled in a new diamond wire. Commonly, the high wear of diamond beads employed in multi-wire machines does not enable their reuse, while beads from primary cuttings are generally reused for 3 to 6 times according to the material, surface and characteristics of the previous cuttings.

Table 47 lists the input and output flows of the LCI dataset related to the production of 1 m of sintered diamond wire for primary cuttings; Figure 70 shows the connected LC model.

Table 47: Inventory of the sintered diamond wire for primary cuttings, source of the flow values and the proposed correspondent reference processes.

	FLOW NAME	VALUE	DATA SOURCE	REFERENCE PROCESS
INPUTS	Sintered diamond bead [kg]	0,0427	-Cutting tool enterprise	Created (cf. Par. 5.2.8): Sintered diamond bead; for quarry diamond wires
	Electricity, IT grid mix [MJ]	3,24	-Cutting tool	Gabi:

			enterprise	IT Electricity grid mix
	Steel rope [kg]	0,095	-Cutting tool enterprise -Technical sheets	Gabi: Steel wire rod
	Plastic coating [kg]	0,15	-Cutting tool enterprise	Gabi- PlasticsEurope: Polyurethane flexible foam (PU)
	Lorry transportation [kg*km]	3	Calculated	Gabi: Lorry transport
OUTPUTS	Sintered diamond wire; for stone quarrying [m]	1	-	-
	Plastic waste [kg]	0,045	-Cutting tool enterprise	-

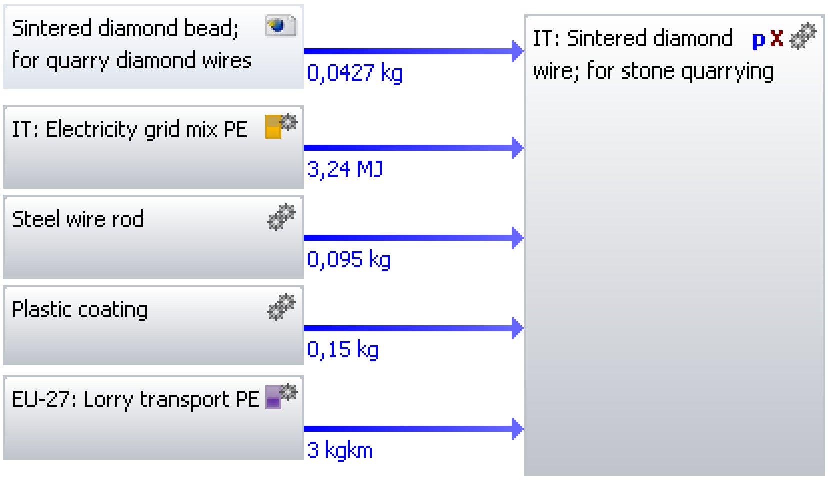


Figure 70: LCI dataset of 1 m of sintered diamond wire for primary cuttings

The steel rope has been modeled according to the Metalfuni technical sheet (Annex 8): it has a diameter of 4,85 mm and it is composed by 6 strands (each one composed by 7 wires) wrapped around a 19 wires core (Figure 70). The mass for 1 linear meter is 0,095 kg. The wire has been modelled considering 30 sintered beads/m, each bead having a diameter of 10,5 mm and a mass of 4 g and being regenerated 3 times.

Figure 71: a) picture of the steel wire employed for the production of diamond wires employed in quarries; b) cross-sectional scheme of the steel wire.

In Table 48 are listed the input and output flows of the LCI dataset related to the production of 1 m of sintered diamond wire for multi-wire cutting machineries. It has been considered a galvanised steel rope with a diameter of 3,2 mm, with the same geometry of the rope in Figure 71 and having a linear mass of 0,05 kg. The wire has been modelled considering 40 sintered beads/m, each bead having a diameter of 6,5 mm and a mass of 2 g.

Table 48: Inventory of the sintered diamond wire for multiwire machineries, source of the flow values and the proposed correspondent reference processes.

	FLOW NAME	VALUE	DATA SOURCE	REFERENCE PROCESS
INPUTS	Sintered diamond bead [kg]	0,08	-Tool producer	Created (cf. Par. 5.2.8): Sintered diamond bead; for quarry diamond wires
INPUTS	Electricity, IT grid mix [MJ]	3,24	-Tool producer	Gabi: IT Electricity grid mix
INPUTS	Steel rope [kg]	0,05	-Tool producer -Technical sheets	Gabi: Steel wire rod
INPUTS	Plastic coating [kg]	0,09	-Tool producer	Gabi- PlasticsEurope: Polyurethane flexible foam (PU)
INPUTS	Lorry transportation [kg*km]	0,15	Calculated	Gabi: Lorry transport

OUTPUTS	Sintered diamond wire [m]	1	-	-
	Plastic waste [kg]	0,028	-Tool producer	-

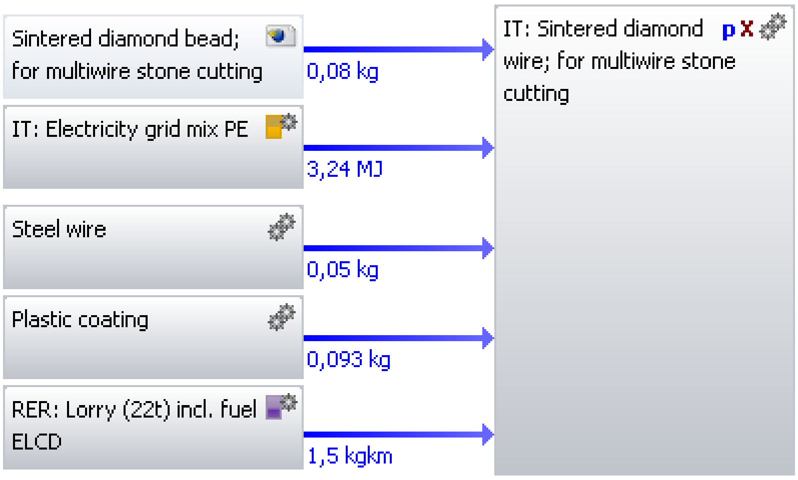


Figure 72: LCI dataset of 1 m of sintered diamond wire for multiwire machineries

5.2.8 LCI of sintered diamond beads

The LC dataset of sintered diamond beads has been created thanks to the collaboration of Mega Diamant enterprise (Carrara), which produces both diamond beads and diamond wires, and Mimitalia enterprise, specialized in the production of sintered tools. Other complementary information were collected through the literature analysis (Bobrovnitchii et al., 2003; de Oliveira et al., 2007; Karagöz and Zeren, 2001; Konstanty, 2007; Tillmann et al., 2010; Zeren and Karagöz, 2007, 2006) and technical sheets from Umicore and Tungstene.

The production of sintered diamond beads starts with the blended mixture of synthetic diamond powders with different metallic powders (which are the matrix precursor). The blended composite is dried in a little oven and then it is pressed to a steel bushing to obtain the green body of the future beads. After that, they are placed in graphite moulds and placed into an oven for the free sintering. The system has some pumps to filter the emissions created during the sintering process.

The choice of the metal matrix composition depends on the characteristics of the material to cut (such as, in particular, hardness) and beads with different compositions are nowadays available on the market. Generally, matrices are mainly composed of: cobalt, iron, nickel, copper, tin, tungsten and tungsten carbide. In the recent past, iron and cobalt were largely employed because of their good wear resistance; nevertheless since waste containing high percentages of these metals have to be treated as special waste, stone enterprises are starting asking for beads with a low percentage of these metals. Moreover, cobalt is among the critical raw materials (COM/2017/0490) (European Commission, 2017): just few countries produce it and it is subject to great variations. For all these reasons, the percentage of cobalt has today percentages lower than 20% and researchers and enterprises have developed new alloys to minimize its usage.

The LC dataset of the sintered diamond bead has been created considering a metal matrix with the composition listed in Table 49. Nevertheless, parameters have been set to easily allow the adaptation of the dataset to specific metal matrices.

Table 49: Composition of the metal matrix considered for the development of the diamond bead LCI dataset.

METAL POWDER	PERCENTAGE	METAL POWDER	PERCENTAGE
Iron	50%	Tungsten	5%
Copper	30%	Nickel	3%
Cobalt	10%	Phosphorus	2%

According to the collected data, the blended composite is made of the 70% in weight of metallic powders, 2% of synthetic diamond powder, 21% of silver weld, 5% of hardener and 2% of thickener. Moreover, according to primary data, during the bead production, nitrogen and hydrogen are employed. The following table summarizes the input flows for the production of 1 sintered bead for primary cuttings diamond wires, weighting 4 g.

Table 50: Inventory of the sintered diamond bead for primary cuttings, source of the flow values and the proposed correspondent reference processes.

	FLOW NAME	VALUE	DATA SOURCE	REFERENCE PROCESS
INPUT	Electricity, IT grid mix [MJ]	0,36	-Tool producers	Gabi: Electricity grid mix

	Steel core [g]	3	-Tool producers -Technical sheets	Gabi: Steel billet (20MoCr4)
	Cobalt [g]	7E-05	-Tool producers -Literature -Technical sheets	Ecoinvent: cobalt, at plant
	Copper [g]	0,00021	-Tool producers -Literature -Technical sheets	Gabi: Copper mix (99,999% from electrolysis)
	Iron [g]	3,5E-04	-Tool producers -Literature -Technical sheets	Ecoinvent: pig iron, at plant
	Nickel [g]	2,1E-05	-Tool producers -Literature -Technical sheets	Ecoinvent: nickel, 99.5%, at plant
	Tungsten [g]	3,5E-05	-Tool producers -Literature -Technical sheets	Created (cf. Par. 5.2.6): Tungsten (W)
	Diamond powder [g]	2E-05	-Tool producers -Literature -Technical sheets	Created (cf. Par. 5.2.9): Diamond powder
	Thickener [kg]	2E-05	-Tool producers -Literature -Technical sheets	Gabi: Polymethylmethacrylate granulate (PMMA)
	Hardener [kg]	5E-05	-Tool producers -Literature	Ecoinvent: cobalt, at plant
	Silver weld [kg]	2,1E-04	-Literature	Ecoinvent: silver, at regional storage
	Nitrogen [kg]	0,0323	-Tool producers	Gabi:

				Nitrogen
	Hydrogen [kg]	9E-04	-Tool producers	Gabi: Hydrogen
OUTPU	Sintered diamond bead; for quarrying [g]	4	-	-

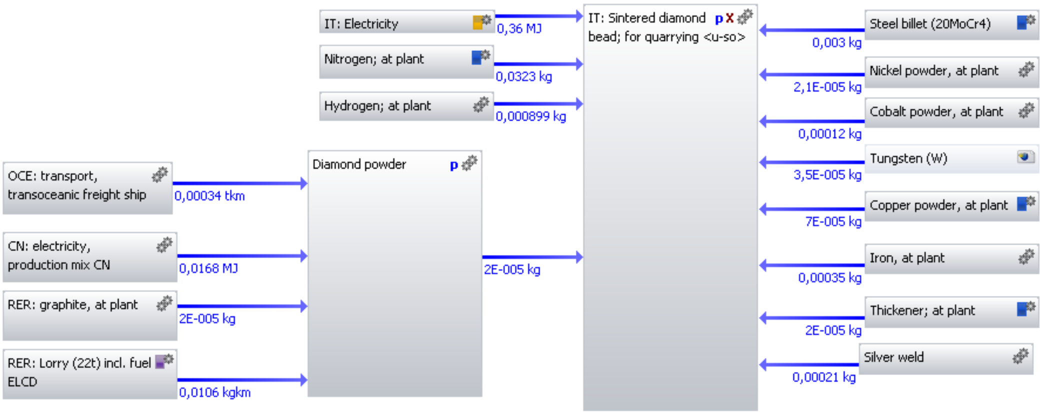


Figure 73: LCI dataset of 1 sintered diamond bead (weight: 4 g) for primary cuttings

Diamond beads of 6,5 mm diameter (used for cutting blocks into slabs) have also been modeled, as shown in Figure 74. The weight of each bead is of 2 g and the matrix composition has been assumed equal to the primary cuttings' beads.

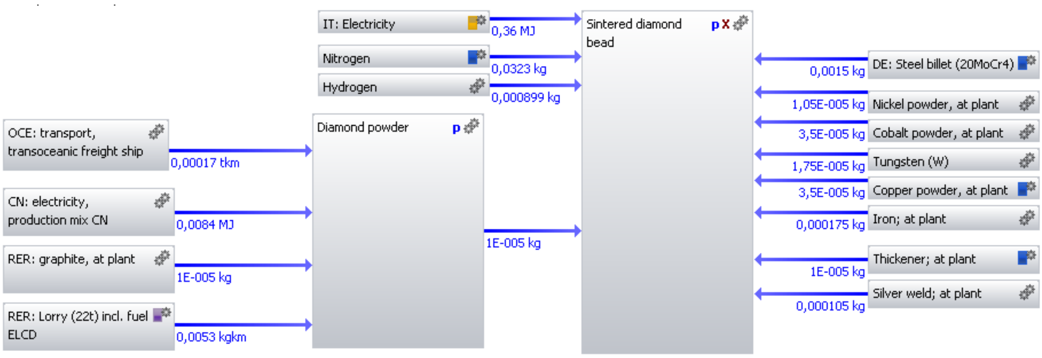


Figure 74: LCI dataset of 1 sintered diamond bead (weight: 2 g) for wires employed in multi-wire machineries.

5.2.9 LCI of diamond powder

Diamond powder is mostly produced industrially, and about 90% of the diamond powder employed for the Italian production of beads comes from Chinese enterprises. The high pressure, high temperature (HTHP) technique is the most largely employed: synthetic diamonds are produced by subjecting graphite and a metal catalyst to high pressures produced by four pistons; when the pressure target has been reached, electric current flowing through a resistance heater generates the required high temperatures. This process allows the creation of small diamond bits and dust, widely used for the production of cutting tools.

The dataset of the diamond powder is not available in Life Cycle database and, as a consequence, it has been created. Since the producing companies are mostly Chinese and since also European ones (such as Element Six) can not disclose process data, the dataset has been based on literature, in particular on the studies of Ali (2011) and Larsson et al. (2009).

Table 51 summarizes the input flows of the diamond powder dataset (referred to 1 kg of diamond powder). Transport inputs have been calculated for a transportation from Henan (China) to Carrara (Italy) and distances have been calculated through the website www.searates.com.

Table 51: Inventory of the diamond powder production, source of the flow values and the proposed correspondent reference processes.

	FLOW NAME	VALUE	DATA SOURCE	REFERENCE PROCESS
INPUTS	Electricity, IT grid mix [MJ]	3024	-Literature	Ecoinvent: electricity, production mix CN
	Graphite [kg]	1	-Literature	Ecoinvent: graphite, at plant
	Transport, transoceanic ship [kg*km]	170000	-Calculated	Ecoinvent: transport, transoceanic freight ship
	Transport, lorry [kg*km]	530	-Calculated	Ecoinvent: transport, lorry 16-32t, EURO4

OUTP	Diamond powder [kg]	1	-	Created

5.2.10 LCI of grease

Grease employed for the chain cutting technology (cf. Paragraphs 4.3.3 and 5.1.3) is a special grease with thickener based on aluminium complex soaps, of class 2 according to the NLGI (National Lubricating Grease Institute). According to Rudnick (2009), *a typical lubricating grease is made up of a high percentage of liquid lubricant or base oil (70- 95%), some thickeners (5-25%) and, depending on the grease destination, a little part of additives (0,5-10%)* (Fig. 8).

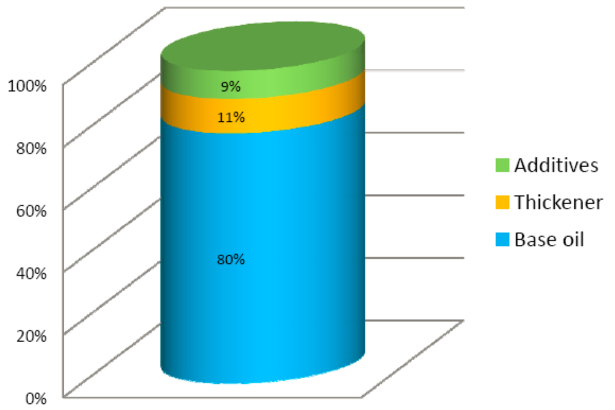


Figure 75: Typical grease composition (sources: Rudnick, 2009; AddNano project)

According to the studies developed by the European Addnano project (https://sites.google.com/site/addnanoeu/), the most representative base oils in the market are mineral base oil, synthetic base oil and hydrocracked base oil. According to technical data (Annex 9), the grease employed in quarries is a mineral base oil.

European Addnano project studied the LCA of mineral oil selecting, as a thickener, lithium soap. Nevertheless, the grease used in quarries has an aluminium soap, which is obtained by the reaction between aluminium isopropylate and carbonic acids in high quality mineral oil. As a consequence, the dataset of grease has been based on Addnano LCI, with some changing to adapt it to the specific grease employed for chain cutting. Annex 10 shows the aggregate process of grease; the unit process is here not showed because of the confidentiality of Addnano project data.

5.2.11 LCI of diamond disks

Diamond disks are largely employed in the dimension stone sector for squaring and cutting both soft and hard stones. The disk diameter can vary according to the disk function: giant disks (with diameter up to 4000 mm) are employed for squaring irregular blocks or for cutting thick slabs, while diameters of 400-1000 mm are commonly used for cutting slabs into tiles. Nevertheless the production chain of diamond disks is the same independently from the dimensions.

Disks are composed by a circular stainless steel core and a set of diamond sectors (cf. Paragraph 5.2.12) welded all along the perimeter. Two types of disks are available on the market: i) standard disks, with core made of high quality steel; ii) Silent disks, made of two disks separated by a copper sheet able to reduce the noise during the cutting.

Braze-welding technology is used to join diamond segments with the steel core. During this process it is employed a filler metal composed by silver, zinc, copper and other minor additions at a temperature of 650-700°C. Finally, the disk is grinded with a grinder machine, which employs water of recirculation (Figure 76).

Figure 76: a) welding of diamond sectors on the steel core of a disk; b) grinding of the diamond disk (images from Unidiamant - https://youtu.be/gYJsozO2YvE)

Generally diamond disks with diameter inferior than 600 mm are not reused and when disks are worn out, they are completely sent to recycling. For higher diameters, when diamond sectors are worn out, the disk is usually restored: sectors are detached and the steel core is cleaned in order to be employed for the production of a new disk. The steel core is recycled as long as it maintain a proper strain and then it is sent to recycling plants. Average values of the number of times steel core is reused were provided by Stein Varz enterprise, in relation to the diameter of the disk and the hardness of the stone to cut, as summarized in Table 52.

Table 52: Number of times that the steel core is generally reused, according to the disk diameter and the hardness of the stone.

Disk diameter [mm]	Reuse of disk steel core [number of times]	
	Soft stones	Hard stones
600-1400	2-3	5-10
1400-2000	5-10	20-30
>2000	30-40	50-100

Datasets were developed for the production of giant disks, disks for hard stones and disks for soft stones. Here follow the details.

LCI of giant diamond disks

The LC dataset of the giant disk has been modeled mainly with reference to primary data collected in Stein Varz enterprise (Crevoladossola) and in the stone transformation plants of Rinaudo (Scarnafigi), Chiri (Santena) and O.M.G. (Domodossola). The dataset is modeled for a disk with diameter of 3500 mm and thickness of 9,3 mm, 180 diamond sectors, each one with dimensions of 30mm x 20 mm x 13 mm. The steel core is supposed to be reused 55 times. In order to create a flexible dataset, able to be adapted to giant disks with different characteristics, the values have been set through a series of parameters which can be easily modified (Figure 77). Table 53 lists the inventory of giant disk dataset, while Figure 78 shows the related LC model.

Parameter

Parameter	Formula	Value	Comment, units, defaults
Weld_1sector		0,795	kWh - Electric energy for welding and rebore 1 slot
Thickness_disk		9,3	mm - thickness of the disk
n_steel_reuse		55	number of times that the steel core of the disk is reemployed
n_sectors		180	number of slots on a disk
Diameter_disk		3,5E003	mm - diameter of the disk
Diameter_bore		150	mm - diameter of the disk bore
Density_steel		7,8	kg/dm3 - Specific weight of steel
Radius_steel	(Diameter_disk-(2*20))/2	1,73E003	mm - radius of the steel part of the disk
Electricity	Weld_1sector*n_sectors	143	kWh - Electricity for welding and rebore 1 disk
Area_steel_disk	((Radius_steel)^2*3,14)-((Diameter_bore/2)^2*3,14)	9,38E006	mm - radius of the steel part of the disk
Volume_sector	3*2*1,3	7,8	cm3 - volume of the diamond slots
Vol_steel_disk	Area_steel_disk*Thickness_disk/1000000	87,2	dm3 - Volume of the steel part of the disk
Mass_1sector	Volume_sector*8,82/1000	0,0688	kg - mass of 1 slot (d=8,82 g/cm3; source: Stein Varz)
Steel_mass	Vol_steel_disk*Density_steel/n_steel_reuse	12,4	kg - mass of the steel part of the disk (divided by the number of reuse
Sector_mass	Mass_1sector*n_sectors	12,4	kg - mass of diamond slot
Transport	10*(Steel_mass+Sector_mass)	248	kgkm - Distance = 10 km; Weight = of the disk
Parameter			

Figure 77: editable parameters of the giant disk dataset

Table 53: Inventory of the giant disk, source of the flow values and the proposed correspondent reference processes.

	FLOW NAME	VALUE	DATA SOURCE	REFERENCE PROCESS
INPUTS	Steel [kg]	12,4	-Enterprise -Transformation plants	Gabi: Stainless steel Quarto plate (304)
INPUTS	Diamond sectors [kg]	12,4	-Enterprise -Transformation plants	Created (cf. Par. 5.2.11): Diamond sector; for cutting tools; Mix 49%Fe-18%Co (or Mix 57%Fe-25%Co)
INPUTS	Electricity [MJ]	515	-Enterprise -Transformation plants	Gabi: IT Electricity grid mix
INPUTS	Transport [kg*km]	248	Calculated	Gabi: Lorry (22t) incl. fuel
OUTP	Giant diamond disk [pcs]	1	-	-

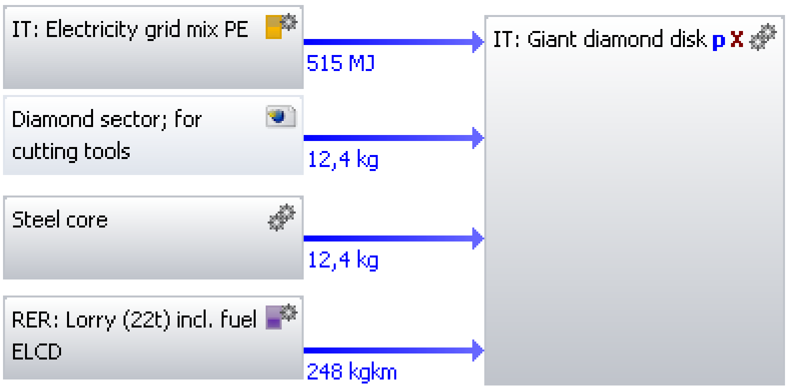


Figure 78: LCI dataset of 1 diamond disk with diameter of 3500 mm.

LCI of diamond disks for soft/hard stones

The LC dataset of diamond disks for cutting soft and/or hard stones has been modeled with reference to data collected from Stein Varz (Crevoladossola) enterprise and from the stone transformation plants of three transformation plants (located in Piedmont and Carrara district). To take into account the different End-of-Life of disks (cf. Table 52), three datasets were developed.

- Diamond disk; d=0,4m. This dataset is referred to a disk having a diameter of 400 mm and thickness of 1,5 mm, 28 sintered diamond sectors, each one with dimensions of 40 mm x 15 mm x 3,4 mm (for a weight of 18 g each). The steel core (of the standard type) is not reused. Table 54 shows the inventory of the diamond disk.

Table 54: Inventory of diamond disk with diameter d=400mm, source of the flow values and the proposed correspondent reference processes.

	FLOW NAME	VALUE	DATA SOURCE	REFERENCE PROCESS
INPUTS	Steel [kg]	1,39	-Tool producer -Transformation plants	Gabi: Stainless steel Quarto plate (304)
	Diamond sectors [kg]	0,504	-Tool producer -Transformation plants	Created (cf. Par. 5.2.11): Diamond sector; for cutting tools; Mix 49%Fe-18%Co (or Mix 57%Fe-25%Co)
	Electricity [MJ]	107	-Tool producer -Transformation plants	Gabi: IT Electricity grid mix
	Transport [kg*km]	18,9	Calculated	Gabi: Lorry (22t) incl. fuel
OUTPU	Diamond disk; d=400 mm [pcs]	1	-	-

- Diamond disk; for soft stones cutting; d=600mm. This dataset refers to a disk with diameter of 600 mm, thickness of 3,5 mm and 39 sintered diamond sectors, each one with dimensions of 40 mm x 7 mm x 5,5 mm (weight=14 g). A standard type steel core is considered and it is supposed to be reused 3 times. Table 55 shows the inventory of this diamond disk.

- Diamond disk; for hard stones cutting; d=600mm. This dataset refers to a disk with diameter of 600 mm, thickness of 3,5 mm and 39 sintered diamond sectors, each one with dimensions of 40 mm x 15 mm x 4,4 mm (weight=23 g). A standard type steel core is considered and it is supposed to be reused 7 times. Table 55 shows the inventory of this diamond disk.

Table 55: Inventory of diamond disks (for both soft and hard stones) with diameter d=600mm, source of the flow values and the proposed correspondent reference processes.

	FLOW NAME	VALUE		DATA SOURCE	REFERENCE PROCESS
		Soft stones	Hard stones		
INPUTS	Steel [kg]	2,49	1,07	-Enterprise -Transformation plants	Gabi: Stainless steel Quarto plate (304)
INPUTS	Diamond sectors [kg]	0,546	0,897	-Enterprise -Transformation plants	Created (cf. 5.2.11): Diamond sector; for cutting tools; Mix 49%Fe-18%Co (or Mix 57%Fe-25%Co)
INPUTS	Electricity [MJ]	149		-Enterprise -Transformation plants	Gabi: IT Electricity grid mix
INPUTS	Transport [kg*km]	72,8	19,6	Calculated	Gabi: Lorry (22t) incl. fuel
OUTPU	Giant diamond disk [pcs]	1		-	-

In order to further increase the datasets flexibility and enable their adaptation to diamond disks with different characteristics, geometries and performances, the values have been set through parameters which can be easily modified. Figure 79 shows the parameters.

Parameter

Parameter	Formula	Value	Comment, units, defaults
Area_steel_disk	((Radius_steel)^2*3,14)-((Diameter_bore/2)^2*3,14)	1,19E005	mm - radius of the steel part of the disk
Density_steel		7,8	kg/dm3 - Specific weight of steel
Diameter_bore		60	mm - diameter of the disk bore
Diameter_disk		400	mm - diameter of the disk
Electricity	Weld_1sector*n_sectors	29,7	kWh - Electricity for welding and grind 1 disk
Height_sectors		3,4	mm - height of the diamond sectors
Mass_1sector		18	g - mass of 1 sector
n_sectors		28	number of sectors on a disk
n_steel_reuse		3	number of times that the steel core of the disk is reemployed
Radius_steel	(Diameter_disk-(2*Height_sectors))/2	197	mm - radius of the steel part of the disk
Sector_mass	Mass_1sector*n_sectors/1000	0,504	kg - mass of diamond sector
Steel_mass	Vol_steel_disk*Density_steel/n_steel_reuse	0,462	kg - mass of the steel part of the disk
Thickness_disk		1,5	mm - thickness of the disk
Transport	24*(Steel_mass+Sector_mass)	23,2	kgkm - Distance= 24 km (Seravezza - Colonnata); Weight= of the disk
Vol_steel_disk	Area_steel_disk*Thickness_disk/1000000	0,178	dm3 - Volume of the steel part of the disk
Weld_1sector		1,06	kWh - Electric energy for welding and grind 1 slot
Parameter			

Figure 79: editable parameters of the diamond disk datasets

5.2.12 LCI of diamond sectors

The diamond sector is the abrasive element of different cutting tools commonly employed in the dimension stone supply chain, such as diamond blades and diamond disks. Primary data on the diamond sectors production were provided by Stein Varz enterprise (Crevoladossola); secondary data were also collected from technical sheets and publications of the enterprises Diam Edil (Lumino), Cuts Diamant (Noceto), Unidiamant (Carpaneto Piacentino).

Diamond sectors are obtained by sintering, which can be performed through different processes. One of the most common sintering methods is here described and modelled for the LC dataset of the diamond sector. The production consists in:

1. Mixing of metallic powders (precursor of the metal matrix of the sector) with diamond powders through apposite mixers, as shown in Figure 80a. Since the composition of the metal matrix is very variable, two datasets of diamond sector have been modeled, with two different metal matrixes. Details on the production of diamond powder are available at Paragraph 5.2.9.

2. Cold pressing of the mixed powders according to the desired geometry of the sector (Figure 80b). The total electricity for mixing powders and pressing them into segments is approximately of 43 MJ/kg.

3. Cooking of segments in an electric oven (Figure 80c-d). Three variants for this process are employed by enterprises:

- The most well-established process makes use of graphite moulds, which have a life time of about 80 cycles. The electricity consumed for this process is approximately of 212 MJ/kg of sector produced. The LC dataset is calculated according to this process;
- A more recent technology is the cooking of sectors in steel moulds. The life time of moulds is "infinite" and the electrical consumption is about three times lower than in the previous case. Nevertheless, the reason why the first technology is still predominant is the much higher cost of steel moulds in comparison to graphite ones;
- Cooking of moulds in an hydrogen environment. In this case there is no need of moulds, but the quality of the final product decreases.

Figure 80: Production chain of diamond sectors: a) mixing of metallic and diamond powders; b) cold pressing of powders; c) preparation of green bodies to the sintering process; c) sintering of diamond sectors

Emissions into air of the whole process are within the limits set by law, but specific quantitative data were not available. Table 56 shows the inventory of the diamond sector dataset, while Figure 81 shows the models of the two LC datasets of sintered diamond sector, which differs for the metal matrix composition.

Table 56: Inventory of 1 kg of sintered diamond sector, source of the flow values and the proposed correspondent reference processes.

	FLOW NAME	VALUE	DATA SOURCE	REFERENCE PROCESS
INPUTS	Electricity [MJ]	255	-Tool producer -Literature	Gabi: IT Electricity grid mix
	Graphite [kg]	0,0394	-Tool producer	Ecoinvent: graphite, at plant
	Diamond powder [kg]	0,02	-Tool producer -Literature	Created (cf. Par.5.2.9): Diamond powder
	Metal matrix; for diamond cutting tools [kg]	0,98	-Tool producer -Literature	Created (cf. Par.5.2.12): Metal matrix; for diamond cutting tools; Mix 57%Fe-25%Co or Metal matrix; for diamond cutting tools; Mix 49%Fe-25%Co
OUTP	Diamond sector; for cutting tools [kg]	1	-	-

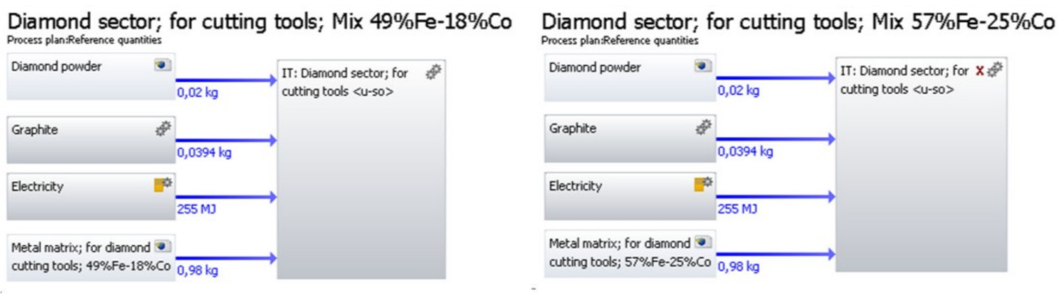


Figure 81: LCI datasets of 1 kg of sintered diamond sectors, with two different metal matrix compositions.

5.2.13 LCI of metal matrix for cutting tools

To produce diamond abrasive sectors of cutting tool, synthetic diamond powder (cf. Paragraph 5.2.9) is embedded in a metal matrix through a sintering process. The metal matrix is made from a set of metal powders whose composition can greatly vary from enterprise to enterprise.

The enterprises Stein Varz (Crevoladossola) and MIMitalia (Vado Ligure) provided information about the general composition of metal matrixes, while 19 technical sheets from Umicore-Tungstene were analysed and taken as reference for the identification of two plausible composition of metal powders. Table 57 shows the information from the technical sheets and the two mix designs chosen for the development of the LC datasets.

Table 57: metal matrix compositions according to technical sheets and the two mix designs employed for the development of the LCI datasets.

Product	Maximum % (in weight) in the metal mixture						
	Cobalt (Co)	Iron (Fe)	Copper (Cu)	Nickel (Ni)	Tungsten carbide (WC)	Phosphorus (P)	Tin (Sn)
keen10	30	65	20	0	0	0	0
keen20	25	50	35	0	0	0	0
keen30	25	75	5	0	0	0	0
KX1290	25	55	15	10	0	0	0
KX2250	15	30	20	60	0	0	0
MX 1660	20	40	30	0	20	0	0
MX 2480	30	50	20	0	0	0	0
MX4380	20	45	40	10	0	0	0
MX 4885	25	60	40	0	0	0	0
MX4940 (HCF3)	6	18	12	11	47	0	0
MX1180	20	20	40	0	20	0	0
MX1480	25	50	40	0	0	0	0
MX 1760	25	40	50	0	0	0	0
MX4590	15	45	40	11	0	0	0

MXB370	15	40	50	10	0	2	0
MXB380	15	40	40	10	0	0	0
Cobalite601	10	70	20	0	0	0	0
Cobalite HDR	27	66	7	0	0	0	0
Cobalite CNF	0	68,4	26	0	2	0	3
AVERAGE	21	49	29	6	5	0	0
MIN	6	18	5	0	0	0	0
MAX	30	75	50	60	47	2	3
Mix design 1	18	49	20	6	4	0	3
Mix design 2	25	57	5	12	1	0	0

Table 58 shows the inventories of the two LC datasets of metal matrix, while Figure 82 illustrates the related LCI models.

Table 58: Inventory of 1 kg of metal matrix according to two mix designs, source of the flow values and the proposed correspondent reference processes.

	FLOW NAME	**VALUE Mix 1** **49%Fe-18%Co**	**VALUE Mix 2** **57%Fe-25%Co**	**DATA SOURCE**	**REFERENCE PROCESS**
INPUTS	Iron [kg]	0,49	0,57	-Tool producers -Technical sheets	Ecoinvent: iron ore, 65% Fe, at beneficiation
	Cobalt [kg]	0,18	0,25	-Tool producers -Technical sheets	Ecoinvent: cobalt, at plant
	Nickel [kg]	0,06	0,12	-Tool producers -Technical sheets	Ecoinvent: nickel, 99.5%, at plant
	Copper [kg]	0,20	0,05	-Tool producers -Technical sheets	Ecoinvent: copper oxide, at plant
	Tungsten carbide [kg]	0,04	0,01	-Tool producers -Technical sheets	Created: Tungsten carbide

	Tin [kg]	0,03	0	-Tool producers -Technical sheets	Ecoinvent: tin, at regional storage
OUTPUTS	Metal matrix; for diamond cutting tools [kg]	1	1	-Tool producers -Technical sheets	-

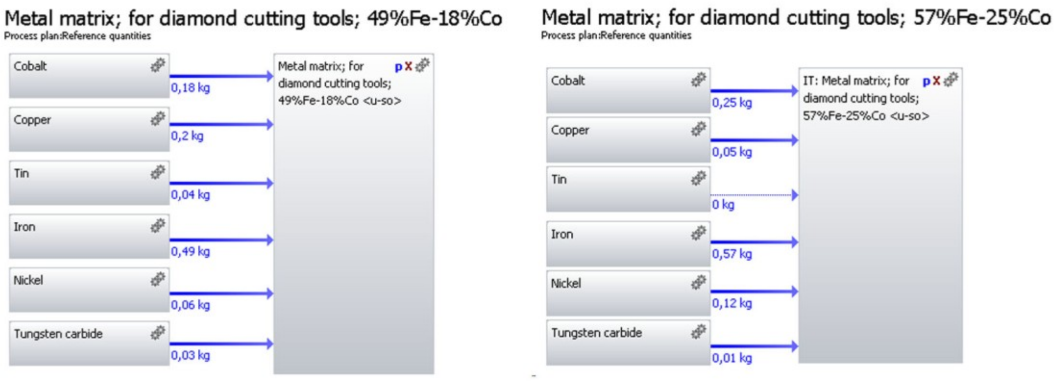


Figure 82: LCI datasets of 1 kg of metal matrix, according to two different compositions.

5.2.14 LCI of diamond blade

Diamond blades are employed both in single blade frame saws to square irregular blocks and in multi-blade gang saws to obtain slabs. Diamond blades are composed by a stainless steel blade with a set of diamond segments fixed on its edge. The dataset of diamond blade has been modelled on the basis of primary data provided by Stein Varz enterprise (Crevoladossola) and technical sheets of other enterprises (BM and Dellas). More in detail, the dataset is referred to a blade of dimensions 4,5 m x 0,08 m x 0,005 m, having 35 diamond segments of 20 mm x 5 mm x 7 mm. Table 59 shows the input flows.

Table 59: Inventory of 1 diamond blade (of weight 14,3 kg), source of the flow values and the proposed correspondent reference processes.

	FLOW NAME	VALUE	DATA SOURCE	REFERENCE PROCESS
INPUTS	Blade diamond insert (sintered) [kg]	0,2	-Tool producer -Technical	Created (cf. Par. 5.2.11) Diamond sector; for

			sheets	cutting tools; Mix 49%Fe-25%Co
	Stainless steel [kg]	14,1	-Tool producer -Technical sheets	PE: Stainless steel quarto plate (304)
	Electricity [MJ]	66,8	-Tool producer	PE: IT Electricity grid mix
	Transport [kg*km]	344	Calculated	PE: Lorry transport
OUTPUTS	Diamond blade [kg]	14,3	-	Created
	Stainless steel scrap	14,1	Calculated	-

The electricity for the production of the diamond blade is the sum of the electrical energy necessary for welding the diamond sectors and rebore the blade (same technology employed for the diamond disks, cf. Paragraph 5.2.11).

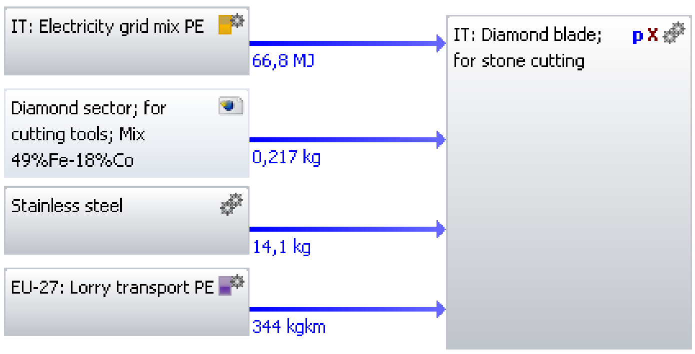


Figure 83: LCI datasets of 1diamond blade

5.2.15 LCI of metal abrasives

Metal abrasives are employed in the first stage of smoothing surface treatment. Many different metal abrasives are available on the market. The dataset here developed refers to a metal abrasive of 2,4 kg, made of 9 sintered diamond sectors welded on a steel support (Figure 84). Data were collected through direct measurements and information provided by Stein Varz enterprise (Crevoladossola) and Campolonghi transformation plant (Avenza). A set of parameters allow the dataset to be modified and adapted to metal abrasives of different geometry and characteristics. Table 60 shows the inventory of the metal abrasive.

Figure 84: metallic abrasive of reference for the LCI dataset.

Table 60: Inventory of 1 metal abrasive (of weight 2,4 kg), source of the flow values and the proposed correspondent reference processes.

	FLOW NAME	VALUE	DATA SOURCE	REFERENCE PROCESS
INPUTS	Electricity [MJ]	12,6	-Tool producer	PE: IT Electricity grid mix
	Diamond sector [kg]	0,144	-Tool producer	Created: Diamond sector; for cutting tools; Mix 49%Fe-18%Co
	Steel [kg]	2,22	-Transformation plants	PE: Steel hot rolled section
	Transportation [kg*km]	450	Calculated	PE: Lorry (22t) incl.

				fuel
OUTPUTS	Metal abrasive; for stone surface treatment [pcs]	1	-	-

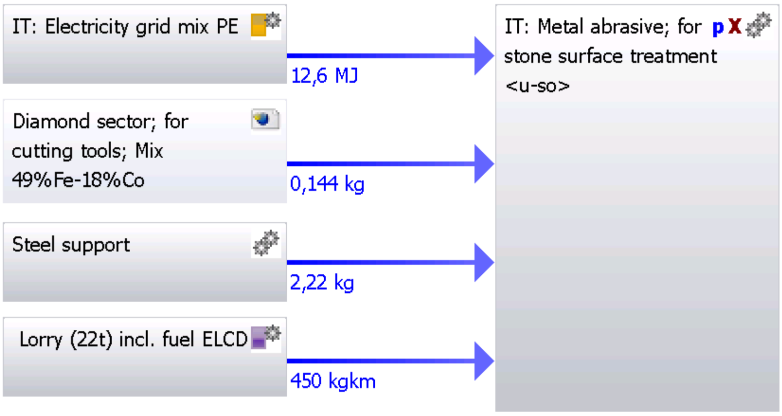


Figure 85: LCI datasets of 1 metal abrasive

5.2.16 LCI of resin diamond abrasives

The composition of resin diamond abrasive can highly vary according to the desired abrasive performances (different grit sizes correspond to different levels of roughness on the stone surface) and to the specific recipes of the producers. Because of the strong industrial secret on the abrasives production, it has not been possible to collect primary data and the dataset has been developed with secondary data. The analysis has been based, in particular, on patents (Scalari, 2007; Thimmappaiah et al., 1999; Wiand, 1995; 周华 et al., 2012; 尹育航 and 郑锐, 2006).

From literature, it emerged that, generally, resin diamond abrasives are made of at least one synthetic resin (such as epoxy resins, polyester resins, melamine resins, phenolic resins), abrasive materials (such as diamond, silicon carbide, corundum or boron carbide), fillers (such as calcium carbonate, ceramic oxides, quartz, barium sulfate, pumice), lubricants (such as graphite and metallic stearates), wetting agents (such as diethyl ether or ethanol) and curing agents (such as 4 4'-methylene dianiline, or diamino diphenyl methane). For each function, Table 61 shows the elements that have been selected for the LC dataset of diamond resin abrasive, as well as their typical (according to literature) percentage range (in weight) and the specific percentage inserted in the LC dataset model.

Table 61: Elements composing resin diamond abrasives according to literature and composition set for the LCI dataset.

Function	**Element**	**elements % range (in weight)**	**LC dataset: elements % (in weight)**
Synthetic resin of the thermosetting type	Epoxy resin	20-40	30
Filler	Calcium carbonate/quartz powder	15-35	25
Lubricating	Graphite/ metallic stearates	4-18	7
Wetting	Ethanol	1-4	3
Curing agent	4 4'-methylene dianiline	0.5-18	10
Abrasive	Industrial diamond	5-20	7
Additive abrasive	Silicon carbide	5-20	18

As explained in the Final Report of Midwest Research Institute (1994), for producing resin diamond abrasives, a synthetic resin is mixed with abrasive grains and a plasticizer allowing the mixture to be molded. The mixture is then hydraulically pressed and cured at 150 to 200°C for a period of from 12 hours to 4 or 5 days depending on the size of the wheel. After cooling, the wheels are checked for distortion, shape, and size.

Table 62 summarizes the inventory of the LC dataset of diamond resin, referring to an abrasive of volume 0,42 l; the electricity has been estimated for the mixing phase and for a curing period of 20 hours.

Table 62: Inventory of 1 resin diamond abrasive (of volume 0,42 l), source of the flow values and the proposed correspondent reference processes.

	FLOW NAME	**VALUE**	**DATA SOURCE**	**REFERENCE PROCESS**
INPUT	Epoxy resin [kg]	0,145	- Patents -Technical	Gabi: Epoxy resin

			sheets	
	Diamond powder [kg]	0,034	- Patents -Technical sheets	Created (cf. Par. 5.2.9): Diamond powder
	Silica sand [kg]	0,121	- Patents -Technical sheets	Gabi: Silica sand (Excavation and processing)
	Ethanol [kg]	0,043	- Patents -Technical sheets	Gabi: Ethanol
	Methylene [kg]	0,145	- Patents -Technical sheets	Gabi: Methylene diisocyanate (MDI)
	Silicon carbide [kg]	0,087	- Patents -Technical sheets	Ecoinvemt: silicon carbide, at plant
	Graphite [kg]	0,034	- Patents -Technical sheets	Ecoinvent: graphite, at plant
	Plastic [kg]	0,1	- Patents -Technical sheets	Gabi: Plastic injection moulding part (unspecific)
	Electricity [MJ]	10,8	- Report -Patents -Technical sheets	Gabi: IT Electricity grid mix
	Transportation [kg*km]	127	Calculated	Gabi: Lorry (22t) incl. fuel
OUTPUTS	Resin diamond abrasive; for stone polishing [kg]	1	-	-

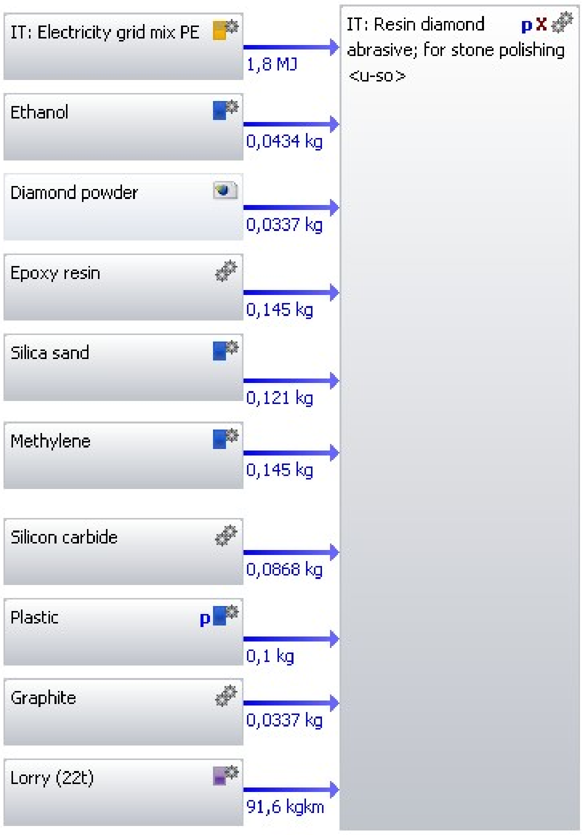


Figure 86: LCI datasets of 1 resin diamond abrasive (of volume 0,42 l)

5.2.17 LCI of magnesite abrasives

Magnesite abrasives had an important diffusion before the availability on the market of resin diamond abrasives, while nowadays their diffusion is quite limited. The major drawbacks of magnesite abrasives lies in the shorter lifetime and in the larger amount of sludge produced during its use. The LCI dataset of this tool has been modeled on the basis of secondary data, especially taken from patent CN101885897 (刘平安 et al., 2012).

For this kind of abrasives, the binder is the magnesia cement. This latter is also called Sorel cement, from the name of Frenchman Stanislas Sorel, which firstly produced it in 1867. The cement is a mixture of magnesium oxide (MgO) with magnesium chloride ($MgCl_2$) with a weight ratio of 2.5–3.5 parts MgO to one part $MgCl_2$ (Wiberg et al., 2001).

For producing magnesite abrasive, magnesium chloride is mixed with water to prepare a magnesium chloride solution; magnesium oxide, silicon carbide, a thermosetting resin powder/quartz powder are uniformly mixed and then added to the solution of $MgCl_2$ in a plastic mold. After 10 hours at room temperature, it is placed into a drying room, at a temperature of 80° C for 72 hours. Finally it is cooled to room temperature.

Table 63 shows the elements that have been selected for the LC dataset of magnesite abrasive, as well as their common (according to literature) percentage range (in weight) and the specific percentage of reference for the LC dataset model.

Table 63: Elements composing magnesite abrasives according to literature and composition set for the LCI dataset.

Function	**Element**	**Elements % range (in weight)**	**LC dataset: elements % (in weight)**
Abrasive materials	Silicon carbide (SiC)	12-18	12
	Brown aluminium oxide/ corundum	6-10	6
	Quartz powder	0-3	2
Binder (Sorel cement)	Magnesium oxide (MgO)	30-38	37
	Magnesium chloride ($MgCl_2$)	24-28	24
	Water	9-12	9
Resin	Thermosetting phenolic resin powder	6-10	10

The LCI dataset has been developed in reference to an abrasive having a volume of 0,42 l. The electricity employed for the mixing and drying phases have been estimated from technical sheets of industrial machineries.

Table 64 shows the inventory of the dataset. Because of the unavailability in LC databases of the Magnesium chloride dataset, it has been approximated with the dataset of Magnesium.

Table 64: Inventory of 1magnesite abrasive (of volume 0,42 l), source of the flow values and the proposed correspondent reference processes.

	FLOW NAME	VALUE	DATA SOURCE	REFERENCE PROCESS
INPUTS	Phenolic resin [kg]	0,067	- Patents -Technical sheets	Ecoinvent: phenolic resin, at plant
	Magnesium oxide [kg]	0,248	- Patents -Technical sheets	Ecoinvent: magnesium oxide, at plant
	Magnesium chloride [kg]	0,161	- Patents -Technical sheets	Gabi: Magnesium
	Water [kg]	0,063	- Patents -Technical sheets	Gabi: Tap water
	Silicon carbide [kg]	0,080	- Patents -Technical sheets	Ecoinvemt: silicon carbide, at plant
	Aluminium oxide	0,040	- Patents -Technical sheets	Ecoinvemt: aluminium oxide, at plant
	Quartz sand [kg]	0,013	- Patents -Technical sheets	Gabi: Silica sand (Excavation and processing)
	Plastic [kg]	0,1	- Patents -Technical sheets	Gabi: Plastic injection moulding part (unspecific)
	Electricity [MJ]	10,8	- Report -Patents -Technical sheets	Gabi: IT Electricity grid mix
	Transportation [kg*km]	127	Calculated	Gabi:

				Lorry (22t) incl. fuel
OUTPUTS	Resin diamond abrasive; for stone polishing [kg]	1	-	-

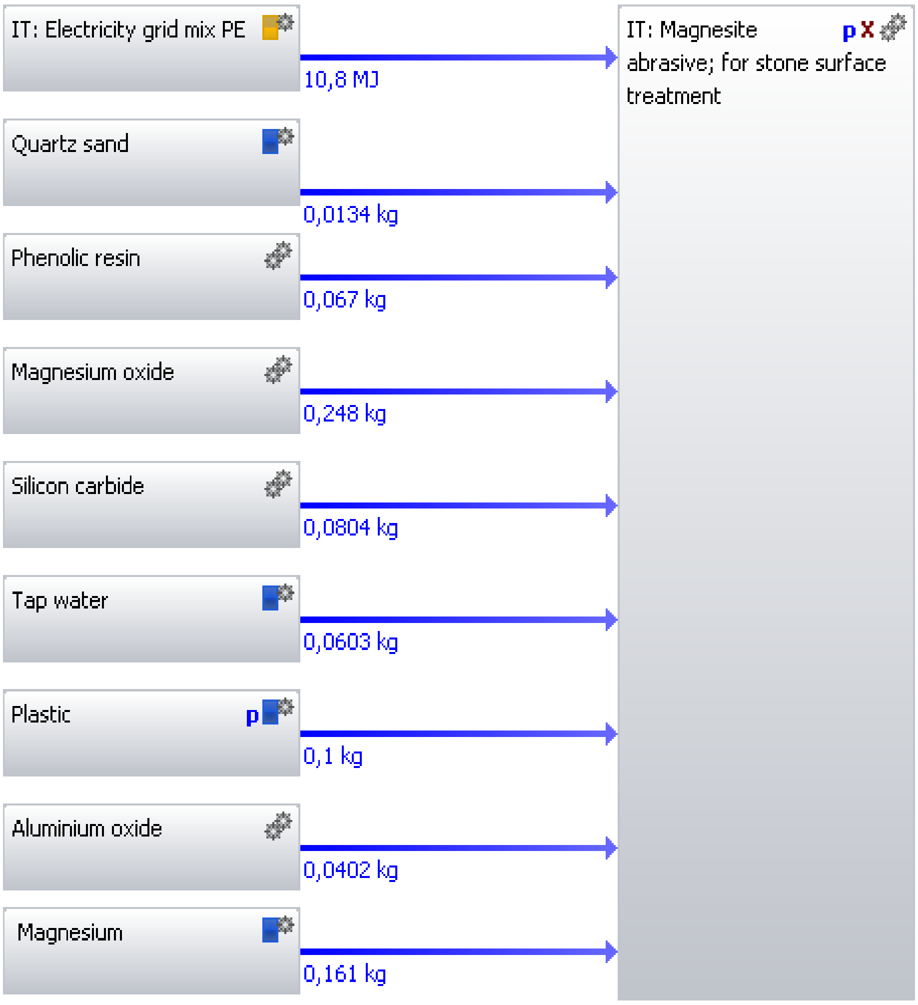


Figure 87: LCI datasets of 1 magnesite abrasive (of volume 0,42 l)

Chapter 6

From LCI to an adaptable LCA model for ornamental stone supply chains

Starting from the LCI datasets of quarrying, cutting and finishing techniques described in Chapter 5, the PhD research project also developed a general and flexible LCA model, aiming to boost and facilitate the Life Cycle impact assessment of specific stone supply chains. The previously created datasets are integrated in this LC model through editable parameters. As a consequence, this structure allows stone enterprises to replicate the model and adapt it to their specific production chains.

The model is organized in plans divided according to the main macro phases of the stone supply chain:

1. “Soft/Hard stone block; technology mix; at quarry”, where are gathered the technologies of the quarrying phase;

2. “Stone slab; technology mix; at plant”, where are gathered the technologies to obtain slabs from the stone blocks.

3. “Stone slab; smoothed/polished; at plant”, containing the processes of slab surface treatments;

4. “Stone tile; technology mix; at plant”, containing the technologies to cut slabs into tiles.

5. “Slurry extractive waste from stone cutting/polishing; End of Life”, containing some possible End-of-Life scenarios of stone sludge deriving from cutting and surface treatment processes.

The plans of the LC model comprehend the LCI processes described in Chapter 5. Through the setting of the parameters, this same model can be adapted to indifferently assess supply chains of enterprises working with soft stones, hard stones or a combination of both the materials. Thus, this structure has been conceived to facilitate the use of this tool also to enterprises which cut, in the same transformation plant, stone blocks coming from different quarries. Plan parameters allow the user to set the technology mix of reference, with possibility to assess, with a unique model, production chains whit multiple outputs (soft/hard stone slabs/tiles, with/without surface treatments). Moreover, these parameters could also be used to set and evaluate different Life Cycle scenarios.

The developed LC model specifically aims to support the stone sector with a tool characterized by detailed contents, which are organized in a general structure to allow their adaptation to different and specific ornamental stone supply chains. As a consequence, this dissertation do not contain the average Impact Assessment of the Italian stone supply chain. In fact, besides being not the aim of the research project, the average environmental burden of the stone production chain would not be very significant because of the large variations characterizing the ornamental stone sector. The environmental impact of the stone supply chain depends on:

- The technology mix, which is highly variable among different enterprises, even when they work with the same category of soft/hard stones (technologies largely employed in some enterprises can be completely absent in other enterprises);
- Even in case of comparable technology mix, the output products could be not comparable (quarries yield is highly instable, while transformation plants can prefer the production of slabs, tiles or thickness, with different geometries or different surface treatments according to specific market demand);

- Ornamental stone is a natural material: different mechanical characteristics correspond to different performances of the machineries.

For these reasons it has been preferred to just show an example of application of the model (Paragraph 6.2), being aware that it does not intend to be representative of the Italian stone supply chain.

Hereafter it is showed the structure of the LCA model.

6.1 LCA model: Stone slab/tile

Figure 88 shows the LC model created to assess specific ornamental stone production chains. As it can be noticed it comprehends all the phases from the quarrying of stone blocks to the final production of slabs or tiles, with the possibility to set also the End-of-Life of the stone sludge. Next paragraphs describe in details each plan.

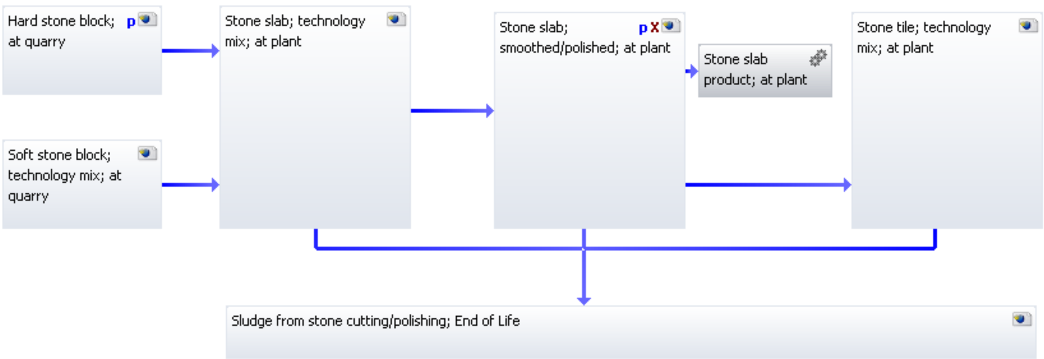


Figure 88: LCA model for the assessment of ornamental stone supply chains

6.1.1 LCA model: quarrying phase

The plan related to the **quarrying phase** of hard stone quarrying includes the processes connected to the dynamic splitting technique (black powder, detonation cord, detonator, drilling beams, electricity and slow burning fuses); while the plan of soft stones includes the technologies of drilling, chain cutting and diamond wire cutting. Moreover, both plans have a diesel input flow, employed for the blocks handling within the quarry and the elementary flows of water, Natural stone and Land Transformation. Three outputs, connected by a price allocation, have been set in both the plans: stone blocks, co-products and solid extractive waste. In the soft stone quarrying plan, the cutting sludge output flow has also been included.

Currently the hard stone quarrying plan is set with the average data collected in Luserna and Ossola Valley quarries. Nevertheless it could be useful to adapt the plan to specific quarries productions by editing the parameters listed in Table 65.

Table 65: Parameters for setting input and output flows of hard stone quarrying.

PARAMETER	UNIT	DESCRIPTION
Black_powder	kg	kg of black powder employed to quarry 1 m^3 of hard stone.
Slow_fuse	m	m of slow fuse employed to quarry 1 m^3 of hard stone.
Det_cord	m	m of detonation cord employed to quarry 1 m^3 of hard stone.
Detonator	n	number of detonators employed to quarry 1 m^3 of hard stone.
Diesel	MJ	Tot diesel employed to quarry 1 m^3 of hard stone.
Drilling_beam	m	m of steel beam employed to quarry 1 m^3 of hard stone.
Electricity	MJ	electricity necessary employed to quarry 1 m^3 of hard stone.
Water	kg	kg of water employed to quarry 1 m^3 of hard stone.
Land_transforma	m^2	area transformed to quarry 1 m^3 of hard stone.
Natural_stone	kg	Weight of 1 m^3 of hard stone.
Regular_block	m^3	m^3 of regular block for 1 m^3 of quarried stone.
Co_products	m^3	Volume of co-products for 1 m^3 of quarried stone.
Solid extractive waste	m^3	m^3 of solid extractive waste for 1 m^3 of quarried stone.

As far as concern the soft stone quarrying, the plan is currently referred to data collected in Gioia quarry (cf. Paragraph 5.1.4), but the parameters listed in Table 66 allow the user to set the plan according to specific productions.

Table 66: Parameters for setting input and output flows of soft stone quarrying.

PARAMETER	UNIT	DESCRIPTION
Chain_surface	m^2	Surface cut with chain technology for 1 m^3 of stone.

Co_products	m^3	Co-products (cliff blocks).
Diesel	MJ	Diesel necessary for cutting 1 m^3 of marble.
Drilling_length	m	Length of drilling for 1 m^3 of extracted stone.
DW_surface	m^2	Surface cut with DW technology for 1 m^3 of stone.
Solid extractive waste	m^3	m^3 of solid extractive waste for 1 m^3 of quarried stone.
Water		Water necessary for cutting 1 m^3 of marble.
Land_transforma	m^2	area transformed to quarry 1 m^3 of soft stone.
Natural_stone	kg	Weight of soft stone (for the total output volume).

6.1.2 LCA model: cutting into slabs phase

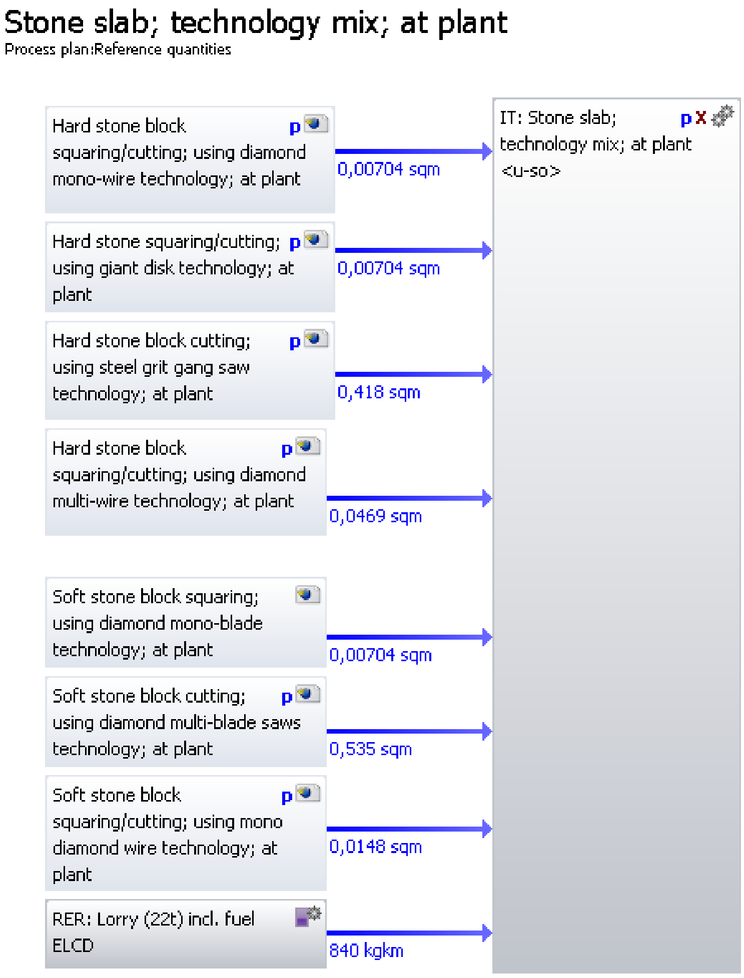


Figure 89: LCA plan for the cutting phase of ornamental stone supply chains

As it can be noticed in Figure 89, this plan includes the LCI datasets of the technologies of diamond mono-wire, giant disk, diamond mono-blade, steel grit gang saw, diamond multi-wire and diamond multi-blade saws + the transport of blocks from the quarry to the transformation plant. A list of editable parameters (Table 67, Figure 90) enables to adapt the plan to the different combinations of specific enterprises technology mix. With reference to the average production of specific enterprises, the user will have to fulfill the following data and the model will be automatically resized.

Table 67: Parameters for setting input and output flows for the phase of stone cutting into slabs.

PARAMETER	UNIT	DESCRIPTION
H_TOT_MultiBlad	m^2	Total area of hard stone cut via Steel grit gang saw
H_TOT_MultiWire	m^2	Total area of hard stone cut via Diamond Multi Wire technology
H_Vol_TOT_block	m^3	TOT volume of the hard stone block before squaring and cutting processes
H_area_TOT_prod	m^2	Total area of hard stone slabs produced from the initial blocks (having volume = Vol_TOT_block)
H_TOT_GiantDisk	m^2	Total area of hard stone cut via Giant Disk
H_TOT_MonoDW	m^2	Total area of hard stone cut via Diamond Mono Wire
S_area_TOT_prod	m^2	Total area of soft stone slabs produced from the initial blocks (having volume = Vol_TOT_block)
S_TOT_Multiblad	m^2	Total area of soft stone cut via Diamond multi blade technology
S_Vol_TOT_block	m^3	TOT volume of the soft stone block before squaring and cutting processes
S_TOT_MonoBlade	m^2	Total area of soft stone cut via Mono Diamond Blade technology
S_TOT_MonoDW	m^2	Total area of soft stone cut via Mono Diamond wire technology
Transport	kg*km	Average weight of 1 m^2 of slab * km from quarry to transformation plant

Parameter

Parameter	Formula	Value	Comment, units, defaults
H_TOT_MultiBlad		356	m2 - Total area of hard stone cut via Steel grit gangsaw
H_TOT_MultiWire		40	m2 - Total area of hard stone cut via Multi Diamond Wire technique
H_Vol_TOT_block		12,6	m3 - TOT volume of the hard stone block before squaring and cutting processes
H_area_TOT_prod		396	m2 - Total area of hard stone slabs produced from the initial blocks (having volume = Vol_TOT_block)
H_TOT_GiantDisk		6	m2 - Total area of hard stone cut via Giant Disk
H_TOT_MonoDW		6	m2 - Total area of hard stone cut via Mono Diamond Wire
S_area_TOT_prod		456	m2 - Total area of soft stone slabs produced from the initial blocks (having volume = Vol_TOT_block)
S_TOT_Multiblad		456	m2 - Total area of soft stone cut via Diamond multi blade technique
S_Vol_TOT_block		12,6	m3 - TOT volume of the soft stone block before squaring and cutting processes
S_TOT_MonoBlade		6	m2 - Total area of soft stone cut via Mono Diamond Blade technique
S_TOT_MonoDW		6	m2 - Total area of soft stone cut via Mono Diamond wire technique
Transport		840	kg*km - Average weight of 1 m2 of slab * km from quarry to transformation plant
TOT_slabs	H_area_TOT_prod+S_area_TOT_prod	852	m2 - TOT area of hard and soft stone slabs produced
H_rate	H_area_TOT_prod/TOT_slabs	0,465	- rate of hard stone slabs produced
S_MonoBlade	S_TOT_MonoBlade/TOT_slabs	0,00704	m2 - area of soft stone cut with mono diamond blade technique
S_Mono_DW	S_TOT_MonoDW/TOT_slabs	0,00704	m2 - area of soft stone cut with mono diamond wire technique
S_Diam_Multibl	S_TOT_Multiblad/TOT_slabs	0,535	m2 - area of soft stone cut with diamond multi blade technique
S_rate	S_area_TOT_prod/TOT_slabs	0,535	- rate of soft stone slabs produced
H_Mono_DW	H_TOT_MonoDW/TOT_slabs	0,00704	m2 - area of hard stone cut with mono diamond wire technique
H_Giant_disk	H_TOT_GiantDisk/TOT_slabs	0,00704	m2 - area of hard stone cut with giant disk techique
H_Multiwire	H_TOT_MultiWire/TOT_slabs	0,0469	m2 - area of hard stone cut with diamond multiwire technique
H_Multiblade	H_TOT_MultiBlad/TOT_slabs	0,418	m2 - area of hard stone cut with multiblade gangsaw technique
S_Stone_Block	S_Vol_TOT_block/S_area_TOT_prod*S_rate	0,0148	m3 - TOT volume of the soft stone block before squaring and cutting processes
H_Stone_Block	H_Vol_TOT_block/H_area_TOT_prod*H_rate	0,0148	m3 - Volume of hard stone block necessary for the production of 1 m2 of slab
Parameter			

Figure 90: screenshot (from Gabi software) of the plan parameters for the phase of stone slabs cutting

As a default the parameters have been set for a block of soft stone and a block of hard stone, both having dimensions of 3x2x2,10 m^3 and squared for a total surface of 12 m^2 (for the soft stone block: 50% provided by mono-blade technology, 50% by mono-wire technology; for the hard stone block: 50% provided by giant disk technology, 50% by mono-wire technology). The parameters related to the soft stone production have been set for 33 slabs/m of thickness, cut with the diamond multi-blade technology, with a total surface of 456 m^2. While the parameters of hard stone cutting refers to a production of 38 slabs/m of thickness, cut with the steel grit gang saw technology (90%) and with the diamond multi-wire technology (10%), for a total surface of 396 m^2.

6.1.3 LCA model: surface treatment phase

The surface treatment plan is composed by the dataset of smoothing and by the processes related to the polishing phase (electricity, resin diamond abrasives, water). As a consequence, the polishing values can be edited to set the rate of slabs that is just smoothed and the rate of slabs that is also polished. The default value is set for a 100% of slabs polished (Figure 91).

Parameter

Parameter	Formula	Value	Minimum	Maximum	Standar	Comment, units, defaults
Electricity		0,63	0,47	0,8	37 %	MJ - electricity for grinding 1 mq of marble slab
Flocculant		7,5E-006			0 %	kg
Rate_slab		0,7			0 %	- rate of slabs (not subjected to transformation into tiles)
Rate_to_tile	1-Rate_slab	0,3				- rate of slabs destined to be transformed into tiles
Resin_Abrasive		0,052	0,037	0,067	40 %	pcs/m2 - number of resin diamond abrasives necessary for smoothing 1 m2 of marble slab
Steel_scrap		1			0 %	kg/mq - mass of diamond metal abrasive at End of Life per mq of brushed slab
Waste_treated		3			0 %	kg - mass of the treated sludge (after filter-press, hp: 22% of weight is water)
Water_use		0,76	0,48	1,03	52 %	l - New water for smoothing 1 mq of slab
Parameter						

Figure 91: screenshot (from Gabi software) of the plan parameters for the surface treatment phase of ornamental stone supply chains

6.1.4 LCA model: tile production

The plan related to the **tile production** is composed by the diamond disk cutting technologies. The choice of the kind of disk to use is mainly related to the thickness of the slab to cut. Moreover, the performance of the disks significantly change according to hardness of the stone to cut. A set of parameters have been defined (Figure 92) and, through the editable ones (Table 68), the user can adapt the plan to specific tile productions. The default values have been set for the cutting of stone tiles (50% soft stones, 50% hard stones) having dimensions of 0,6 x 0,6 m^2. 70% of the tiles has been set with a thickness of 3 cm (cut with a disk of 400 mm diameter) and the other 30% with a thickness of 12 cm (cut with a disk of 600 mm diameter).

Parameter

Parameter	Formula	Value	M	Comment, units, defaults
S_TOT_area_tile		2		m2 -Insert the total area of thin+thick soft stone slabs produced
S_area_disk2		0,16		m2 - Insert the TOT area (thickess) cut to produce soft stone thick tiles
S_area_disk1		0,04		m2 - Insert the TOT area (thickess) cut to produce soft stone thin tiles
H_TOT_area_tile		2		m2 -Insert the total area of thin+thick hard stone slabs produced
H_area_disk2		0,16		m2 - Insert the TOT area (thickess) cut to produce hard stone thick tiles
H_area_disk1		0,04		m2 - Insert the TOT area (thickess) cut to produce hard stone thin tiles
TOT_area_tiles	H_TOT_area_tile+S_TOT_area_tile	4		m2 -total area of stone slabs produced
S_disk2	S_area_disk2/TOT_area_tiles	0,04		m2 - Area (thickness) of soft stone cut with disks≥600 mm for producing 1 m2 of stone tile
S_disk1	S_area_disk1/TOT_area_tiles	0,01		m2 - Area (thickness) of soft stone cut with disks<600 mm for producing 1 m2 of stone tile
H_disk2	H_area_disk2/TOT_area_tiles	0,04		m2 - Area (thickness) of hard stone cut with disks≥600 mm for producing 1 m2 of stone tile
H_disk1	H_area_disk1/TOT_area_tiles	0,01		m2 - Area (thickness) of hard stone cut with disks<600 mm for producing 1 m2 of stone tile
Parameter				

Figure 92: screenshot (from Gabi software) of the plan parameters for the phase of stone tiles cutting

Table 68: Parameters for setting input and output flows for the phase of stone cutting into tiles.

PARAMETER	UNIT	DESCRIPTION
S_TOT_area_tile	m^2	Total area of thin+thick soft stone slabs produced.

S_area_disk2	m^2	TOT area (thickness) cut to produce soft stone thick tiles.
S_area_disk1	m^2	TOT area (thickness) cut to produce soft stone thin tiles.
H_TOT_area_tile	m^2	total area of thin+thick hard stone slabs produced.
H_area_disk2	m^2	TOT area (thickness) cut to produce hard stone thick tiles.
H_area_disk1	m^2	TOT area (thickness) cut to produce hard stone thin tiles.

6.1.5 LCA model: slurried extractive waste from stone cutting/finishing processes

As explained in Paragraph 4.6, cutting and finishing processes generally produce slurried extractive waste, whose physical and chemical characteristics are directly related to the stone that has been processed and to the specific techniques and cutting tools employed (Zichella et al., 2017).

In the adaptable LCA model, a plan has been created to give the possibility of considering different End-of-Life scenarios for the stone slurried waste produced during the cutting and finishing processes. As it is showed in Figure 93, this plan is composed by the scenarios of: i) landfill; ii) sending to recycling processes; iii) direct disposal into the ecosphere. This latter has been modeled in reason of the quite diffused practice of cumulating the filter-pressed slurried extractive waste in an area close to the transformation plant where it has been generated. It is worth noting that the chemical composition of the slurried waste is highly variable and that, as a consequence, the hereafter showed LC processes are strictly connected to a specific slurried waste, but may be not completely representative of other slurried extractive waste.

The End-of-Life processes of slurried waste to the ecosphere (Figures 94 and 95) have been modeled with reference to chemical analysis of:

- 4 samples collected in hard stone transformation plants located in Verbano-Cusio-Ossola province. The chemical analysis have been provided by L. Zichella and her working group.

- Carrara marble sludge, data from literature (Tinti et al., 2005).

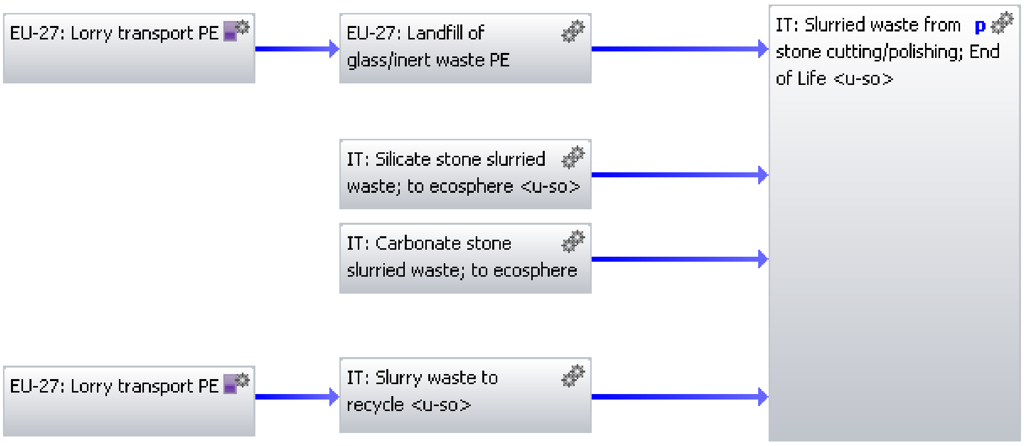


Figure 93: LCA plan for modeling the sludge End-of-Life in the ornamental stone supply chain

Outputs

Flow	Quantity	Amount	Unit	Tra	Standar	Origin	Comment
Silicate stone slurried waste; to ecosphere [STONE	**Mass**	**1,28**	**kg**	**X**	**0 %**	**Calculated**	
Aluminium (+III) [Inorganic emissions to fresh water]	Mass	2,3E-005	kg		0 %	Measured	Chemical analysis
Arsenic [Heavy metals to industrial soil]	Mass	5E-008	kg		0 %	Measured	Chemical analysis
Cadmium [Heavy metals to industrial soil]	Mass	3E-009	kg		0 %	Measured	Chemical analysis
Cesium [Heavy metals to fresh water]	Mass	2E-009	kg		0 %	Measured	Chemical analysis
Chromium (unspecified) [Heavy metals to industrial soil]	Mass	3,7E-007	kg		0 %	Measured	Chemical analysis
Cobalt [Heavy metals to industrial soil]	Mass	9E-007	kg		0 %	Measured	Chemical analysis
Copper [Heavy metals to industrial soil]	Mass	5,1E-007	kg		0 %	Measured	Chemical analysis
Iron [Heavy metals to industrial soil]	Mass	4,85E-005	kg		0 %	Measured	Chemical analysis
Lead [Heavy metals to industrial soil]	Mass	9,5E-008	kg		0 %	Measured	Chemical analysis
Manganese [Heavy metals to industrial soil]	Mass	1,41E-006	kg		0 %	Measured	Chemical analysis
Nickel [Heavy metals to industrial soil]	Mass	1,5E-007	kg		0 %	Measured	Chemical analysis
Rubidium [Inorganic emissions to fresh water]	Mass	5,7E-007	kg		0 %	Measured	Chemical analysis
Selenium [Heavy metals to industrial soil]	Mass	0	kg		0 %	Measured	Chemical analysis
Silver [Heavy metals to industrial soil]	Mass	3E-008	kg		0 %	Measured	Chemical analysis
Strontium [Inorganic emissions to industrial soil]	Mass	5,9E-006	kg		0 %	Measured	Chemical analysis
Vanadium [Heavy metals to industrial soil]	Mass	1,9E-007	kg		0 %	Measured	Chemical analysis
Zinc [Heavy metals to industrial soil]	Mass	1,11E-006	kg		0 %	Measured	Chemical analysis
Flow							

Figure 94: proposed process for the silicate stone slurried waste to ecosphere

Outputs

Flow	Quantity	Amount	Unit	Tra	Standar	Origin
Carbonate stone slurried waste; to ecosphere	**Mass**	**0,6**	**kg**	**X**	**0 %**	**Literature**
Aluminium [Inorganic emissions to industrial soil]	Mass	0,00012	kg		0 %	Literature
Iron [Heavy metals to industrial soil]	Mass	0,0066	kg		0 %	Literature
Limestone (calcium carbonate) [Waste for recovery]	Mass	0,926	kg		0 %	Literature
Magnesium [Inorganic emissions to industrial soil]	Mass	0,0034	kg		0 %	Literature
Manganese [Heavy metals to industrial soil]	Mass	0,0005	kg		0 %	Literature
Silicon dust [Particles to air]	Mass	0,0165	kg		0 %	Literature
Flow						

Figure 95: proposed process for the carbonate stone slurried waste to ecosphere

As far as concern the landfill scenario, the Gabi process “Landfill of glass/inert waste” has been considered, with a transport of 20 km. While the sending to recycle plants consider a Lorry transport for 40 km.

As it can be noticed in Figure 96, the slurried waste End-of-Life plan include parameters to set the rates of the different End-of-Life scenarios to which the waste is destined. The default values of the rates have been set to: 0,7 for the landfill scenario; 0,1 for the sending to recycling; 0,1 for the soft stone sludge to the ecosphere; 0,1 for the hard stone sludge to the ecosphere.

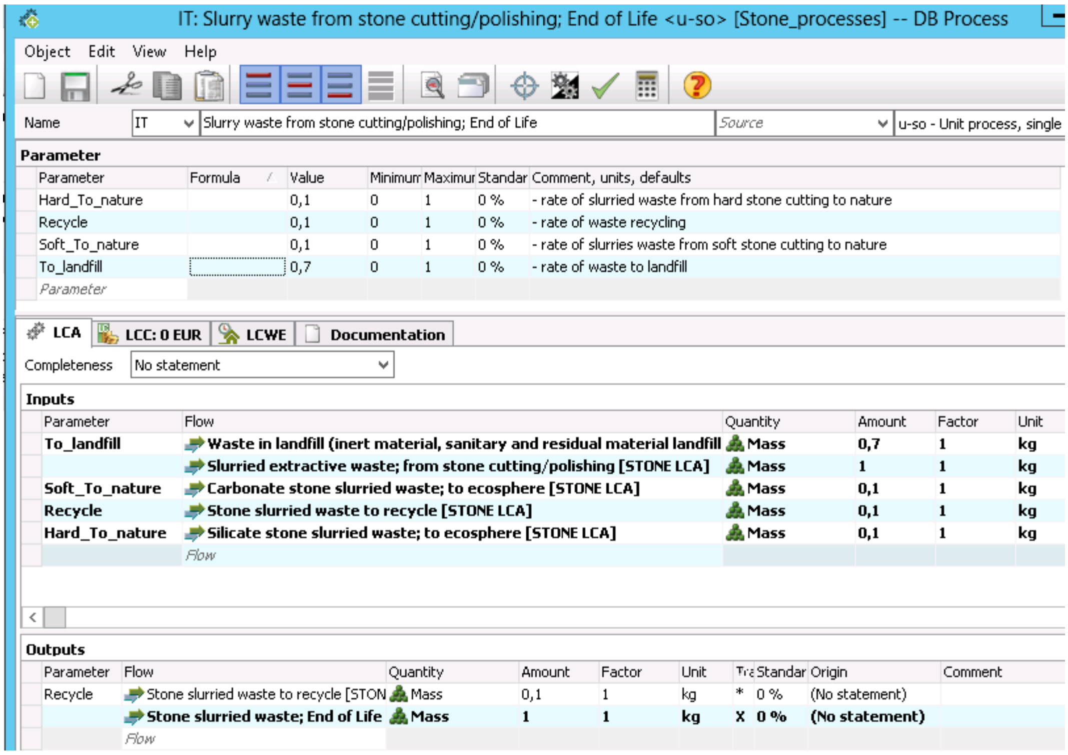


Figure 96: End-of-Life parameters in the stone slurry waste LC plan

6.2 Impact categories for the assessment of ornamental stone supply chains

The environmental evaluation of the ornamental stone supply chain should be carried out including the potential impact areas mostly affected by the extractive and processing activities. In particular, because of use of electricity and diesel during all the phases of the production chain, it could be interesting to evaluate the potential impacts in terms of global warming potential and acidification and to identify the processes which are responsible of the major contributions. Moreover, the stone sector is directly connected to issues related to the terrestrial, water and air contamination because of the waste water and of particulate matter produced in quarries (cf. Paragraph 1.5) and of the possible presence of heavy metals and oils in slurried extractive waste (cf. Paragraph 4.6). As a consequence, it could be interesting to investigate the composition of waste and its End-of-Life scenario for specific stone supply chains and evaluate the impact categories of freshwater and terrestrial eutrophication and particulate matter/respiratory inorganics. Because of the quarrying activity, other important issues for the ornamental stone sector are Mineral resource depletion and the natural land transformation.

Nevertheless, it is worth noting that the characterization factors of the LCIA methods describing the above mentioned impact categories, in some cases do not find scientific consensus. Annex 5 (from the ILCD Handbook on recommended LCIA methods for Europe) presents the summary of methods recommended by the European Commission (models and associated characterisation factors) and their classification both at midpoint and at endpoint. These methods are classified into three quality level: I) recommended and satisfactory; II) recommended but in need of some improvements; III) recommended, but to be applied with caution. As it can be noticed, for some impact categories which are relevant for the ornamental stone sector, the reliability of the connected methods still has to be improved.

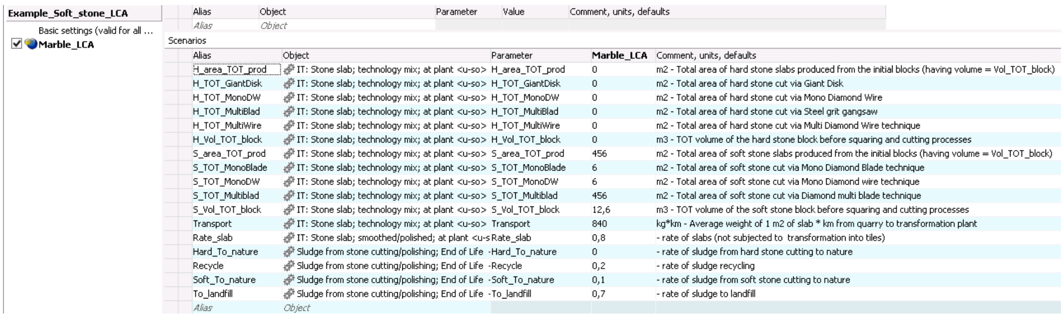
Moreover, the reliability of the impact results has to be evaluated also in accordance with the level of representativeness of the LC model to the specific input/output flows of the stone production chain under study.

6.3 Example of LCA development for a specific stone supply chain

The LC model has been tested through the development of an illustrative Life Cycle Assessment. The model has been set with reference to the average data collected in soft stone quarries and transformation plants for a production of stone slabs. As previously explained, the intent is not to show the environmental impact of soft stone products, but to show the methodology for adapting the LC model in order to assess specific stone supply chains.

The model has been developed assuming a production chain of soft stone products: 80% of slabs and 20% of tiles (average dimensions of 0,6 x 0,6 m^2), both with average thickness of 3 cm and 100% with polished surface. The stone slurried waste End-of-life has been set with a percentage of 70% to landfill, 20% sent to recycling plants and 10% stocked in nature.

For adapting the model to that assumed supply chain, parameters have to be set according to the desired values. This procedure can be easily managed creating a dedicated scenario through the “Parameter Explorer” function of Gabi software. Scenarios allow users to introduce changes in the general model in order to assess the environmental impacts of specific supply chains. As shown in Figure 97, the procedure starts with the creation of a new scenario (in this case it has been named “Marble_LCA”) and it follows with the upload of the parameters to edit. In the case under study, since it has been assumed a production of just soft stone products, parameters quantifying the extraction of hard stone and of the related technologies have been set with null values, while the technologies of soft stones have been put according to the desired values previously explained. With the same procedure, parameters related to the rate of slabs and tiles produced and to the slurry waste End-of-life have been edited.



Alias	Object	Parameter	Marble_LCA	Comment, units, defaults
H_area_TOT_prod	IT: Stone slab; technology mix; at plant <u-so>	H_area_TOT_prod	0	m2 - Total area of hard stone slabs produced from the initial blocks (having volume = Vol_TOT_block)
H_TOT_GiantDisk	IT: Stone slab; technology mix; at plant <u-so>	H_TOT_GiantDisk	0	m2 - Total area of hard stone cut via Giant Disk
H_TOT_MonoDW	IT: Stone slab; technology mix; at plant <u-so>	H_TOT_MonoDW	0	m2 - Total area of hard stone cut via Mono Diamond Wire
H_TOT_MultiBlad	IT: Stone slab; technology mix; at plant <u-so>	H_TOT_MultiBlad	0	m2 - Total area of hard stone cut via Steel grit gangsaw
H_TOT_MultiWire	IT: Stone slab; technology mix; at plant <u-so>	H_TOT_MultiWire	0	m2 - Total area of hard stone cut via Multi Diamond Wire technique
H_Vol_TOT_block	IT: Stone slab; technology mix; at plant <u-so>	H_Vol_TOT_block	0	m3 - TOT volume of the hard stone block before squaring and cutting processes
S_area_TOT_prod	IT: Stone slab; technology mix; at plant <u-so>	S_area_TOT_prod	456	m2 - Total area of soft stone slabs produced from the initial blocks (having volume = Vol_TOT_block)
S_TOT_MonoBlade	IT: Stone slab; technology mix; at plant <u-so>	S_TOT_MonoBlade	6	m2 - Total area of soft stone cut via Mono Diamond Blade technique
S_TOT_MonoDW	IT: Stone slab; technology mix; at plant <u-so>	S_TOT_MonoDW	6	m2 - Total area of soft stone cut via Mono Diamond wire technique
S_TOT_Multiblad	IT: Stone slab; technology mix; at plant <u-so>	S_TOT_Multiblad	456	m2 - Total area of soft stone cut via Diamond multi blade technique
S_Vol_TOT_block	IT: Stone slab; technology mix; at plant <u-so>	S_Vol_TOT_block	12,6	m3 - TOT volume of the soft stone block before squaring and cutting processes
Transport	IT: Stone slab; technology mix; at plant <u-so>	Transport	840	kg*km - Average weight of 1 m2 of slab * km from quarry to transformation plant
Rate_slab	IT: Stone slab; smoothed/polished; at plant <u-s	Rate_slab	0,8	- rate of slabs (not subjected to transformation into tiles)
Hard_To_nature	Sludge from stone cutting/polishing; End of Life -	Hard_To_nature	0	- rate of sludge from hard stone cutting to nature
Recycle	Sludge from stone cutting/polishing; End of Life -	Recycle	0,2	- rate of sludge recycling
Soft_To_nature	Sludge from stone cutting/polishing; End of Life -	Soft_To_nature	0,1	- rate of sludge from soft stone cutting to nature
To_landfill	Sludge from stone cutting/polishing; End of Life -	To_landfill	0,7	- rate of sludge to landfill

Figure 97: parameters setting to adapt the LC model to specific stone supply chains

Once that the parameters have been set, it is possible to check how the model has changed. As shown in Figures 98 and 99, as expected, the flow of the hard stone block is null, as well as the parameters connected to hard stone cutting techniques, while the production is divided among slabs and tiles according to the set rates.

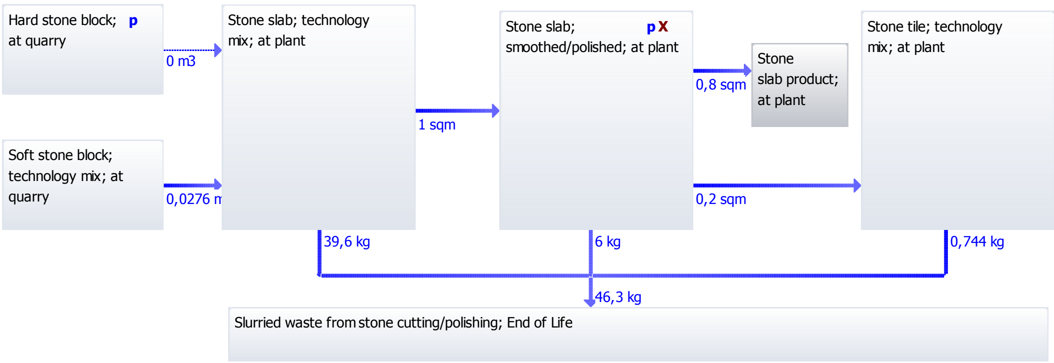


Figure 98: LC model of the ornamental stone supply chain of reference

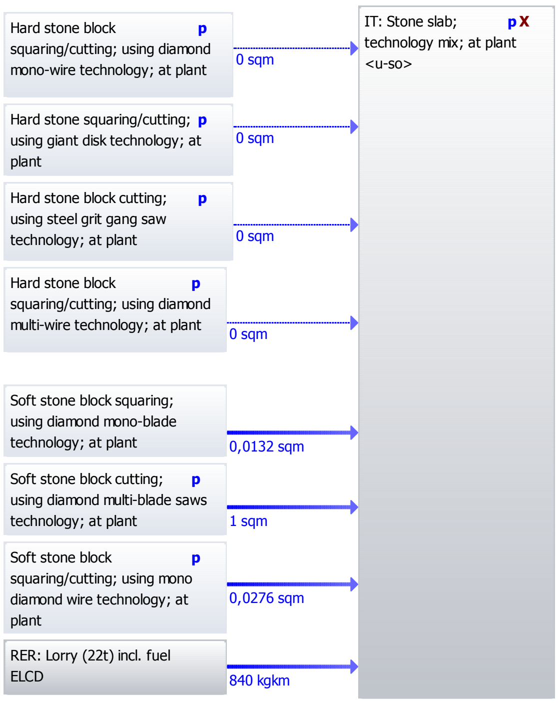


Figure 99: LC model of the cutting phase related to the ornamental stone supply chain of reference

Once that the model has been adapted to the supply chain of interest, it is possible to develop the Life Cycle Impact Assessment (LCIA). Here are presented some illustrative evaluations that can be carried out to quantify the environmental impact of the supply chain under study and to identify the most critical processes.

According to the goal of the study, different impact categories can be chosen to assess the processes. Supposing that the enterprise is interested in evaluating its supply chain with reference to the impact categories of climate change, acidification, resource depletion and terrestrial eutrophication a first analysis can be carried out to quantify the total impact of the production chain and the partial impacts of the single macrophases (Table 69). Graphs can be elaborated directly on the software or data can be exported (Figure 100).

Table 69: LCIA results of the stone supply chain of reference for four impact categories.

Impact category and assessment method	TOTAL	Soft stone block; at quarry	Stone slab; at plant	Stone slab; smoothed/ polished; at plant	Stone tile; at plant	Sludge; End of Life
IPCC global warming, incl biogenic carbon [kg CO_2-Equiv.]	11,83	4,31	1,24	5,60	0,18	0,50
Acidification, accumulated exceedance [Mole of H+ eq.]	0,082	0,039	0,005	0,033	0,0005	0,004
Resource Depletion, fossil and mineral, reserve Based, CML2002 [kg Sb-Equiv.]	0,0011	0,00010	2,26E-05	0,00094	1,89E-06	1,82E-07
Terrestrial eutrophication, accumulated exceedance [Mole of N eq.]	0,248	0,177	0,009	0,047	0,001	0,014

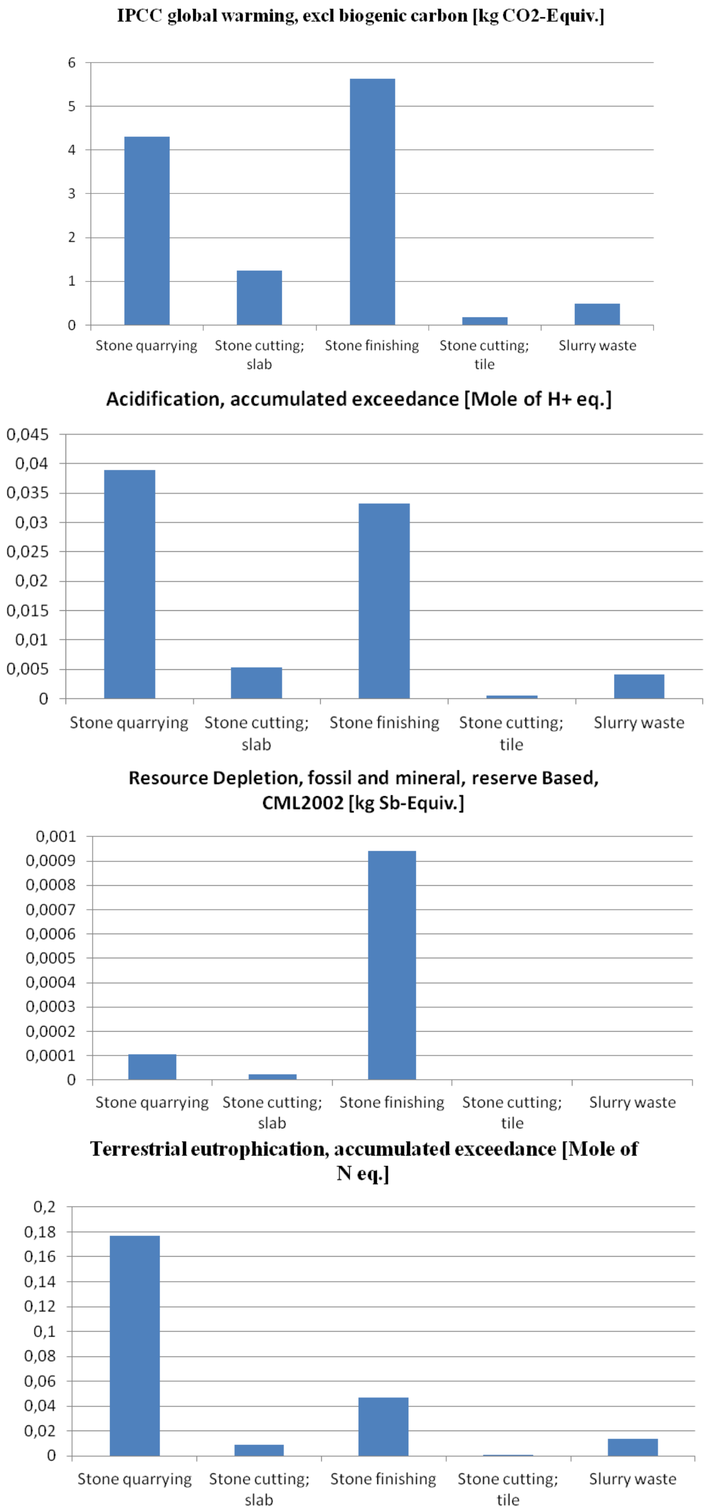


Figure 100: some LCIA graphs for the stone supply chain of reference

For the macrophases showing the highest impacts, it could be interesting to identify the processes or materials majorly responsible of the environmental burden. For example, from the Climate change graph, it results that, with reference to the supply chain under study, the macrophase responsible of the major contribute is the smoothing/polishing process, and, in particular, the abrasive tools.

The same procedure can be followed with other environmental impact categories to identify the environmental hot-points of the stone supply chain. As a consequence, enterprises or researchers looking for solutions to increase the sustainability of stone supply chains, can use the model as a starting point to quantify the incidence of processes on the total environmental burden and to evaluate possible alternative scenarios.

In this dissertation a complete LCIA and assessment interpretation is not showed because, as previously explained, the case used to show the assessment method is an example and does not aim to be representative of the average stone supply chain. Thus, since the stone supply chain is highly variable according to the hardness of the stone, the type of production, the employed technologies and many other variables, this thesis specifically aims to provide LCI datasets and a flexible model to be employed for the LCA of different and specific ornamental stone supply chains.

Chapter 7

Preliminary analyses on social aspects of the stone sector

7.1 Brief state-of-the-art on social assessments in the stone sector

As explained in Chapter 1, the sustainability is composed by the complex interaction of environmental, economic and social variables. Despite the main aim of the PhD research is to provide practical tools enabling the environmental assessment of stone supply chains, a preliminary study on social aspects has also been carried out during a PhD period spent at the Brazilian CETEM research centre (Centro de Tecnologia Mineral) of Rio de Janeiro.

Researchers of CETEM already developed some studies on the social aspects related to the Brazilian ornamental stone quarries. In particular Castro et al. (2011) developed a study to understand the perception of the stone sector according to the local community of Espírito Santo state, the major Brazilian producer of ornamental stones. Another study, developed during the PhD research project of Viana (2012), aimed at defining appropriate indicators to evaluate the sustainability of the Mineral sector. To this aim, Viana developed different indicators to assess environmental, social and economical aspects. Figure 101 shows the social indicators developed in that thesis.

Dimensão Social		
Nº Atual	Nº Inicial	Indicador
S1	S5	Responsabilidade Social
S2	S13	Desempenho Socioambiental
S3	S6	Saúde e Segurança
S4	S9	Acidentes de Trabalho
S5	S8	Multas Trabalhistas
S6	S7	Qualificação Profissional
S7	S10	Taxa de Rotatividade
S8	S14	Sindicalização
S9	S15	Benefícios Trabalhistas
S10	S16	Participação Feminina
S11	S17	Participação de Trabalhadores Locais
S12	S19	Descomissionamento Social da Mina
S13	S11	Atuação Sociopolítica
S14	S12	Comunicação Social
S15	S18	Percepção da Mineração
S16	S2	Empregos
S17	S20	Desempenho Social do Município Minerador
S18	S1	Desenvolvimento Municipal
S19	S4	Concentração de Renda e Pobreza
S20	S3	IDHM

Figure 101: sustainable indicators for the mineral sector (according to Viana, 2012)

The mentioned studies have been compared with the methodology of Social Life Cycle Assessment (SLCA) to identify if the previous studies could converge to obtain also SLCA results.

The Social Life Cycle Assessment (SLCA) methodology is aligned with the LCA one and follows the ISO 14040 framework. SLCA is not yet a mature scientific methodology, but it is more and more arising the interest of the scientific community. The main reference for the SLCA are the UNEP/SETAC guidelines on Social Life Cycle Assessment (United Nations Environment Programme (UNEP), 2009). According to these guidelines, the social sustainability should take into account five stakeholders: Local Community, Value Chain Actors, Consumer, Worker, Society. For each stakeholder, guidelines define different subcategories, to which quantitative, semi-quantitative and qualitative indicators are related. The SLCA inventory phase should consider primary data (especially for indicators at sector, enterprise or site-specific levels) and secondary data from reliable databases (especially for indicators at national, regional or sector levels).

In the last years, different methods of Impact Assessment have been developed (Wu et al., 2014), but currently no specific LCIA methods are recommended in the guidelines.

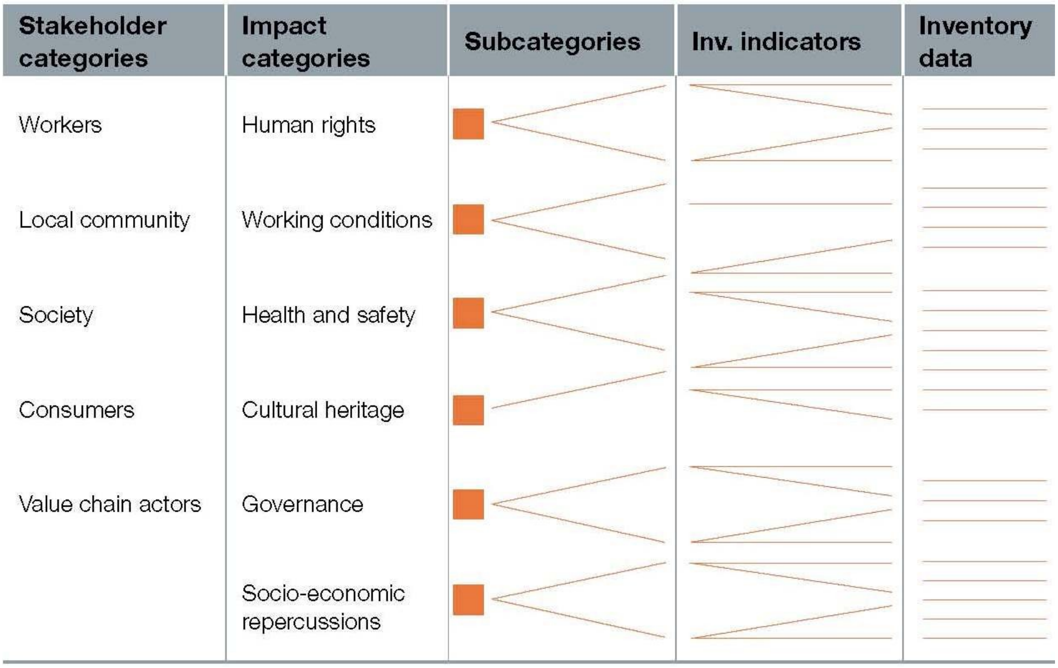


Figure 102: assessment system for SLCA according to UNEP/SETAC Guidelines (source: UNEP, 2009, p. 45)

7.2 Preliminary Social LCI of the stone sector

Following the UNEP/SETAC guidelines, a first Social Life Cycle Inventory has been developed for both Brazilian and Italian stone sectors. For the Brazilian case, the Inventory has been based on primary data that were collected during the previous CETEM researches and on secondary data from different databases. As far as concern the Italian case, most part of data have been collected in public databases, since no social studies have been developed in this field. Once defined this starting point, questionnaires addressed to the different stakeholders have been developed. Questionnaires will be useful for collecting data able to create a more detailed Social Life Cycle Inventory. This preliminary study aims to be a starting point for future researches on SLCA of the ornamental stone sector.

The following tables list the inventory for the Brazilian stone sector (Table 70) and for the Italian one (Table 71). Tables 72 to 75 show the proposed questionnaires to address to Enterprise, Local Community, Workers and Suppliers stakeholders to enhance the SLC Inventory. Some questions are proposed with the same contents to more than one stakeholder to cross-check the data.

Table 70: data collection for the Social Life Cycle Inventory on Brazilian ornamental stone supply chain.

SUBCATEGORY	INDICATOR [Unit]	QUANTITY	SOURCE AND NOTES
WORKERS			
Child Labour	Children in employment, male [% of male children ages 7-14]	0	On site investigation
	Children in employment, female [% of female children ages 7-14]	0	On site investigation
	Children in employment, total [% of all children ages 7-14]	0	On site investigation
Fouced Labour	Evidence of forced labour [Text]	NO	On site investigation
	Frequency of forced labour [%]	0	On site investigation
Fair Salary	Living wage, per month [local currency]	1240	http://wageindicator-wages-in-context.silk.co/page/Brazil
	Minimum wage, per month [local currency]	880,00	http://www.wageindicator.org/main/salary/minimum-wage/brazil
	Sector average wage, per month [local currency]	1517,5	http://www.worldsalaries.org/brazil.shtml; (International Labour Organization (ILO), 2014)
Working Time	Hours of work per employee, per day [h]	7,6	h per week/6
	Hours of work per employee, per week [h]	45,5	(International Labour Organization (ILO), 2014)
	Standard weekly hours [h]	40,1	https://stats.oecd.org/Index.aspx?DataSetCode=ANHRS
	Standard daily hours [h]	6,7	h per week/6
Discrimination	Occurrence of discrimination [Text]		On site investigation
		There is no occurrence of discrimination: in quarries men are employed because of the heavy work, but woman works in the administrative area.	
	Women in the labour force [% of economically active female population]	59,0%	IBGE website (https://www.ibge.gov.br/) + http://data.worldbank.org/indicator/SL.TLF.TOTL.FE.ZS
	Men in the labour force [% of economically active male population]	81%	IBGE website (https://www.ibge.gov.br/) + http://data.worldbank.org/indicator/SL.TLF.CACT.MA.ZS
	Ratio of salary of women wages to men [%]	n.a.	-
Health and Safety	Accident rate at workplace [#/100000 workers]	n.a.	-
	Fatal accident at workplace [#/100000 workers]	40,5	Article: Castro et al., 2011

	Occupational risks [Text]		Article: Castro et al., 2011
		Risk of accidents during the transportation and management of blocks, problems due to air pollution (dusts...).	
	DALY due to indoor and outdoor air and water pollution [DALY/1000 persons]	n.a.	Can be obtained though LCA
	Presence of sufficient safety measures [# of security incidents]	n.a.	Article: Castro et al., 2011
Social Benefit/Legal issues	Social security expenditures out of the total GDP [%]	21,29	(International Labour Organization (ILO), 2014, p. 303)
	Evidence of violations of laws and employment regulations [#/yr h]	n.a.	-
	% of workers with a contract [%]	n.a.	-
Freedom of Association, Collective Bargaining, Right to strike	Trade union density [% of employees organised in trade unions]	n.a.	-
	Right of association [Index value]	n.a.	-
	Right of collective bargaining [Index value]	n.a.	-
	Right to strike [Index value]	n.a.	-
	Existence of standard rates [Y/N]	n.a.	-
LOCAL COMMUNITY			
Access to Material Resources	Level of industrial water use [% of total withdrawal]	17%	http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en
	Level of industrial water use [% of actual renewable]	0,15%	
	Extraction of material resources (fossil fuels, biomass, ores, minerals) [t/capita]	23,0499	www.materialflows.net
	Extraction of material resources (fossil fuels) [t/capita]	0,9256	www.materialflows.net
	Extraction of material resources (biomass) [t/capita]	14,942	www.materialflows.net
	Extraction of material resources (ores) [t/capita]	3,827	www.materialflows.net
	Extraction of material resources (minerals) [t/capita]	3,3554	www.materialflows.net
	Presence of certified environmental management systems [#]	1,04	https://www.iso.org/the-iso-survey.html + https://stats.oecd.org/Index.aspx?DataSetCode=ANHRS
	Description of (potential) material resource conflicts [Text]	No conflicts	-
Respect of	Presence of indigenous population [Y/N]	Y	https://en.wikipedia.org/wiki/List_of_indigenous_peoples#South_America

Indigenous Rights	Human rights issues faced by indigenous people [Text]	5	http://www.ohchr.org/EN/Countries/LACRegion/Pages/BRIndex.aspx
	Respect of Indigenous Rights [Text]	n.a.	-
Safe and Healthy living conditions	Pollution level of the country [Index value]	61,17	https://www.numbeo.com/pollution/rankings_by_country.jsp
	Contribution of the sector to environmental load [Text]	n.a.	-
	Drinking water coverage [% of the population]	98%	(UNICEF and World Health Organization, 2015)
	Sanitation coverage [% of the population]	83%	(UNICEF and World Health Organization, 2015)
Local employment	Unemployment rate in the country [%]	6,9%	https://stats.oecd.org/Index.aspx?DataSetCode=ANHRS
	Work force hired locally [%]	n.a.	-
	Percentage of spending on locally based suppliers [%]	n.a.	-
Migration	Migrant workers in the sector [%]	n.a.	-
SOCIETY			
Contribution to Economic Development	Economic situation of the country [Index value]	52,9	http://www.heritage.org/index/ranking
	Contribution of the sector to economic development [% of total GDP]	n.a.	
	Public expenditure on education [% of GDP]	5,9%	http://data.worldbank.org/indicator/SE.XPD.TOTL.GD.ZS + http://hdr.undp.org/en/content/expenditure-education-public-gdp
Education	Illiteracy rate, male [% of male population]	7,51007	http://data.uis.unesco.org/OECDStat_Metadata/ShowMetadata.ashx?Dataset=EDULIT_DS&ShowOnWeb=true&Lang=en
	Illiteracy rate, female [% of female population]	5,83489	
	Illiteracy rate, total [% of total population]	6,65308	
Health and safety	Health expenditure out of the total GDP of the country [%]	8,3	http://wdi.worldbank.org/table/2.15
	Health expenditure, public [% of the total]	46	http://wdi.worldbank.org/table/2.15
	Health expenditure, out of pocket [% of the total]	25,5	http://wdi.worldbank.org/table/2.15
	External resources for health [% of the total]	0,1	http://wdi.worldbank.org/table/2.15
	People affected by natural disasters [% of population]	9,53%	World risk report 2016 (http://weltrisikobericht.de/english/)
	Life expectancy at birth [Years]	74	The World Bank (http://wdi.worldbank.org/table/2.15)
Prevention and Mitigation of Conflicts	Risk of conflicts with regard to the sector [Text]	n.a.	-

VALUE CHAIN ACTORS			
Fair Competition	Presence of anti-competitive behaviour or violation of anti-trust and monopoly legislation [Text]	n.a.	-
	Presence of policies to prevent anti-competitive behaviour [Y/N]	n.a.	-
Corruption	Corruption index of country [Index value]	40	https://www.transparency.org/country/BRA
	Evidence of an active involvement of the enterprises in corruption and bribery [%]	19	(OECD, 2014)
Promoting Social Responsibility	Presence of codes of conduct that protect human rights of workers among suppliers [Index value]	n.a.	-
	Membership in an initiative that promotes social responsibility along the supply chain (number of enterprises) [#]	n.a.	-
Supplier Relationships	Interaction of the companies with suppliers (payment on time, sufficient lead time, reasonable volume fluctuations, appropriate communication...) [Text]	n.a.	-
CONSUMERS			
Health and Safety	Presence of management measures to assess consumer health and safety [Y/N]	n.a.	-
Transparency	Presence of certifications or labels for the product/sites sector [Y/N]	n.a.	-
End-of-Life Responsibility	Strength of national legislation covering product disposal and recycling [Text]	n.a.	-

Table 71: data collection for the Social Life Cycle Inventory on Italian ornamental stone supply chain.

SUBCATEGORY	INDICATOR [Unit]	QUANTITY	SOURCE AND NOTES
WORKERS			
Child Labour	Children in employment, male [% of male children ages 7-14]	0	On site investigation
	Children in employment, female [% of female children ages 7-14]	0	On site investigation
	Children in employment, total [% of all children ages 7-14]	0	On site investigation
Fouced Labour	Evidence of forced labour [Text]	no evidences	On site investigation

	Frequency of forced labour [%]	0	On site investigation
Fair Salary	Living wage, per month [local currency]	709,00	http://www.ibge.gov.br/mtexto/pnadcoment6.htm
	Minimum wage, per month [local currency]	There is no minimum wage amount in the European nation of Italy, as the amount one is paid is agreed upon through collective bargaining agreements on a job to job basis. http://www.wageindicator.org/main/salary/minimum-wage/italy	
	Sector average wage, per month [local currency]	1987	http://wageindicator-wages-in-context.silk.co/page/Italy
Working Time	Hours of work per employee, per day [h]	6,9	h per week/6
	Hours of work per employee, per week [h]	41,4	(International Labour Organization (ILO), 2014)
	Standard weekly hours [h]	35,5	https://stats.oecd.org/Index.aspx?DataSetCode=ANHRS
	Standard daily hours [h]	5,9	h per week/6
Discrimination	Occurrence of discrimination [Text]	There is no occurrence of discrimination: in quarries men are employed because of the heavy work, but woman works in the administrative area.	
	Women in the labour force [% of economically active female population]	40%	http://data.worldbank.org/indicator/SL.TLF.TOTL.FE.ZS
	Men in the labour force [% of economically active male population]	60%	http://data.worldbank.org/indicator/SL.TLF.CACT.MA.ZS
	Ratio of salary of women wages to men [%]	n.a.	-
Health and Safety	Accident rate at workplace [#/100000 workers]	n.a.	-
	Fatal accident at workplace [#/100000 workers]	n.a.	-
	Occupational risks [Text]	n.a.	-
	DALY due to indoor and outdoor air and water pollution [DALY/1000 persons]		-
	Presence of sufficient safety measures [# of security incidents]	n.a.	-
Social Benefit/Legal issues	Social security expenditures out of the total GDP [%]	28,44	(International Labour Organization (ILO), 2014, p. 302)
	Evidence of violations of laws and employment regulations [#/yr h]	n.a.	-
	% of workers with a contract [%]	n.a.	-
Freedom of Association, Collective Bargaining, Right to strike	Trade union density [% of employees organised in trade unions]	n.a.	-
	Right of association [Index value]	n.a.	-
	Right of collective bargaining [Index value]	n.a.	-
	Right to strike [Index value]	n.a.	-

	Existence of standard rates [Y/N]	n.a.	-
LOCAL COMMUNITY			
Access to Material Resources	Level of industrial water use [% of total withdrawal]	36%	http://www.fao.org/nr/water/aquastat/data/query/results.html
	Level of industrial water use [% of actual renewable]	9%	http://www.fao.org/nr/water/aquastat/data/query/results.html
	Extraction of material resources (fossil fuels, biomass, ores, minerals) [t/capita]	9,1064	www.materialflows.net
	Extraction of material resources (fossil fuels) [t/capita]	0,2198	www.materialflows.net
	Extraction of material resources (biomass) [t/capita]	3,1607	www.materialflows.net
	Extraction of material resources (ores) [t/capita]	0	www.materialflows.net
	Extraction of material resources (minerals) [t/capita]	5,726	www.materialflows.net
	Presence of certified environmental management systems [#]	70,38	https://www.iso.org/the-iso-survey.html + https://stats.oecd.org/Index.aspx?DataSetCode=ANHRS
	Description of (potential) material resource conflicts [Text]	No conflicts	-
Respect of Indigenous Rights	Presence of indigenous population [Y/N]	N	https://en.wikipedia.org/wiki/List_of_indigenous_peoples#South_America
	Human rights issues faced by indigenous people [Text]	not applicable	-
	Respect of Indigenous Rights [Text]	not applicable	-
Safe and Healthy living conditions	Pollution level of the country [Index value]	51,57	https://www.numbeo.com/pollution/rankings_by_country.jsp
	Contribution of the sector to environmental load [Text]	n.a.	-
	Drinking water coverage [% of the population]	100%	(UNICEF and World Health Organization, 2015)
	Sanitation coverage [% of the population]	100%	(UNICEF and World Health Organization, 2015)
Local employment	Unemployment rate in the country [%]	12%	https://stats.oecd.org/Index.aspx?DataSetCode=ANHRS
	Work force hired locally [%]	n.a.	-
	Percentage of spending on locally based suppliers [%]	n.a.	-
Migration	Migrant workers in the sector [%]	n.a.	-
SOCIETY			
Contribution to Economic	Economic situation of the country [Index value]	62,5	http://www.heritage.org/index/ranking

Development	Contribution of the sector to economic development [in % of total GDP]	n.a.	-
	Public expenditure on education [% of GDP]	4,5%	http://data.worldbank.org/indicator/SE.XPD.TOTL.GD.ZS + http://hdr.undp.org/en/content/expenditure-education-public-gdp
Education	Illiteracy rate, male [% of male population]	0,4771	http://data.uis.unesco.org/OECDStat_Metadata/ShowMetadata.ashx?Dataset=EDULIT_DS&ShowOnWeb=true&Lang=en
	Illiteracy rate, famale [% of famale population]	0,46786	http://data.uis.unesco.org/OECDStat_Metadata/ShowMetadata.ashx?Dataset=EDULIT_DS&ShowOnWeb=true&Lang=en
	Illiteracy rate, total [% of total population]	0,47245	http://data.uis.unesco.org/OECDStat_Metadata/ShowMetadata.ashx?Dataset=EDULIT_DS&ShowOnWeb=true&Lang=en
Health and safety	Health expenditure out of the total GDP of the country [%]	9,2	http://wdi.worldbank.org/table/2.15
	Health expenditure, public [% of the total]	75,6	http://wdi.worldbank.org/table/2.15
	Health expenditure, out of pocket [% of the total]	21,2	http://wdi.worldbank.org/table/2.15
	External resources for health [% of the total]	-	http://wdi.worldbank.org/table/2.15
	People affected by natural disasters [as % of population]	13,85%	World risk report 2016 (http://weltrisikobericht.de/english/)
	Life expectancy at birth [Years]	83	The World Bank (http://wdi.worldbank.org/table/2.15)
Prevention and Mitigation of Conflicts	Risk of conflicts with regard to the sector [Text]	No conflicts	-
VALUE CHAIN ACTORS			
Fair Competition	Presence of anti-competitive behaviour or violation of anti-trust and monopoly legislation [Text]	n.a.	-
	Presence of policies to prevent anti-competitive behaviour [Y/N]	n.a.	-
Corruption	Corruption index of country [Index value]	47	https://www.transparency.org/country/ITA
	Evidence of an active involvement of the enterprises in corruption and bribery [%]	19	(OECD, 2014)
Promoting Social Responsibility	Presence of codes of conduct that protect human rights of workers among suppliers [Index value]	n.a.	-
	Membership in an initiative that promotes social responsibility along the supply chain (number of enterprises) [#]	n.a.	-
Supplier Relationships	Interaction of the companies with suppliers (payment on time, sufficient lead time,	n.a.	-

	reasonable volume fluctuations, appropriate communication...) [Text]		
CONSUMERS			
Health and Safety	Presence of management measures to assess consumer health and safety [Y/N]	Y	
Transparency	Presence of certifications or labels for the product/sites sector [Y/N]	N	
End-of-Life Responsibility	Strength of national legislation covering product disposal and recycling [Y/N]	Y	

Table 72: Proposed questionnaire for the development of SLCA to be addressed to ornamental stone Enterprises.

N°	QUESTIONS	UNIT
1	Name of the enterprise	Text
2	Location of the enterprise	Text
3	TOT number of workers	#
4	TOT number of male workers in the enterprise (comprising administrative areas)	#
5	TOT number of female workers in the enterprise (comprising administrative areas)	#
6	Which is the average wage of workers, per month?	#
7	How many hours of work per day?	#
8	How many hours of work per week?	#
9	Number of non-fatal accident, year 2016	#
10	Number of non-fatal accident, year 2017	#
11	Number of fatal accident, year 2016	#
12	Number of fatal accident, year 2017	#
13	Which are the most important health and safety risks for workers?	Text
14	Which measures are taken to prevent these risks?	Text
15	Number of security incidents, year 2016	#
16	Number of security incidents, year 2017	#
17	Number of workers affected by natural disasters, per year	#
18	Percentage of workers with a contract	%
19	Percentage of employees organised in trade unions	%

20	Have workers the right of association?	Yes	Yes, with minor restrictions (e.g. recognition procedures, workplace elections, thresholds)	Yes, with major restrictions (e.g. monopoly union, prior authorization, major groups excluded)	No
21	Have workers the right of collettive bargaining?	Yes	Yes, with minor restrictions (e.g. registration, thresholds)	Yes, with major restrictions (e.g. monopoly union, government authorization, limitation on content, major groups excluded)	No
22	Have workers the right to strike?	Yes	Yes, with minor restrictions (e.g. recognized union, balloting, proportionality, respect of peace obligation)	Yes, with major restrictions (e.g. monopoly union, compulsory arbitration or conciliation, restriction on issues or content, major groups excluded)	No
23	Number of ISO 14001 certifications	#			
24	Are there potential material resource conflicts? Why?	Text			
25	Percentage of work force hired locally	%			
26	Percentage of spending on locally based suppliers	%			
27	Migrant workers in the sector	%			
28	Are there risks of conflicts between different parties with regard to the sector (due to different interests, aims or value systems)?	Text			
29	Is the organization doing business in a region with ongoing conflicts?	Text			
30	Are there policies to prevent anti-competitive behaviour?	Yes		No	
31	Are there membership in alliances that behave in an anti-competitive way?	Text			
32	The organization carries out an anti-corruption program?	Text			
33	Research and development costs for the sector	%			
34	Are there partnerships in research and development?	Text			
35	Percentage of suppliers the enterprise has audited with regard to social responsibility in the last year	%			
36	Is the enterprise membership in an initiative that promotes social responsibility along the supply chain (number of enterprises)?	#			
37	How is the interaction of the enterprise with suppliers (payment on time, sufficient lead time, reasonable volume fluctuations, appropriate communication...)?	Text			

Table 73: Proposed questionnaire for the development of SLCA to be addressed to Local communities close to ornamental stone supply chains.

N°	QUESTIONS	UNIT	
1	Sex	Male	Female
2	Age	#	
3	Do you think that the stone sector is affected by discrimination of gender/race?	yes	no
4	If yes, what kind of discrimination?	Text	
5	Which are the most important health and safety risks for people working in the stone sector?	Text	
6	Do you think that there are sufficient safety measures to limit these risks?	yes	no
7	Why?	Text	
8	Do you think there are potential material resource conflicts? Why?	Text	
9	Are there risks of conflicts between different parties with regard to the sector (due to different interests, aims or value systems)?	Text	
10	Are there membership in alliances that behave in an anti-competitive way?	Text	
11	Are there any evidence of an active involvement of the enterprise in corruption and bribery?	Text	
12	According to you, which is the contribution of the sector to economic progress (revenue, gain, paid wages, R+D costs, etc.)	Text	

Table 74: Proposed questionnaire for the development of SLCA to be addressed to Workers of the ornamental stone supply chain

N°	QUESTIONS	UNIT	
1	Sex	Male	Female
2	Age	#	
3	Occupation	Text	
4	Which is the name of the enterprise where you work?	Text	
5	How many workers are there in this enterprise?	#	
6	From how much time do you work in this enterprise?	Text	
7	Do you think that the stone sector is affected by discrimination of gender/race?	yes	no
8	If yes, what kind of discrimination?	Text	
9	What is the avarage wage per month?	#	
10	How many hours do you work per day?	#	
11	How many hours do you work per week?	#	
12	How many non-fatal accident do you think occurred in year 2016?	#	

13	How many non-fatal accident do you think occurred in year 2017?	#			
14	How many fatal accident occurred in year 2016?	#			
15	How many fatal accident occurred in year 2017?	#			
16	Which are the most important health and safety risks in the enterprise where you work?	Text			
17	Are there sufficient safety measures to limit these risks?	yes		no	
18	Why?	Text			
19	Which is the percentage of workers with a contract?	%			
20	Have there ever been violations of laws and employment regulations?	yes		no	
21	If yes, how many violations per year?	#			
22	Have workers the right of association?	Yes	Yes, with minor restrictions (e.g. recognition procedures, workplace elections, thresholds)	Yes, with major restrictions (e.g. monopoly union, prior authorization, major groups excluded)	No
23	Have workers the right of collective bargaining?	Yes	Yes, with minor restrictions (e.g. registration, thresholds)	Yes, with major restrictions (e.g. monopoly union, government authorization, limitation on content, major groups excluded)	No
24	Have workers the right to strike?	Yes	Yes, with minor restrictions (e.g. recognized union, balloting, proportionality, respect of peace obligation)	Yes, with major restrictions (e.g. monopoly union, compulsory arbitration or conciliation,restriction on issues or content, major groups excluded)	No
25	Do you think there are potential material resource conflicts? Why?	Text			
26	Which percentage do you think is the work force hired locally?	%			
27	Which percentage do you think is spent on locally based suppliers?	%			
28	Which percentage do you think are the migrant workers in the sector?	%			
29	Are there risks of conflicts between different parties with regard to the sector (due to different interests, aims or value systems)?	Text			
30	Is the organization doing business in a region with ongoing conflicts?	Text			
31	Are there membership in alliances that behave in an anti-competitive way?	Text			
32	Are there any evidence of an active involvement of the enterprise in corruption and bribery?	Text			
33	According to you, which is the contribution of the sector to economic progress (revenue, gain, paid wages, R+D costs, etc.)	Text			

Table 75: Proposed questionnaire for the development of SLCA to be addressed to suppliers of the ornamental stone production chain.

N°	**QUESTIONS**	**UNIT**	
1	Are payments on time?	yes	no
2	Is there sufficient lead time?	yes	no
3	Volume fluctuations are reasonable?	yes	no
4	Is the communication appropriate?	yes	no

Chapter 8

Conclusions and further developments

The PhD research project has been conceived and carried out with the aim of providing a practical support to enterprises, researchers and LCA practitioners (including data developers) working in the field of ornamental stones. The main aim of the study has been to create a Life Cycle Inventory methodology and related datasets of the most widespread and common techniques and technologies currently employed in the stone supply chain. The choice of the thesis goal came as a meeting point of different considerations. First of all, it arose from the dialogue with people working in the stone field, which have started perceiving the significance, in the current historical context, of improving the sector sustainability. This new need is, from one side, the result of the recent European policies on Circular Economy and Raw materials, which inevitably concern also the ornamental stone sector. From the other side, it is the result of the concurrency, composed by stone materials from developing countries that are modifying the market and by other construction material sectors, which have started thinking in terms of sustainability from quite a long time, gaining a priority with, for examples, Green Public Procurements. Differently from other construction material sectors, the Italian ornamental stone sector is organized in small and medium enterprises and, as a consequence, the investment (in terms of time and money) for developing sustainability studies hindered an organic effort in this field. Moreover, the lack, in Life Cycle databases, of datasets for the technologies commonly used in stone supply chains has further delayed the sustainability studies of stone enterprises. The lack of LCI datasets on stone technologies is mainly a scientific gap, which affect also other research fields. A current high effort of the scientific community is focused on the research of solutions able to improve the stone sector sustainability, in particular through the development of technologies and products reusing stone slurried waste, which represents one of the main problems of the sector. Despite many valuable solutions have been found, complete Life Cycle Assessment to exclude the risk of environmental burden shifting are rare, mainly because of the lack of detailed data on the common stone production technologies.

All these reasons lead to define the goal of providing LCI datasets for the stone sector. To reach this goal, the dialogue with managers and workers of the Italian ornamental stone supply chain, but also with stone association representatives and public administrations has been crucial. The most common technologies of the stone supply chain have been detected and the correspondent LCI datasets have been modeled on the basis of primary data provided by enterprises collaborating to the project and, when necessary, secondary data to complete and cross-check the inventory. Reference of datasets is the Italian stone sector, but since the analysed processes are exported worldwide, datasets are expected to contribute to environmental studies also of other countries stone sectors. As stated in Paragraph 2.2, this goal is in line with the international and European guidance, promoting the availability, accessibility and exchange of free of charge LCI data through the development of public, protected, transparent and accredited databases.

Input and output flows of the processes, as well as the source of data and the uncertainty are shown in the thesis in order to allow the reader to easily reproduce the same datasets. Moreover, in the next future the datasets converted into the ILCD format will be submitted to the validation procedure necessary to assess the compliance of datasets to the ILCD entry level requirements. After the validation, a Node (website dataset Repository) will be created according to the indications given by the European Commission[2], where datasets can be imported. Through the Node, the datasets will be able to be published inside a Network (such as the ILCD Network). Unfortunately, since the validation and publication of datasets is a time-requiring procedure, this latter is still in progress. Nevertheless, updates and more details will be communicated through the website of the LCA research group of Politecnico di Torino (at the page:

[2] http://eplca.jrc.ec.europa.eu/LCDN/howto.xhtml

https://areeweb.polito.it/ricerca/LCA/LCA/Home.html/lca-research-group-politecnico-di-torino/researches/construction-materials-2/).

Therefore, this thesis defines and provides to LCA practitioners detailed Life Cycle Inventories of the most common techniques and technologies in the ornamental stone production chain (Chapter 5). These datasets can be employed in LCA comprehending stone supply chain processes. Moreover, to facilitate and boost the use of LCA tool among stone enterprises, datasets have been organized in a cradle-to-gate LCA generic model (Chapter 6) which, through editable parameters, can be easily adapted to perform LCA of specific stone supply chains. A unique model comprehending technologies for both soft and hard stones has been created, in order to allow the model to be used also by enterprises working with both the materials in the same plant. Therefore, the LCI datasets and the adaptable model could contribute to identify the most critical processes of the stone sector and to define sustainability thresholds, possible improvements and technological enhancements. This study is as well expected to encourage stone enterprises in the use of LCA tool and to allow them carrying out initiatives of transparent and scientific-based promotion for their most environmentally sustainable stone products.

This thesis aims therefore to give a contribution and a way forward to the stone sector and the scientific community. Nevertheless further research is needed to continue the progress in this area. In particular, as far as concern the LCI datasets, stone enterprises are called to participate with their experience to future updates and for the eventual development of new datasets related to processes that were not modelled in this thesis. In particular, further specific analyses should be addressed to better characterise waste water and slurried extractive waste management. As far as concern the development of Life Cycle Assessments, the research community should focus on the enhancement of reliable LCIA methods able to assess impact categories which are significant for the construction materials sectors (cf. Paragraph 6.2). Finally, a preliminary study on Social Life Cycle Assessment in the stone sector has been carried out with the aim of boosting and supporting future works on complementary aspects of sustainability. In this regard, economic assessments should also be investigated to enable more complete evaluations on stone supply chains and to provide further tools to enhance the overall stone sector sustainability.

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Doctoral Dissertation
Doctoral Program in Energy Engineering (30th Cycle)

ANNEXES

of the thesis

Life Cycle Inventory of cutting technologies in the ornamental stone supply chain

By

Isabella Bianco

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Supervisor:
Prof. Gian Andrea Blengini

Politecnico di Torino
2018

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Annex 1

Matrix for scoring raw material extraction management for natural stones (from Decision 2009/607/CE)

Matrix for scoring raw material extraction management for natural stones (from Decision 2009/607/CE)

Indicator	Notes	Score				
		5 (excellent)	3 (good)	1 (sufficient)	Threshold	Relative weights
I.1. Water recycling ratio	$\frac{\text{Waste Water Recycled}}{\text{Total Water Leaving the Process}} \cdot 100$ See Technical appendix — A3	> 80	80 — 70	69 — 65	< 65	W3
I.2. Quarry impact ratio	m2 affected area (quarry front + active dump) / m2 authorised area [%]	< 15	15 — 30	31 — 50	> 50	W1, W2
I.3. Natural resource waste	m3 usable material / m3 extracted material [%]	> 50	50 — 35	34 — 25	< 25	—
I.4. Air quality	Yearly limit value measured along the border of quarry area. PM 10 suspended particles [µg/Nm3] Testing method EN 12341	< 20	20 — 100	101 — 150	> 150	W2
I.5. Water quality	Suspended solids [mg/l] Testing method ISO 5667-17	< 15	15 — 30	31 — 40	> 40	W1, W2, W3
I.6. Noise	Measured along the border of quarry area (dB(A)) Testing method ISO 1996-1	< 30	30 — 55	56 — 60	> 60	W2

Annex 2

Questionnaire to quarries

Nome dell'azienda	
Luogo dell'azienda	
Litotipo estratto	

○ Desidero che non sia pubblicato il nome dell'azienda
◉ Desidero che l'azienda sia citata come collaboratrice del progetto di ricerca

NB: in entrambi i casi i valori numerici pubblicati saranno quelli medi del settore lapideo italiano

L'azienda utilizza le seguenti tecniche di estrazione (mettere una x):

x	Tecnica
	Taglio bancata con catena
	Perforazione + taglio bancata con filo diamantato
	Ribaltamento con cuscinetti idraulici
	Taglio in blocchi con filo diamantato
	Ancoraggi
	Uso di esplosivo
	Uso filtropressa
	Altro (specificare): ___________________________

Produzione 2016

Volume totale di materiale estratto [m^3 o t]	
Volume totale di blocchi per produzione lastre [m^3 o t]	
Volume totale di blocchi irregolari [m^3 o t]	
Volume totale di cocciame e residui solidi [m^3 o t]	
Uso o smaltimento di cocciame/residui solidi: ____	
Volume totale di fanghi dopo trattamento con filtropressa[m^3 o t]	
Altra produzione (specificare): ____________	

Consumi 2016

Elettricità [kW]	
Acqua [l]	
Gasolio [l]	
Qual è la fonte di approvvigionamento dell'acqua? (es: pozzo, acqua di pioggia, …) ______________________________________	

Macchinari presenti (indicare la quantità):

Macchinario	**Quantità**		**Macchinario**	**Quantità**
Tagliatrice a catena			Compressore a scoppio	
Tagliatrice a filo diamantato			Compressore elettrico	
Perforatore			Derrik	
Ruspa			Altro (specificare): ________________	
Escavatore				

Destinazione e percentuale dei blocchi regolari nel 2016:

Italia [%]	
Europa [%]	
Extra UE [%]	
Paesi in cui sono esportati i blocchi	

DATI SPECIFICI DELLE TECNOLOGIE PRESENTI NELLA CAVA

- ***TAGLIO DELLA BANCATA CON TAGLIATRICE A CATENA***

Superficie tagliata [m²/anno o m²/mese]			Settori consumati [n/m² o n/mese o n/anno]	
Energia elettrica [kw/m² o kw/mese o kw/anno]			Lubrificante [l/ m² o l/mese o l/anno]	
Acqua pulita [l/m² o l/mese o l/anno]			Come sono smaltiti i settori usurati? ____	

- ***PERFORAZIONE***

Profondità perforata [m/anno o m/mese]			Martello fondo foro [n/$m_{perforato}$ o n/mese o n/anno]	
Energia elettrica [kw/$m_{perforato}$ o kw/mese o kw/anno]			Inserto in widia [n/$m_{perforato}$ o n/mese o n/anno]	
Acqua pulita [l/m² o l/mese o l/anno]			Peso di 1 inserto in widia [g]	
Aste di ferro [m/$m_{perforato}$ o m/mese o m/anno]			Come sono smaltiti gli inserti in widia usurati? _________________________________	
Diametro aste di ferro [cm]			Come sono smaltite le aste di ferro usurate? _________________________________	

- ***TAGLIO DELLA BANCATA CON FILO DIAMANTATO***

Superficie tagliata [m^2/anno o m^2/mese]			Dimensioni di 1 rete (larghezza x lunghezza) [m]	
Energia elettrica [kw/m^2 o kw/mese o kw/anno]			Gomma vulcanizzata per protezione del volano [n_{gomme}/m^2 o n_{gomme}/mese o n_{gomme}/anno]	
Acqua pulita [l/m^2 o l/mese o l/anno]			Lunghezza di 1 gomma di protezione del volano [m]	
filo diamantato [m/m^2 o m/mese o m/anno]			Tipo di filo diamantato (es: sinterizzato, elettrodeposto, rivestimento in plastica, con molle): ____________________________	
Reti di protezione per il filo diamantato [n_{reti}/m^2 o n_{reti}/mese o n_{reti}/anno]			Come è smaltito il filo diamantato? _____________________________________	

- ***RIBALTAMENTO DELLA BANCATA CON CUSCINETTI IDRAULICI***

Dimensioni cuscinetto (lungh x largh) [cm]			Materiale cuscinetto: ____________________________________	
n cuscinetti usati [n/$m^2_{bancata}$, n/mese o n/anno]			Come sono smaltiti i cuscinetti? _____________________________________	
Acqua pulita [l/m^2 o l/mese o l/anno]				

- ***TAGLIO IN BLOCCHI CON FILO DIAMANTATO***

Superficie tagliata [m^2/anno o m^2/mese]			Dimensioni di 1 rete (larghezza x lunghezza) [m]	
Energia elettrica [kw/m^2 o kw/mese o kw/anno]			Gomma vulcanizzata per protezione del volano [n_{gomme}/m^2 o n_{gomme}/mese o n_{gomme}/anno]	
Acqua pulita [l/m^2 o l/mese o l/anno]			Lunghezza di 1 gomma di protezione del volano [m]	
filo diamantato [m/m^2 o m/mese o m/anno]			Tipo di filo diamantato (es: sinterizzato, elettrodeposto, con molle): ____________________________	
Reti di protezione per il filo diamantato [n_{reti}/m^2 o n_{reti}/mese o n_{reti}/anno]			Come è smaltito il filo diamantato? _____________________________________	

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- ***USO ANCORAGGI***

Diametro medio asta per ancoraggio [mm]			Resina [l/mese o l/anno]	
Aste di ancoraggio [m/mese o m/anno]			Come sono smaltite le aste dopo l'uso? ______________________________	

- ***USO DI ESPLOSIVO E/O DI MALTA ESPANSIVA***

Polvere nera [kg/mese o kg/anno]			Malta espansiva [kg/mese o kg/anno]	
Miccia a lenta combustione [m/mese o m/anno]			Altri tipi di esplosivo (specificare) [kg/mese o kg/anno]: _____________________	
Detonatore [n/mese o n/anno]			Tipo di detonatore: _____________________________	
Miccia detonante [m/mese o m/anno]			Come è smaltito il detonatore? _____________________________	

- ***TRATTAMENTO RESIDUI LIQUIDI CON FILTROPRESSA***

Quantità residui trattati [l/mese o l/anno]			Bentonite [kg/mese o kg/anno]	
Quantità fanghi in uscita [t/mese o t/anno]			Coagulante [kg/mese o kg/anno]	
Acqua trattata in uscita [l/m² o l/mese o l/anno]			Densità media del fango in uscita	
Energia elettrica [kw/m² o kw/mese o kw/anno]			% di acqua nel fango	
Flocculante [kg/mese o kg/anno]			Destinazione del fango: __________________________	

Annex 3

Questionnaire to transformation plants

Nome dell'azienda	
Luogo dell'azienda	
Litotipi lavorati	

○ Desidero che non sia pubblicato il nome dell'azienda

○ Desidero che l'azienda sia citata come collaboratrice del progetto di ricerca

NB: in entrambi i casi i valori numerici pubblicati saranno quelli medi del settore lapideo italiano

L'azienda esegue le seguenti lavorazioni (mettere una X e indicare la percentuale media di utilizzo della tecnica per ogni categoria):

- ***Squadratura blocco***

x	Tecnica	% utilizzo della tecnica
	Squadratura blocchi con filo diamantato	%
	Squadratura blocchi con lama diamantata	%
	Squadratura blocchi con disco gigante	%
	Altro (specificare):	%

- ***Taglio in lastre***

	Taglio in lastre con telaio multi lama	%
	Taglio in lastre con multi filo diamantato	%
	Taglio in lastre con multi lama diamantata	%
	Altro (specificare):	%

- ***Taglio in piastrelle***

	Taglio in piastrelle con fresa a ponte	%
	Taglio in piastrelle con multi disco	%
	Altro (specificare):	%

- ***Finitura e residui***

	Levigatura	%
	Lucidatura	%
	Resinatura	%
	Uso filtropressa	%
	Altro (specificare):	%

Produzione, consumi e sottoprodotti

Riferimento per i dati successivi: volume	

blocchi in entrata [XX m^3 o t]	
Produzione di lastre piano sega [m^2]	
Produzione di lastre levigate [m^2]	
Produzione di lastre lucidate [m^2]	
Produzione di lastre resinate [m^2]	
Produzione di piastrelle levigate [m^2]	
Produzione di piastrelle lucidate [m^2]	
Altra produzione (specificare)	
Elettricità totale [kW]	
Acqua totale [l]	
Gasolio totale [l]	
Cocciame o altri residui solidi [t]	
Destinazione dei residui solidi:	
Fanghi di segagione [t o m^3]	
Densità media dei fanghi di segagione	
% di acqua nei fanghi di segagione	
Destinazione dei fanghi di segagione:	

Paesi di vendita nel 2016

Percentuale vendita in Italia [%]	
Percentuale vendita in Europa [%]	
Percentuale vendita Extra UE [%]	
Paesi in cui viene esportato il materiale	

DATI SPECIFICI DELLE TECNOLOGIE PRESENTI NELL'AZIENDA

- **SQUADRATURA BLOCCHI CON FILO DIAMANTATO**

Superficie tagliata, **riferimento** per i successivi dati (XX m^2)			Filo diamantato [m/m^2 superficie riferimento]	
Energia elettrica [kw/m^2 superficie riferimento]			Tipo di filo diamantato (es: sinterizzato, elettrodeposto, rivestimento in plastica, con molle): ________________________________	
Acqua [l/ m^2 superficie riferimento]			Come è smaltito il filo diamantato? ________________________________	

- **SQUADRATURA BLOCCHI CON LAMA DIAMANTATA**

Superficie tagliata, **riferimento** per i successivi dati (XX m^2)			n di lame diamantate [n/ m^2 superficie riferimento]	
Energia elettrica [kw/ m^2 superficie riferimento]			Come è smaltita la lama diamantata? ____	
Acqua [l/ m^2 superficie riferimento]				

- **SQUADRATURA BLOCCHI CON DISCO GIGANTE**

Diametro del disco [m]			Acqua [l/ m^2 superficie riferimento]]	
Superficie tagliata, **riferimento** per i successivi dati (XX m^2)			n settori diamantati sostituiti [n/ m^2 superficie riferimento]	
Energia elettrica [kw/ m^2 superficie riferimento]			Come sono smaltiti i settori diamantati? ____	

- **TAGLIO IN LASTRE CON TELAIO MULTI LAMA**

Dimensioni medie blocco [alt x lungh x largh]			Acqua pulita [l/ n lastre riferimento]	
lastre ricavate da 1 blocco [n]			Lame consumate [n/ n lastre riferimento]	
Spessore medio lastre [cm]			Graniglia metallica [kg/ n lastre riferimento]	
Lastre prodotte**, riferimento** per i successivi dati [n]			Calce [kg/ n lastre riferimento]	
Energia elettrica [kw/n lastre riferimento]			Bentonite [kg/ n lastre riferimento]	
Come sono smaltite le lame? ____				

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- **TAGLIO IN LASTRE CON MULTI LAMA DIAMANTATA**

Dimensioni medie blocco [alt x lungh x largh]			Energia elettrica [kw/n lastre]	
Spessore medio lastre [cm]			Acqua pulita [l/n lastre]	
Lastre ricavate da 1 blocco, valore di **riferimento** per i dati successivi [n]			Lame consumate [n/n lastre]	
			Come sono smaltite le lame? ____________________________	

- **TAGLIO IN LASTRE CON MULTI FILO DIAMANTATO**

Dimensioni medie blocco [alt x lungh x largh]			Acqua pulita [l/ n lastre]	
Spessore medio lastre [cm]			Filo diamantato [m/ n lastre]	
Lastre ricavate da 1 blocco, valore di **riferimento** per i dati successivi [n]			Tipo di filo diamantato (es: sinterizzato, elettrodeposto, rivestimento in plastica, con molle): ___________________________	
Energia elettrica [kw/n lastre]			Come è smaltito il filo diamantato? ___________________________	

- **TAGLIO IN PIASTRELLE CON FRESA A PONTE**

Dimensioni medie lastra in entrata [largh x lungh x spessore]			Acqua pulita [l/n piastrelle]	
Dimensioni medie piastrella [largh x lungh x spessore]			Dischi diamantati [n/ n piastrelle]	
n piastrelle, **riferimento** per i successivi dati [n]			Come sono smaltiti i dischi usurati? ___________________________	
Energia elettrica [kw/n piastrelle]				

- **TAGLIO IN PIASTRELLE CON MULTI DISCO**

Dimensioni medie lastra in entrata [largh x lungh x spessore]			Acqua pulita [l/ n piastrelle]	
Dimensioni medie piastrella [largh x lungh x spessore]			Dischi diamantati [n/ n piastrelle]	
n piastrelle **riferimento** per i successivi dati [n]			Come sono smaltiti i dischi usurati? ____________________________	
Energia elettrica [kw/ n piastrelle]				

- **LEVIGATURA**

Superficie levigata, **riferimento** per i dati successivi (XX m^2)			Acqua pulita [l/m^2 superficie riferimento]	
Energia elettrica [kw/m^2 superficie riferimento]			n abrasivi consumati [n/m^2 superficie riferimento]	
Tipo di abrasivo usato: _______________________			Come sono smaltiti i dischi usurati? ____________________________	

- **LUCIDATURA**

Superficie lucidata, **riferimento** per i dati successivi (XX m^2)			Acqua pulita [l/ m^2 superficie riferimento]	
Energia elettrica [kw/ m^2 superficie riferimento]			n abrasivi consumati [n/ m^2 superficie riferimento]	
Tipo di abrasivo usato: ____________________________ Come sono smaltiti i dischi usurati? ____________________________				

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- **RESINATURA**

Superficie resinata **riferimento** per i dati successivi (XX m^2)			Energia elettrica [kw/ m^2 superficie riferimento]	
Resina [kg/ m^2 superficie riferimento]			Acqua [l/ m^2 superficie riferimento]	
Tela [m^2/ m^2 superficie riferimento]				

- **TRATTAMENTO RESIDUI LIQUIDI CON FILTROPRESSA**

Quantità residui trattati, **riferimento** per i dati successsiv [l]			Acqua trattata in uscita [l/ l residui tratttati]	
Quantità fanghi in uscita [t/l residui tratttati]			Energia elettrica [kw/ l residui tratttati	
Flocculante [kg/ l residui tratttati]			Coagulante [kg/ l residui tratttati]	
Bentonite [kg/ l residui tratttati]				

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Annex 4

Example of quarry Inventory (Regione Piemonte)

BDAE - Banca Dati delle Attività Estrattive

Dettaglio scheda statistica Annuale

Codice regionale cava: [redacted]
Anno: 2016
Data di ricezione: 16/03/2017

SEZIONE A - OCCUPAZIONE, ORE DI LAVORO, SPESE PER PERSONALE

1. Numero degli occupati alla fine di ciascun trimestre:

	Imprenditori coadiuvanti dirigenti e impiegati	Operai e apprendisti				TOTALE
		A giorno			In sotterraneo	
		Esplosivo	Filo diamantato	Mezzi meccanici		
Al 31/3	1				2	3
Al 31/6	1				2	3
Al 31/9	1				2	3
Al 31/12	1				2	3
Media annua	1,00				2,00	3,00

---

2. Numero di ore di lavoro prestate dal personale operaio ed apprendista: - 2520

---

3. Valutazione delle ore lavoratie svolte dalle Società appaltatrici: - -

---

4. Spese globali annuali per il personale dipendente al lordo degli oneri sociali (Euro)

- **Per impiegati: -** -
- **Per operai ed apprendisti: -** 45240
- **Costi eventuali appalti: -** -

SEZIONE B - INFORTUNI NELL'ANNO

Causa infortuni		Casi	Morti	Feriti gravi	Feriti leggeri
Franamento e distacco roccia					
In sotterraneo					
A giorno	Esplosivo				
	Filo diamantato				
	Meccanico				
Caduta, scivolamenti, circolazione e movimento del personale					
In sotterraneo					
A giorno	Esplosivo				
	Filo diamantato				
	Meccanico				
Trasporto e manovra di blocchi					
In sotterraneo					
A giorno	Esplosivo				
	Filo diamantato				
	Meccanico				
Mezzi di trasporto e mezzi di escavazione meccanica					
In sotterraneo					
A giorno	Esplosivo				
	Filo diamantato				
	Meccanico				
Impiego macchine, maneggio di utensili e attrezzi					
In sotterraneo					
A giorno	Esplosivo				
	Filo diamantato				
	Meccanico				
Folgorazione per corrente elettrica					
In sotterraneo					
A giorno	Esplosivo				
	Filo diamantato				
	Meccanico				
Esplosivi					
In sotterraneo					
A giorno	Esplosivo				
	Filo diamantato				
	Meccanico				
Cause diverse					
In sotterraneo					
A giorno	Esplosivi				
	Filo diamantato				
	Meccanico				
TOTALE					
In sotterraneo		0	0	0	0
A giorno	Esplosivo	0	0	0	0

Causa infortuni		Casi	Morti	Feriti gravi	Feriti leggeri
	Filo diamantato	0	0	0	0
	Meccanico	0	0	0	0

SEZIONE C - PRODUZIONE

Litotipo: - [redacted]

Utilizzo	Produzione		Valore unitario	
	Tonn	m³	Euro/Tonn	Euro/m³
Per laterizi				
Per argilla espansa				
Per terre refrattarie ed usi speciali				
Per l'indutria del cemento e/o della calce				
Per blocchi da scogliera	12144,94	4582,996	4,5	
Per pietrisco				
Per altri usi	5225,04	1971,713	50	
In pezzame per cuocere (gesso)				
Per usi industriali				
Blocchi per telaio				
Blocchi per fresa	2154,33	812,955	100	
Lastra a spacco naturale				
Pezzame ad altri usi				
Sabbia 0/3 mm				
Ghiaia 3/30 mm				
Pietrisco 30/70 mm				
Tout-venant				
Stabilizzati				
Usi da fonderia (sabbie silicee)				
Macinati per usi industriali (sabbie silicee)				
Torba				

Cubatura autorizzata (mc): 262000
Cubatura residua della cava o miniera (mc): 160714

Destinazione prodotti %

Comune: 40
Provincia: 30
Regione: 30
Altre regioni: -
Estero: -

SEZIONE D - CONSUMO DI MATERIALI VARI E FONTI ENERGETICHE

MATERIALI IMPIEGATI PER ABBATTIMENTO		Quantità	Valore unitario ?
Esplosivi	I Categoria	990Kg	7
	II Categoria	Kg	
Detonatori	elettrici		
	normali	340	0,75
Miccia detonante		38900m	0,5
Filo diamantato		m	
Fioretti		18m	
Aste di perforazione		m	
Acqua		m^3	

Altri materiali di normale consumo	Quantità	Valore unitario ?

FONTI ENERGETICHE	Quantità	Valore unitario ?
Olio combustibile	tonn	
Gasolio (per trazione ad uso industriale)	34,42tonn	
Gasolio per gruppi elettrogeni	tonn	
Altri combustibili	tonn	
Energia elettrica acquistata	Kwh x 1000	
Energia elettrica autoprodotta	Kwh x 1000	
Cabine elettriche - potenza installata	KVA	
Motori elettrici		
Altri motori		

SEZIONE E - MACCHINE E IMPIANTI

ESTRAZIONE E COLTIVAZIONE	N° macchine	Potenza installata		Potenzialità (t/h)
		C V	K w	
Escavatori meccanici gommati				
Escavatori meccanici cingolati	2	533	397	
Bulldozers				
Benne mordenti				
Drag lines				
Pale meccaniche gommate	1	200	147,2	
Pale meccamniche cingolate				
Pompe a suzione				
Pompe per abbattimento				
Macchine per filo diamantato				
Compressori	1	97	71,85	
Macchine perforatrici	1			
Altri				

CARICO SOLLEVAMENTO E TRASPORTO INTERNO	N°	Potenza installata (Kw)
Derricks		
Autocarri fino a 33 tonn		
Autocarri oltre 33 tonn		
Altro		

LAVORAZIONE		Numero impianti		Potenza installata (Kw)	Potenzialità (t/h)
		Fissi	Mobili		
Lavaggio					
Classificazione					
Frantumazione	Frantoi primari				
	Frantoi secondari				
	Mulini				
Pompe					
Compressori					
Altro					

NASTRO TRASPORTATORE	Numero	Metri Lineari	Potenza installata (Kw)

ALTRI IMPIANTI	Numero impianti	Potenza installata (Kw)
Gruppi elettrogeni		
Altri		

SEZIONE F - LAVORI ESEGUITI NELL'ANNO

TIPO DI LAVORO		Quantità
Gallerie	Lunghezza	m
	Sezione	m^2
	Volume	m^3
Scavi a giorno complessivi		11703m^3
Materiale sistemato in discarica		4472m^3
Sondaggi esplorativi		m
Fori da mina	Sino a Φ 64 mm	1800m
	Φ 65-100 mm	m
	Maggiori di Φ 100 mm	m

SEZIONE G - COMUNICAZIONI DELL'ESERCENTE ED ALTRE INFORMAZIONI

NELLA SEZ. D ALLA VOCE GASOLIO IL VALORE UNITARIO E' PARI A 1,04 EURO AL LITRO
PER UN TOTALE DI 1223,53 A TONNELLATA

Annex 5

Recommended LCIA methods (from ILCD Handbook)

Table 1 Recommended methods and their classification at midpoint

	Recommendation at midpoint		
Impact category	**Recommended default LCIA method**	**Indicator**	**Classification**
Climate change	Baseline model of 100 years of the IPCC	Radiative forcing as Global Warming Potential (GWP100)	I
Ozone depletion	Steady-state ODPs 1999 as in WMO assessment	Ozone Depletion Potential (ODP)	I
Human toxicity, cancer effects	USEtox model (Rosenbaum et al, 2008)	Comparative Toxic Unit for humans (CTU_h)	II/III
Human toxicity, non-cancer effects	USEtox model (Rosenbaum et al, 2008)	Comparative Toxic Unit for humans (CTU_h)	II/III
Particulate matter/Respiratory inorganics	RiskPoll model (Rabl and Spadaro, 2004) and Greco et al 2007	Intake fraction for fine particles (kg PM2.5-eq/kg)	I
Ionising radiation, human health	Human health effect model as developed by Dreicer et al. 1995 (Frischknecht et al, 2000)	Human exposure efficiency relative to U^{235}	II
Ionising radiation, ecosystems	No methods recommended		Interim
Photochemical ozone formation	LOTOS-EUROS (Van Zelm et al, 2008) as applied in ReCiPe	Tropospheric ozone concentration increase	II
Acidification	Accumulated Exceedance (Seppälä et al. 2006, Posch et al, 2008)	Accumulated Exceedance (AE)	II
Eutrophication, terrestrial	Accumulated Exceedance (Seppälä et al. 2006, Posch et al, 2008)	Accumulated Exceedance (AE)	II
Eutrophication, aquatic	EUTREND model (Struijs et al, 2009b) as implemented in ReCiPe	Fraction of nutrients reaching freshwater end compartment (P) or marine end compartment (N)	II
Ecotoxicity (freshwater)	USEtox model, (Rosenbaum et al, 2008)	Comparative Toxic Unit for ecosystems (CTU_e)	II/III
Ecotoxicity (terrestrial and marine)	No methods recommended		
Land use	Model based on Soil Organic Matter (SOM) (Milà i Canals et al, 2007b)	Soil Organic Matter	III
Resource depletion, water	Model for water consumption as in Swiss Ecoscarcity (Frischknecht et al, 2008)	Water use related to local scarcity of water	III
Resource depletion, mineral, fossil and renewable[6]	CML 2002 (Guinée et al., 2002)	Scarcity	II

[6] Depletion of renewable resources is included in the analysis but none of the analysed methods is mature for recommendation

Table 2 Recommended models and their classification at endpoint

	Recommendation from midpoint to endpoint		
Impact category	**Recommended default LCIA method**	**Indicator**	**Classification**
Climate change	No methods recommended		interim
Ozone depletion	No methods recommended		interim
Human toxicity, cancer effects	DALY calculation applied to USEtox midpoint (Adapted from Huijbregts et al., 2005a)	Disability Adjusted Life Years (DALY)	II/interim
Human toxicity, non-cancer effects	No methods recommended		interim
Particulate matter/Respiratory inorganics	DALY calculation applied to midpoint (adapted from van Zelm et al, 2008, Pope et al, 2002)	Disability Adjusted Life Years (DALY)	I/II
Ionising radiation, human health	No methods recommended		interim
Ionising radiation, ecosystems	No methods recommended		
Photochemical ozone formation	Model for damage to human health as developed for ReCiPe (Van Zelm et al, 2008)	Disability Adjusted Life Years (DALY)	II
Acidification	No methods recommended		interim
Eutrophication, terrestrial	No methods recommended		
Eutrophication, aquatic	No methods recommended		interim
Ecotoxicity (freshwater, terrestrial and marine)	No methods recommended		
Land use	No methods recommended		interim
Resource depletion, water	No methods recommended		
Resource depletion, mineral, fossil and renewable	No methods recommended		interim

Annex 6

Slow-burning fuse technical sheet

MONETTI SRL

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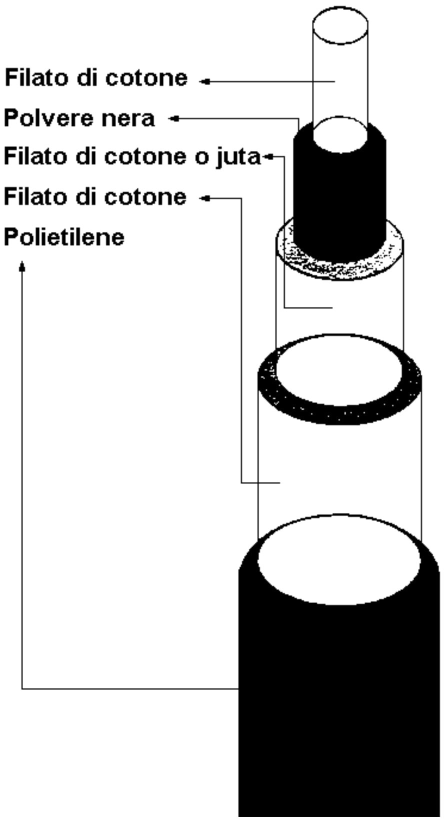
E mail: info@monetti.net - Web: www.monetti.net

SCHEDA TECNICA

MICCIA LENTA PL 5 – PL6 – PL8 - PL 10



Caratteristiche

Denominazione manufatto:	PL 5	PL 6	PL 8	PL 10
Diametro esterno	5,4 mm	6 mm	8 mm	10 mm
Peso lineare	26 g/m	30 g/m	57 g/m	85 g/m
Rivestimento esterno	Polietilene rosso	Polietilene rosso	Polietilene rosso	Polietilene rosso
Tipo di esplosivo	Polverino di polvere nera	Polverino di polvere nera	Polverino di polvere nera	Polverino di polvere nera
Quantità esplosivo	8,2 g / m (±5%)	11,0 g / m (±5%)	23,0 g / m (±5%)	35,0 g / m (±5%)
Velocità di combustione	110 sec/m (± 10%)	110 sec/m (± 10%)	110 sec/m (± 10%)	110 sec/m (± 10%)
Lunghezza dardo	≥ 5 cm	≥ 5 cm	≥ 5 cm	≥ 5 cm
Temperatura dardo	> 1100°C	> 1100°C	> 1100°C	> 1100°C
Confezionamento in scatola di cartone	4 Matasse da 250 m = 1000 m	4 Matasse da 200 m = 800 m	6 Matasse da 50 m = 300 m	4 Matasse da 50 m = 200 m
Peso lordo per cassa esterna	ca. Kg 26,00	ca. Kg 26,00	ca. Kg 18,00	ca. Kg 21,50
Classificazione	V cat. Gruppo B N° ONU 105 1.4S	V cat. Gruppo B N° ONU 105 1.4S	V cat. Gruppo B N° ONU 105 1.4S	V cat. Gruppo B N° ONU 105 1.4S

Data: 11/03/2010

Annex 7

Detonator technical sheet

PRAVISANI S.P.A.

Detonatori a fuoco Brimont N

NOTIZIE GENERALI

Sono impiegati per l'innescamento di mine isolate o di linee (di miccia detonante o di tubi ad onda d'urto) che costituiscono il collegamento tra le mine di una volata. Sono costituiti da un bossoletto metallico (alluminio) aperto ad un'estremità, nella quale è introdotta la miccia a lenta combustione e chiuso dall'altra, dove è compressa la carica esplosiva (primaria + secondaria).

CARATTERISTICHE TECNICHE E CONFEZIONI

- Diametro del bossoletto: esterno 6,90 mm – interno 6,10 mm
- Lunghezza del bossoletto: 45 mm
- Peso della carica (primaria + secondaria): ~ 1 g

CONFEZIONI

Sono confezionati in scatolette di plastica contenenti 10 pezzi ciascuna.

OMOLOGAZIONE e CERTIFICAZIONE

MINISTERO DELL'INTERNO		MINISTERO ATTIVITA' PRODUTTIVE		CERTIFICAZIONE CE ORGANISMO – n° certificato	
RICONOSCIMENTO	Data	CODICE M.A.P.	Data	N°	Data
n.557/PAS.XVJ/2/7/2004-CE/18 G.U. Serie Generale n.296	03.08.04 18.12.04	2A 0020	30.01.96 13.11.03	0589.EXP.0002/01 BAM	27.05. 02

CLASSIFICAZIONE secondo le raccomandazioni delle Nazioni Unite (Orange Book)

DETONATORI DA MINA NON ELETTRICI 1.1 B ADR / DIR - N. ONU 0029

PRAVISANI S.p.A.
SEDE COMMERCIALE-UFFICIO TECNICO
Piazza Roma, 1 – 25080 Carzago della Riviera (BS)
Tel.: 030.6000006 – Fax: 030.6000049
e-mail: *italesplosivi@iol.it*

PRAVISANI S.P.A.

Miccia detonante flessibile - SIPECORD

NOTIZIE GENERALI

La miccia detonante è abitualmente usata per l'innescamento delle cariche esplosive ad essa collegate, per il taglio delle pietre ornamentali e per la profilatura delle pareti rocciose. Si impiega inoltre per trasmettere l'onda d'urto ai tubicini dei detonatori sistema NONEL.

CARATTERISTICHE TECNICHE E CONFEZIONI

È costituita da un'anima di PETN (pentrite) avvolta da più strati spiraliformi di filati e da un rivestimento di materiale plastico che proteggono l'esplosivo dall'umidità e dai tormenti meccanici ed assicurano la flessibilità del cordone e la stabilità dell'esplosivo, sia alle basse sia alle alte temperature. Il suo innescamento viene ottenuto con un qualsiasi detonatore da mina (elettrico, ad onda d'urto, a fuoco). Per trasmettere la detonazione da uno spezzone di miccia ad un altro è sufficiente collegarli tra loro con nastro adesivo, nodo adeguato o specifici connettori.
In relazione agli impieghi, il contenuto di PETN può variare da 6 a 100 grammi per metro.
La resistenza a trazione è superiore a 50 kg.

CONTENUTO IN PETN [g/m]	VELOCITÀ DI DETONAZIONE [m/s]	DIAMETRO ESTERNO [mm]
6	7200	3,9 ± 0,4
10	7150	5,2 ± 0,4
12	7100	5,3 ± 0,5
15	7100	5,9 ± 0,5
20	6950	6,1 ± 0,6
24	6950	6,1 ± 0,6
40	6950	8,3 ± 0,7
60	6900	10,5 ± 1,0
80	6900	11,8 ± 1,0
100	6900	12,9 ± 1,0

La miccia detonante è avvolta su bobine in grado di resistere alle normali sollecitazioni di cantiere ed all'azione dell'umidità. Le bobine sono contenute in cassette di cartone (4 o 9 bobine per cassetta). La lunghezza della miccia di ciascuna bobina (funzione del contenuto di PETN) è specificata nella tabella a fianco riportata.

Contenuto in PETN (g/m)	Contenuto per cassetta	
	4 bobine da (m)	9 bobine da (m)
6 – 10	250	100
12	250	50-100
15	200	50-100
20 – 24	150	50
40	75	-
60 – 80	50	-
100	30	-

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e-mail: *italesplosivi@iol.it*

OMOLOGAZIONI e CERTIFICAZIONI:

	MINISTERO DELL'INTERNO		MINISTERO ATTIVITÀ PRODUTTIVE		CERTIFICAZIONE CE ORGANISMO – n°certificato	
TIPO [g/m]	RICONOSCIMENTO	Data	Codice M.A.P.	Data	N°	Data
6	n.559/C.19647-XVJ(1301) G.U. n.276	17.10.97 06.11.97	2F 1069	20.01.98 26.09.03	0589.EXP.1240/02 BAM	20.04.04
10	n.559/C.11645-XVJ(1303) G.U. n.244	11.09.97 18.10.97	2F 1071	20.01.98 26.09.03	0589.EXP.1236/02 BAM	20.04.04
12	n.559/C.11644-XVJ(1304) G.U. n.244	11.09.97 18.10.97	2F 1072	20.01.98 26.09.03	0589.EXP.1936/02 BAM	03.04.03
15	n.559/C.11642-XVJ(1306) G.U. n.244	11.09.97 18.10.97	2F 1074	20.01.98 26.09.03	0589.EXP.1237/02 BAM	20.04.04
20	n.559/C.11641-XVJ(1307) G.U. n.244	11.09.97 18.10.97	2F 1075	20.01.98 26.09.03	0589.EXP.1937/02 BAM	03.04.03
24	n.559/C.11652-XVJ(1308) G.U. n.244	12.09.97 18.10.97	2F 1076	20.01.98 26.09.03	0589.EXP.1242/02 BAM	20.04.04
40	n.559/C.11651-XVJ(1297) G.U. n.244	11.09.97 18.10.97	2F 1077	20.01.98 26.09.03	0589.EXP.1938/02 BAM	03.04.03
60	n.559/C.11650-XVJ(1298) G.U. n.244	11.09.97 18.10.97	2F 1078	20.01.98 26.09.03	0589.EXP.1238/02 BAM	20.04.04
80	n.559/C.11649-XVJ(1299) G.U. n.244	11.09.97 18.10.97	2F 1079	20.01.98 26.09.03	0589.EXP.1239/02 BAM	20.04.04
100	n.559/C.11648-XVJ(1300) G.U. n.244	12.09.97 18.10.97	2F 1080	20.01.98 26.09.03	0589.EXP.1939/02 BAM	03.04.03

CLASSIFICAZIONE secondo le raccomandazioni delle Nazioni Unite (Orange Book)

MICCIA DETONANTE FLESSIBILE 1.1 D ADR/RID - N. ONU 0065

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Annex 8

Steel wire technical sheet

METALFUNI S.r.L.
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10042 Nichelino (TO) - ITALY
Tel. 0039/011.62.90.168 r.a.
Fax. 0039/011.62.80.824
http//www.metalfuni.com
E-Mail : metalfuni@libero.it

GLOBE
CERTIFICAZIONI
N°426
UNI EN ISO 9001 : 2008

PRODUZIONE:
FUNI IN ACCIAIO ZINCATO
LUCIDO ED INOX
TIRANTI E ANELLI IMPALMATI
BRACHE DI CATENA E ACCESSORI
NASTRI E ANELLI IN POLIESTERE
TUTTI GLI ACCESSORI PER
IL SOLLEVAMENTO

ATTESTATO "Œ" DI CONFORMITA'
PER FUNE METALLICA

N°1212/10

In conformità alla Direttiva Macchine 2006/42/Œ si certifica che gli accessori di sollevamento sono conformi alle seguenti caratteristiche tecniche:

- Diametro della fune mm. 4,85
- Massa nominale per metro lineare kg 0,095
- Avvolgimento : crociato destro
- Preformata
- Costruzione n° 06 trefoli di 07 fili cadauno
- Su anima acciaio a 19 fili
- Classe di resistenza dei fili kg/mm² 180 — N/mm² 1770
- Carico di rottura minimo garantito kg 1800 — kN 17,65
- Superficie dei fili : zincata (UNI 7304 Classe B)
- Diametro dei fili mm 0,53

Estremi d.d.t. n°933 del 01/12/2010

Quantità : m 6000 di fune acciaio zincato Ø 4,85 mm R 180 kg/mm² a 61 fili.
LOTTO 10541-10543/10322-B

Nichelino 01/12/2010

Il presente certificato è valido anche senza firma.

METALFUNI s.r.l.
Via F.lli Bandiera, 20-32
10042 NICHELINO (TO)
Tel. 011/629.01.68

METALFUNI s.r.l
DI GIOIA Anna

Annex 9

Grease technical sheet

E X P E R T S I N L U B R I C A N T S

Scheda Tecnica

NILEX EP 1

Descrizione

NILEX EP 1 è un grasso ad alto rendimento di colore verde con eccezionale potere adesivo ed ottima stabilità meccanica. Particolari processi di produzione e speciali additivi formano un grasso di proprieta straordinarie per quanto riguarda resistenza a pressioni, acqua e umidità.

Impiego

NILEX EP 1 trova applicazione per tutti i tipi di cuscinetti sottoposti a carichi e sollecitazioni elevate, a temperature relativamente alte ed in condizioni di lavoro gravose.

NILEX EP 1 è completamente resistente all'acqua e pertanto si presta ottimamente per la lubrificazione di punti critici sotto acqua.

NILEX EP 1 trova specifica applicazione nelle acciaierie e fonderie, smalterie e vetrerie e su tutti i macchinari industriali esposti a calore. Ha dimostrato anche la sua superiorità sui martelloni idraulici. Non è consigliabile per cuscinetti veloci con fattori d.n. superiore a 200.000

Avvisi importanti

NILEX EP 1, essendo un grasso speciale con un ispessitore a base di saponi complessi di alluminio, non è miscelabile con grassi con addensanti diversi. Riempire i cuscinetti a rotolamento al massimo a metà.

Dati tecnici

Temp. continue di lavoro		°C	-25 / +150
Temp. max per brevi periodi		°C	+200
Per impieghi a temperature superiori ai 150°C è necessario ridurre gli intervalli di rilubrificazione			
Punto di goccia	DIN ISO 2176	°C	ca. 250
Penetrazione lavorata	DIN ISO 2137	1/10 mm	330 – 350
Consistenza	DIN 51818		0 - 1
Sapone - ispessitore			Alluminio complesso
Resistenza all'acqua	DIN51807 T1		0 - 90
Resistenza alla corrosione	DIN 51802	grado	0
Viscosità dell'olio base a 40°C	DIN 51562	mm^2/s	ca. 840
Resistenza all'ossidazione Scarto di pressione dopo 100 ore / 99°C	DIN 51808	bar	< 0.3
Test Timken carico utile	DIN 51434 T3	N	200.25
Classificazione	DIN 51502 ISO 6743-9		KP 0-1 P-20 ISO-L-XBDHB 0-1

Ulteriori chiarimenti verranno forniti su richiesta dal nostro servizio tecnico

Ed. 01/12

Sede
Sitz

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Annex 10

Aggregated Life Cycle dataset of grease

Name: Grease agg - LCI result 17/06/2016 14.00.00

Included data sets

DE: Phenol PE [Organic intermediate products]
DE: Ethylene glycol PE [Organic intermediate products]
DE: Adipic acid PE [Organic intermediate products]
DE: Aniline (Phenyl amine, Amino benzene) PE [Organic intermediate products]
EU-27: Heat PE [Steam supply]
EU-27: Lubricants at refinery PE [Refinery products]
RER: fatty acids, from vegetarian oil, at plant [organics]
DE: Polypropylene / Ethylene Propylene Diene Elastomer Granulate (PP/EPDM, TPE-O) Mix PE [Plastic productio
IT: Electricity grid mix PE [Electricity grid mix]
RER: aluminium hydroxide, at plant [inorganics]

Inputs

Flow	Quantity	Amount	Unit	Origin
Air [Renewable resources]	Mass	6,595871499	kg	(Calculated)
Aluminium [Non renewable elements]	Mass	0,005995038	kg	(No statement)
Antimonite [Non renewable resources]	Mass	1,99E-12	kg	(No statement)
Antimony [Non renewable elements]	Mass	6,94E-11	kg	(No statement)
Barium sulphate [Non renewable resources]	Mass	6,72E-05	kg	Literature
Basalt [Non renewable resources]	Mass	2,53E-05	kg	Calculated
Bauxite [Non renewable resources]	Mass	0,000236546	kg	(Literature)
Bentonite [Non renewable resources]	Mass	0,001427988	kg	Literature
Biotic Production [Transformation]	Biotic Pro	1,16E-05	kg/a	Literature
Biotic Production [Occupation]	Biotic Pro	0,003356011	kg	Literature
Borax [Non renewable resources]	Mass	1,29E-09	kg	(No statement)
Bromine [Non renewable elements]	Mass	1,68E-06	kg	(No statement)
Cadmium ore [Non renewable resources]	Mass	6,32E-08	kg	(No statement)
Calcium chloride [Non renewable resources]	Mass	4,71E-11	kg	Literature
Carbon dioxide [Renewable resources]	Mass	0,358147361	kg	(Literature)
Carbon, in organic matter, in soil [Non renewable resources]	Mass	0,006140702	kg	(No statement)
Chromium [Non renewable elements]	Mass	0,000266972	kg	(Calculated)
Chrysotile [Non renewable resources]	Mass	1,73E-08	kg	(No statement)
Cinnabar [Non renewable resources]	Mass	1,60E-09	kg	(No statement)
Clay [Non renewable resources]	Mass	0,003191018	kg	(Estimated)
Coalbed methane (in MJ) [Natural gas (resource)]	Energy (ne	0,000289983	MJ	Calculated
Cobalt [Non renewable elements]	Mass	6,71E-10	kg	(No statement)
Colemanite ore [Non renewable resources]	Mass	2,71E-06	kg	Literature
Copper [Non renewable elements]	Mass	0,000159289	kg	(Measured)
Crude oil (in MJ) [Crude oil (resource)]	Energy (ne	40,97289689	MJ	(Literature)
Crude oil ecoinvent [Crude oil (resource)]	Mass	0,0139536	kg	(No statement)
Diatomite [Non renewable resources]	Mass	1,92E-11	kg	(No statement)
Dolomite [Non renewable resources]	Mass	0,000790257	kg	(Calculated)
Energy, calorific value, in organic substance [Renewable energ	Energy (gr	5,17404075	MJ	(No statement)
Energy, gross calorific value, in biomass, primary forest [Rene	Energy (gr	0,425727158	MJ	(No statement)
Energy, kinetic (in wind), converted [Renewable energy resour	Energy (ne	0,002519145	MJ	(No statement)
Energy, potential (in hydropower reservoir), converted [Renew	Energy (ne	0,04719915	MJ	(No statement)
Energy, solar, converted [Renewable energy resources]	Energy (ne	5,63E-05	MJ	(No statement)

Erosion Resistance [Transformation]	Erosion R	1,42E-06	kg/a	Literature
Erosion Resistance [Occupation]	Erosion R	0,000572516	kg	Literature
Feldspar (aluminium silicates) [Non renewable resources]	Mass	8,81E-11	kg	Literature
Ferro manganese [Non renewable resources]	Mass	3,59E-17	kg	Literature
Fluorine [Non renewable elements]	Mass	6,82E-05	kg	(No statement)
Fluorspar (calcium fluoride; fluorite) [Non renewable resource	Mass	1,48E-05	kg	(Calculated)
Gallium [Non renewable elements]	Mass	1,56E-13	kg	(No statement)
Gold [Non renewable elements]	Mass	5,81E-09	kg	(No statement)
Granite [Non renewable resources]	Mass	2,02E-13	kg	Literature
Graphite [Non renewable resources]	Mass	2,11E-10	kg	Estimated
Groundwater Replenishment [Transformation]	Groundwa	0,000950262	(mm*n	Literature
Groundwater Replenishment [Occupation]	Groundwa	0,604472355	mm*m	Literature
Gypsum (natural gypsum) [Non renewable resources]	Mass	6,90E-05	kg	(Literature)
Hard coal (in MJ) [Hard coal (resource)]	Energy (ne	1,512053128	MJ	Literature
Hard coal ecoinvent [Hard coal (resource)]	Mass	0,0103839	kg	(No statement)
Heavy spar (BaSO4) [Non renewable resources]	Mass	3,11E-07	kg	Literature
Ilmenite (titanium ore) [Non renewable resources]	Mass	1,17E-07	kg	Measured
Indium [Non renewable elements]	Mass	1,06E-09	kg	(No statement)
Inert rock [Non renewable resources]	Mass	1,092991608	kg	(Literature)
Iodine [Non renewable elements]	Mass	6,39E-07	kg	(No statement)
Iridium [Non renewable elements]	Mass	2,09E-13	kg	(No statement)
Iron [Non renewable elements]	Mass	0,003416275	kg	Literature
Kaolin ore [Non renewable resources]	Mass	3,48E-06	kg	Measured
Kaolinite (24% in ore as mined) [Non renewable resources]	Mass	5,17E-07	kg	(No statement)
Kieserite (25% in ore as mined) [Non renewable resources]	Mass	8,09E-09	kg	(No statement)
Land Occupation [Occupation]	Areatime	0,004316191	m2*yr	Literature
Land Transformation [Transformation]	Area	1,60E-05	sqm	Literature
Lead [Non renewable elements]	Mass	2,46E-05	kg	(Calculated)
Lignite (in MJ) [Lignite (resource)]	Energy (ne	0,481158406	MJ	Literature
Lignite ecoinvent [Lignite (resource)]	Mass	0,006214395	kg	(No statement)
Limestone (calcium carbonate) [Non renewable resources]	Mass	0,011452345	kg	Literature
Lithium [Non renewable elements]	Mass	7,20E-10	kg	(No statement)
Magnesit (Magnesium carbonate) [Non renewable resources]	Mass	3,29E-05	kg	Calculated
Magnesium [Non renewable elements]	Mass	1,36E-09	kg	Literature
Magnesium chloride leach (40%) [Non renewable resources]	Mass	0,000128458	kg	Literature
Manganese [Non renewable elements]	Mass	2,75E-05	kg	(Literature)
Manganese ore [Non renewable resources]	Mass	-1,93E-09	kg	Calculated
Mechanical Filtration [Transformation]	Mechanica	-1,42E-05	cm*m2	Literature
Mechanical Filtration [Occupation]	Mechanica	1,96557572	cm*m²	Literature
Mercury [Non renewable elements]	Mass	1,25E-16	kg	Literature
Metamorphic stone, containing graphite [Non renewable resou	Mass	1,33E-07	kg	(No statement)
Molybdenum [Non renewable elements]	Mass	3,79E-06	kg	Estimated
Natural Aggregate [Non renewable resources]	Mass	0,040591084	kg	(Literature)
Natural gas (in MJ) [Natural gas (resource)]	Energy (ne	15,91462045	MJ	(Literature)
Natural gas ecoinvent [Natural gas (resource)]	Standard v	0,0091599	Nm3	(No statement)
Nickel [Non renewable elements]	Mass	0,000180713	kg	Literature
Nitrogen [Renewable resources]	Mass	9,11E-12	kg	Literature
Occup. as Convent. arable land [Hemeroby]	Areatime	0,003901989	m2*yr	(No statement)
Occup. as Forest land [Hemeroby]	Areatime	-2,48E-15	m2*yr	(No statement)
Occupation, arable, non-irrigated [Hemerobie ecoinvent]	Areatime	0,088698908	m2*yr	(No statement)

Occupation, construction site [Hemerobie ecoinvent]	Areatime	0,000306194	m2*yr	(No statement)
Occupation, dump site [Hemerobie ecoinvent]	Areatime	0,000124835	m2*yr	(No statement)
Occupation, dump site, benthos [Hemerobie ecoinvent]	Areatime	5,77E-06	m2*yr	(No statement)
Occupation, forest, intensive [Hemerobie ecoinvent]	Areatime	6,10E-05	m2*yr	(No statement)
Occupation, forest, intensive, normal [Hemerobie ecoinvent]	Areatime	0,00310622	m2*yr	(No statement)
Occupation, forest, intensive, short-cycle [Hemerobie ecoinver	Areatime	0,10679404	m2*yr	(No statement)
Occupation, industrial area [Hemerobie ecoinvent]	Areatime	0,000110544	m2*yr	(No statement)
Occupation, industrial area, benthos [Hemerobie ecoinvent]	Areatime	5,03E-08	m2*yr	(No statement)
Occupation, industrial area, built up [Hemerobie ecoinvent]	Areatime	0,001050122	m2*yr	(No statement)
Occupation, industrial area, vegetation [Hemerobie ecoinvent]	Areatime	6,55E-05	m2*yr	(No statement)
Occupation, mineral extraction site [Hemerobie ecoinvent]	Areatime	6,34E-05	m2*yr	(No statement)
Occupation, permanent crop, fruit, intensive [Hemerobie ecoin	Areatime	0,250335057	m2*yr	(No statement)
Occupation, shrub land, sclerophyllous [Hemerobie ecoinvent]	Areatime	9,02E-06	m2*yr	(No statement)
Occupation, traffic area, rail embankment [Hemerobie ecoinve	Areatime	4,90E-05	m2*yr	(No statement)
Occupation, traffic area, rail network [Hemerobie ecoinvent]	Areatime	5,41E-05	m2*yr	(No statement)
Occupation, traffic area, road embankment [Hemerobie ecoinv	Areatime	6,77E-05	m2*yr	(No statement)
Occupation, traffic area, road network [Hemerobie ecoinvent]	Areatime	0,000306399	m2*yr	(No statement)
Occupation, urban, discontinuously built [Hemerobie ecoinven	Areatime	0,000189783	m2*yr	(No statement)
Occupation, water bodies, artificial [Hemerobie ecoinvent]	Areatime	6,87E-05	m2*yr	(No statement)
Occupation, water courses, artificial [Hemerobie ecoinvent]	Areatime	0,000140708	m2*yr	(No statement)
Oil sand (10% bitumen) (in MJ) [Crude oil (resource)]	Energy (ne	0,00767918	MJ	Literature
Oil sand (100% bitumen) (in MJ) [Crude oil (resource)]	Energy (ne	0,006704307	MJ	Literature
Olivine [Non renewable resources]	Mass	1,05E-09	kg	Literature
Osmium [Non renewable elements]	Mass	2,55E-13	kg	(No statement)
Oxygen [Renewable resources]	Mass	-0,0016558	kg	Literature
Palladium [Non renewable elements]	Mass	2,71E-10	kg	(No statement)
Peat (in MJ) [Peat (resource)]	Energy (ne	0,004745671	MJ	Calculated
Peat ecoinvent [Non renewable resources]	Mass	1,58E-06	kg	(No statement)
Phosphorus [Non renewable elements]	Mass	0,000275773	kg	Literature
Physicochemical Filtration [Transformation]	Physicoch	-4,62E-06	(cmol*	Literature
Physicochemical Filtration [Occupation]	Physicoch	0,004906354	(cmol*	Literature
Pit gas ecoinvent [Natural gas (resource)]	Standard v	0,000100495	Nm3	(No statement)
Pit Methane (in MJ) [Natural gas (resource)]	Energy (ne	0,025682789	MJ	Calculated
Platinum [Non renewable elements]	Mass	1,60E-11	kg	(No statement)
Potashsalt, crude (hard salt, 10% K2O) [Non renewable resour	Mass	4,97E-05	kg	Literature
Potassium chloride [Non renewable resources]	Mass	3,57E-11	kg	Literature
Primary energy from geothermics [Renewable energy resource	Energy (ne	0,194277252	MJ	(Estimated)
Primary energy from hydro power [Renewable energy resource	Energy (ne	0,804698082	MJ	Literature
Primary energy from solar energy [Renewable energy resource	Energy (ne	0,40433449	MJ	Literature
Primary energy from waves [Renewable energy resources]	Energy (ne	2,45E-13	MJ	Literature
Primary energy from wind power [Renewable energy resources	Energy (ne	0,304169615	MJ	Literature
Primary forest [Renewable resources]	Mass	4,06E-09	kg	Calculated
Pyrite [Non renewable resources]	Mass	2,35E-10	kg	Literature
Quartz sand (silica sand; silicon dioxide) [Non renewable resou	Mass	0,000433294	kg	Literature
Raw pumice [Non renewable resources]	Mass	2,18E-06	kg	Literature
Rhenium [Non renewable elements]	Mass	4,89E-13	kg	(No statement)
Rhodium [Non renewable elements]	Mass	2,55E-12	kg	Literature
Ruthenium [Non renewable elements]	Mass	1,23E-12	kg	(No statement)
Sand [Non renewable resources]	Mass	1,40E-07	kg	(No statement)
Secondary fuel [Production residues in life cycle]	Energy (ne	0,005776274	MJ	Literature

Secondary fuel renewable [Production residues in life cycle]	Energy (ne	0,000549902	MJ	Literature
Shale gas (in MJ) [Natural gas (resource)]	Energy (ne	0,000350973	MJ	Calculated
Silicon [Non renewable elements]	Mass	2,18E-11	kg	Literature
Silver [Non renewable elements]	Mass	5,89E-08	kg	(No statement)
Slate [Non renewable resources]	Mass	6,52E-09	kg	(No statement)
Sodium chloride (rock salt) [Non renewable resources]	Mass	0,004174943	kg	Literature
Sodium nitrate [Non renewable resources]	Mass	3,47E-13	kg	Literature
Sodium sulphate [Non renewable resources]	Mass	2,50E-06	kg	Literature
Soil [Non renewable resources]	Mass	0,00962703	kg	(Literature)
Stone from mountains [Non renewable resources]	Mass	0,000124206	kg	Literature
Sulphur [Non renewable elements]	Mass	3,80E-07	kg	Literature
Sylvite (25% in Sylvinite) [Non renewable resources]	Mass	0,004634467	kg	(No statement)
Talc [Non renewable resources]	Mass	3,52E-08	kg	Calculated
Tantalum [Non renewable elements]	Mass	1,07E-08	kg	(No statement)
Tellurium [Non renewable elements]	Mass	7,15E-10	kg	(No statement)
Tight gas (in MJ) [Natural gas (resource)]	Energy (ne	0,001291725	MJ	Calculated
Tin [Non renewable elements]	Mass	2,39E-07	kg	Estimated
Tin ore [Non renewable resources]	Mass	8,26E-08	kg	Estimated
Titanium [Non renewable elements]	Mass	4,81E-07	kg	Literature
Titanium dioxide [Non renewable resources]	Mass	8,82E-06	kg	(No statement)
Titanium ore [Non renewable resources]	Mass	1,02E-14	kg	Measured
Transformation, from arable [Hemerobie ecoinvent]	Area	2,31E-06	sqm	(No statement)
Transformation, from arable, non-irrigated [Hemerobie ecoinve	Area	0,163935569	sqm	(No statement)
Transformation, from arable, non-irrigated, fallow [Hemerobie	Area	7,28E-07	sqm	(No statement)
Transformation, from dump site, inert material landfill [Hemer	Area	4,42E-07	sqm	(No statement)
Transformation, from dump site, residual material landfill [Her	Area	2,66E-06	sqm	(No statement)
Transformation, from dump site, sanitary landfill [Hemerobie e	Area	5,16E-08	sqm	(No statement)
Transformation, from dump site, slag compartment [Hemerobie	Area	5,58E-09	sqm	(No statement)
Transformation, from forest [Hemerobie ecoinvent]	Area	1,66E-05	sqm	(No statement)
Transformation, from forest, extensive [Hemerobie ecoinvent]	Area	0,003550259	sqm	(No statement)
Transformation, from forest, intensive, clear-cutting [Hemerob	Area	0,003814021	sqm	(No statement)
Transformation, from industrial area [Hemerobie ecoinvent]	Area	9,58E-08	sqm	(No statement)
Transformation, from industrial area, benthos [Hemerobie ecoi	Area	2,52E-10	sqm	(No statement)
Transformation, from industrial area, built up [Hemerobie ecoi	Area	5,42E-09	sqm	(No statement)
Transformation, from industrial area, vegetation [Hemerobie ec	Area	9,25E-09	sqm	(No statement)
Transformation, from mineral extraction site [Hemerobie ecoin	Area	4,83E-06	sqm	(No statement)
Transformation, from pasture and meadow [Hemerobie ecoinve	Area	7,75E-06	sqm	(No statement)
Transformation, from pasture and meadow, intensive [Hemerol	Area	0,000133785	sqm	(No statement)
Transformation, from sea and ocean [Hemerobie ecoinvent]	Area	5,79E-06	sqm	(No statement)
Transformation, from shrub land, sclerophyllous [Hemerobie e	Area	2,01E-06	sqm	(No statement)
Transformation, from tropical rain forest [Hemerobie ecoinven	Area	0,003814021	sqm	(No statement)
Transformation, from unknown [Hemerobie ecoinvent]	Area	1,12E-05	sqm	(No statement)
Transformation, to arable [Hemerobie ecoinvent]	Area	2,71E-06	sqm	(No statement)
Transformation, to arable, non-irrigated [Hemerobie ecoinvent	Area	0,164070569	sqm	(No statement)
Transformation, to arable, non-irrigated, fallow [Hemerobie ec	Area	7,95E-07	sqm	(No statement)
Transformation, to dump site [Hemerobie ecoinvent]	Area	6,48E-07	sqm	(No statement)
Transformation, to dump site, benthos [Hemerobie ecoinvent]	Area	5,77E-06	sqm	(No statement)
Transformation, to dump site, inert material landfill [Hemerobi	Area	4,42E-07	sqm	(No statement)
Transformation, to dump site, slag compartment [Hemerobie ec	Area	5,58E-09	sqm	(No statement)
Transformation, to forest [Hemerobie ecoinvent]	Area	2,78E-06	sqm	(No statement)

Transformation, to forest, intensive [Hemerobie ecoinvent]	Area	4,06E-07	sqm	(No statement)
Transformation, to forest, intensive, clear-cutting [Hemerobie (	Area	0,003814021	sqm	(No statement)
Transformation, to forest, intensive, normal [Hemerobie ecoinv	Area	2,50E-05	sqm	(No statement)
Transformation, to forest, intensive, short-cycle [Hemerobie ec	Area	0,003814021	sqm	(No statement)
Transformation, to heterogeneous, agricultural [Hemerobie ecc	Area	8,18E-07	sqm	(No statement)
Transformation, to industrial area [Hemerobie ecoinvent]	Area	1,40E-06	sqm	(No statement)
Transformation, to industrial area, benthos [Hemerobie ecoinve	Area	1,40E-08	sqm	(No statement)
Transformation, to industrial area, built up [Hemerobie ecoinve	Area	3,58E-06	sqm	(No statement)
Transformation, to industrial area, vegetation [Hemerobie ecoi	Area	1,34E-06	sqm	(No statement)
Transformation, to mineral extraction site [Hemerobie ecoinve	Area	2,13E-05	sqm	(No statement)
Transformation, to pasture and meadow [Hemerobie ecoinvent	Area	4,83E-07	sqm	(No statement)
Transformation, to permanent crop, fruit, intensive [Hemerobie	Area	0,003524041	sqm	(No statement)
Transformation, to sea and ocean [Hemerobie ecoinvent]	Area	2,52E-10	sqm	(No statement)
Transformation, to shrub land, sclerophyllous [Hemerobie ecoi	Area	1,80E-06	sqm	(No statement)
Transformation, to traffic area, rail embankment [Hemerobie e	Area	1,14E-07	sqm	(No statement)
Transformation, to traffic area, rail network [Hemerobie ecoinv	Area	1,25E-07	sqm	(No statement)
Transformation, to traffic area, road embankment [Hemerobie (	Area	3,44E-07	sqm	(No statement)
Transformation, to traffic area, road network [Hemerobie ecoir	Area	1,96E-06	sqm	(No statement)
Transformation, to unknown [Hemerobie ecoinvent]	Area	3,79E-07	sqm	(No statement)
Transformation, to urban, discontinuously built [Hemerobie ec	Area	3,78E-06	sqm	(No statement)
Transformation, to water bodies, artificial [Hemerobie ecoinve	Area	7,26E-07	sqm	(No statement)
Transformation, to water courses, artificial [Hemerobie ecoinve	Area	1,32E-06	sqm	(No statement)
Ulexite [Non renewable resources]	Mass	7,28E-09	kg	(No statement)
Uranium ecoinvent [Uranium (resource)]	Mass	4,85E-07	kg	(No statement)
Uranium natural (in MJ) [Uranium (resource)]	Energy (ne	1,204689838	MJ	Literature
Vanadium [Non renewable elements]	Mass	1,10E-08	kg	Estimated
Vermiculite [Non renewable resources]	Mass	2,88E-08	kg	(No statement)
Volume occupied, final repository for low-active radioactive w	Volume	9,88E-10	m3	(No statement)
Volume occupied, final repository for radioactive waste [Heme	Volume	2,29E-10	m3	(No statement)
Volume occupied, reservoir [Hemerobie ecoinvent]	Ecoinvent	0,0008837	m3a	(No statement)
Volume occupied, underground deposit [Hemerobie ecoinvent]	Volume	1,30E-09	m3	(No statement)
Water [Water]	Mass	3,93333	kg	(No statement)
Water (ground water) [Water]	Mass	1,688124548	kg	Literature
Water (lake water) [Water]	Mass	123,6008923	kg	Literature
Water (rain water) [Water]	Mass	1,192242873	kg	Literature
Water (river water) [Water]	Mass	2691,678194	kg	Calculated
Water (sea water) [Water]	Mass	2,260624495	kg	Literature
Water, salt, sole [Water]	Volume	0,000730417	m3	(No statement)
Water,turbine use, unspecified natural origin [Water]	Volume	0,3404175	m3	(No statement)
Wood, hard, standing [Renewable resources]	Volume	2,44E-07	m3	(No statement)
Wood, primary forest, standing [Renewable resources]	Volume	3,95E-05	m3	(No statement)
Wood, soft, standing [Renewable resources]	Volume	1,48E-06	m3	(No statement)
Zinc [Non renewable elements]	Mass	5,28E-05	kg	(Calculated)
Zirconium [Non renewable elements]	Mass	7,23E-09	kg	(No statement)

Outputs

Grease_quarry [STONE LCA]	Mass	1	kg	(No statement)
High radioactive waste [Radioactive waste]	Mass	7,05E-07	kg	Literature
Low radioactive wastes [Radioactive waste]	Mass	8,95E-06	kg	Literature
Medium radioactive wastes [Radioactive waste]	Mass	4,25E-06	kg	Literature

Radioactive tailings [Radioactive waste]	Mass	0,000462335	kg	(Calculated)
1,1,1-Trichloroethane [Halogenated organic emissions to air]	Mass	1,34E-13	kg	Estimated
1,2-Dibromoethane [Halogenated organic emissions to fresh w	Mass	1,34E-19	kg	Literature
1,3,5-Trimethylbenzene [Group NMVOC to air]	Mass	3,64E-19	kg	Estimated
1-Butanol [Group NMVOC to air]	Mass	1,34E-10	kg	(No statement)
1-Butanol [Organic emissions to fresh water]	Mass	8,77E-10	kg	(No statement)
1-Pentanol [Organic emissions to fresh water]	Mass	3,27E-11	kg	(No statement)
1-Pentanol [Group NMVOC to air]	Mass	1,36E-11	kg	(No statement)
1-Pentene [Organic emissions to fresh water]	Mass	2,47E-11	kg	(No statement)
1-Pentene [Group NMVOC to air]	Mass	1,03E-11	kg	(No statement)
2,4-Dichlorophenol [Halogenated organic emissions to air]	Mass	4,39E-10	kg	(No statement)
2,4-Dichlorophenoxyacetic acid (2,4-D) [Pesticides to agricult	Mass	1,39E-06	kg	(No statement)
2-Aminopropanol [Group NMVOC to air]	Mass	2,28E-11	kg	(No statement)
2-Aminopropanol [Organic emissions to fresh water]	Mass	5,73E-11	kg	(No statement)
2-Chlorotoluene [Halogenated organic emissions to fresh wate	Mass	2,29E-09	kg	(No statement)
2-Chlorotoluene [Halogenated organic emissions to air]	Mass	1,12E-09	kg	(No statement)
2-Methyl-2-butene [Group NMVOC to air]	Mass	2,28E-15	kg	(No statement)
2-Methyl-2-butene [Hydrocarbons to fresh water]	Mass	5,47E-15	kg	(No statement)
2-Nitrobenzoic acid [Group NMVOC to air]	Mass	4,13E-11	kg	(No statement)
Acenaphthene [Hydrocarbons to fresh water]	Mass	3,26E-09	kg	Literature
Acenaphthene [Group NMVOC to air]	Mass	1,60E-10	kg	(No statement)
Acenaphthene [Hydrocarbons to sea water]	Mass	9,36E-10	kg	Literature
Acenaphthylene [Hydrocarbons to fresh water]	Mass	1,40E-09	kg	Literature
Acenaphthylene [Hydrocarbons to sea water]	Mass	4,02E-10	kg	Literature
Acenaphthylene [Organic emissions to air (group VOC)]	Mass	3,15E-10	kg	(No statement)
Acetaldehyde (Ethanal) [Group NMVOC to air]	Mass	1,54E-05	kg	(Calculated)
Acetaldehyde (Ethanal) [Organic emissions to fresh water]	Mass	4,85E-08	kg	(No statement)
Acetic acid [Hydrocarbons to sea water]	Mass	5,24E-16	kg	Literature
Acetic acid [Group NMVOC to air]	Mass	0,000100552	kg	(Calculated)
Acetic acid [Hydrocarbons to fresh water]	Mass	3,20E-07	kg	Estimated
Acetochlor [Pesticides to fresh water]	Mass	1,43E-16	kg	Calculated
Acetochlor [Pesticides to air]	Mass	2,28E-15	kg	Calculated
Acetone (dimethylcetone) [Group NMVOC to air]	Mass	1,63E-05	kg	(Calculated)
Acetone (dimethylcetone) [Organic emissions to fresh water]	Mass	1,91E-08	kg	(No statement)
Acetonitrile [Hydrocarbons to fresh water]	Mass	1,93E-10	kg	(No statement)
Acetonitrile [Group NMVOC to air]	Mass	4,15E-06	kg	(No statement)
Acetyl chloride [Organic emissions to fresh water]	Mass	2,56E-11	kg	(No statement)
Acid (calculated as H+) [Inorganic emissions to fresh water]	Mass	0,000111278	kg	Literature
Aclonifen [Pesticides to agricultural soil]	Mass	3,53E-07	kg	(No statement)
Acrolein [Group NMVOC to air]	Mass	3,88E-10	kg	Literature
Acrylic acid [Group NMVOC to air]	Mass	8,49E-11	kg	(No statement)
Acrylonitrile [Hydrocarbons to fresh water]	Mass	2,23E-09	kg	Literature
Acrylonitrile [Group NMVOC to air]	Mass	3,82E-10	kg	Measured
Adsorbable organic halogen compounds (AOX) [Analytical me	Mass	1,42E-06	kg	Literature
Adsorbable organic halogen compounds (AOX) [Analytical me	Mass	8,67E-11	kg	Literature
Aktinide (general) [Radioactive emissions to air]	Activity	1,20E-05	Bq	(No statement)
Aktinide (general) [Radioactive emissions to sea water]	Activity	0,001192866	Bq	(No statement)
Alachlor [Pesticides to fresh water]	Mass	2,30E-15	kg	Calculated
Aldehyde (unspecified) [Group NMVOC to air]	Mass	5,24E-09	kg	Literature
Aldrin [Pesticides to agricultural soil]	Mass	2,18E-12	kg	(No statement)

Alkane (unspecified) [Group NMVOC to air]	Mass	2,97E-06	kg	Calculated
Alkane (unspecified) [Hydrocarbons to fresh water]	Mass	7,35E-08	kg	(No statement)
Alkane (unspecified) [Hydrocarbons to sea water]	Mass	2,91E-08	kg	(No statement)
Alkene (unspecified) [Group NMVOC to air]	Mass	3,30E-06	kg	Calculated
Alkene (unspecified) [Hydrocarbons to fresh water]	Mass	7,95E-09	kg	(No statement)
Alkene (unspecified) [Hydrocarbons to sea water]	Mass	2,69E-09	kg	(No statement)
Aluminium [Particles to air]	Mass	4,58E-06	kg	Literature
Aluminium [Inorganic emissions to agricultural soil]	Mass	2,48E-06	kg	(No statement)
Aluminium [Inorganic emissions to industrial soil]	Mass	3,74E-07	kg	(No statement)
Aluminium (+III) [Inorganic emissions to fresh water]	Mass	0,000250019	kg	Literature
Aluminium (+III) [Inorganic emissions to sea water]	Mass	7,00E-08	kg	Literature
Aluminium (+III) [Inorganic emissions to industrial soil]	Mass	2,16E-09	kg	Literature
Aluminium oxide (dust) [Particles to air]	Mass	4,95E-08	kg	Measured
Americium (Am241) [Radioactive emissions to fresh water]	Activity	4,76E-05	Bq	(Calculated)
Ammonia [Inorganic emissions to industrial soil]	Mass	1,04E-08	kg	Literature
Ammonia [Inorganic emissions to fresh water]	Mass	9,23E-07	kg	(Literature)
Ammonia [Inorganic emissions to air]	Mass	0,000238935	kg	(Literature)
Ammonia [Inorganic emissions to sea water]	Mass	1,87E-15	kg	Literature
Ammonium [Inorganic emissions to air]	Mass	4,17E-09	kg	Measured
Ammonium (total N) [Inorganic emissions to fresh water]	Mass	1,55E-13	kg	Literature
Ammonium / ammonia [Inorganic emissions to sea water]	Mass	2,56E-08	kg	Literature
Ammonium / ammonia [ecoinvent long-term to fresh water]	Mass	6,72E-09	kg	(No statement)
Ammonium / ammonia [Inorganic emissions to fresh water]	Mass	1,63E-05	kg	Literature
Ammonium carbonate [Inorganic emissions to air]	Mass	3,95E-11	kg	(No statement)
Ammonium nitrate [Inorganic emissions to air]	Mass	1,93E-15	kg	Literature
Aniline [Group NMVOC to air]	Mass	2,69E-09	kg	(No statement)
Aniline [Hydrocarbons to fresh water]	Mass	6,48E-09	kg	(No statement)
Anthracene [Group PAH to air]	Mass	4,90E-11	kg	Literature
Anthracene [Hydrocarbons to fresh water]	Mass	6,08E-09	kg	Literature
Anthracene [Hydrocarbons to sea water]	Mass	1,75E-09	kg	Literature
Anthranilic acid [Group NMVOC to air]	Mass	3,01E-11	kg	(No statement)
Antimony [Heavy metals to air]	Mass	5,72E-09	kg	(Calculated)
Antimony [ecoinvent long-term to fresh water]	Mass	1,08E-07	kg	(No statement)
Antimony [Heavy metals to fresh water]	Mass	2,34E-08	kg	Literature
Antimony [Heavy metals to industrial soil]	Mass	1,47E-14	kg	Literature
Antimony [Heavy metals to agricultural soil]	Mass	2,46E-13	kg	(No statement)
Antimony (Sb122) [Radioactive emissions to fresh water]	Activity	3,75E-06	Bq	(No statement)
Antimony (Sb124) [Radioactive emissions to air]	Activity	0,000947905	Bq	(Literature)
Antimony (Sb124) [Radioactive emissions to fresh water]	Activity	0,025993066	Bq	(Literature)
Antimony (Sb125) [Radioactive emissions to air]	Activity	9,70E-08	Bq	(No statement)
Antimony (Sb125) [Radioactive emissions to fresh water]	Activity	0,029203248	Bq	(Literature)
Argon [Inorganic emissions to air]	Mass	1,99E-07	kg	Estimated
Argon (Ar41) [Radioactive emissions to air]	Activity	34,73848834	Bq	(Literature)
Aromatic hydrocarbons (unspecified) [Hydrocarbons to fresh v	Mass	3,36E-07	kg	Literature
Aromatic hydrocarbons (unspecified) [Hydrocarbons to sea wa	Mass	1,30E-07	kg	Literature
Arsenic (+V) [Heavy metals to fresh water]	Mass	2,83E-06	kg	Literature
Arsenic (+V) [Heavy metals to industrial soil]	Mass	1,52E-10	kg	Measured
Arsenic (+V) [Heavy metals to agricultural soil]	Mass	7,90E-10	kg	(No statement)
Arsenic (+V) [Heavy metals to air]	Mass	9,53E-08	kg	(Calculated)
Arsenic (+V) [Heavy metals to sea water]	Mass	6,84E-07	kg	Literature

Arsenic trioxide [Heavy metals to air]	Mass	2,37E-13	kg	Measured
Atrazine [Pesticides to agricultural soil]	Mass	5,73E-13	kg	(No statement)
Atrazine [Pesticides to fresh water]	Mass	2,50E-16	kg	Calculated
Atrazine [Pesticides to air]	Mass	3,99E-15	kg	Calculated
Barium [Inorganic emissions to sea water]	Mass	5,92E-06	kg	Literature
Barium [ecoinvent long-term to fresh water]	Mass	8,60E-07	kg	(No statement)
Barium [Inorganic emissions to industrial soil]	Mass	1,87E-07	kg	(No statement)
Barium [Inorganic emissions to air]	Mass	1,53E-07	kg	(Calculated)
Barium [Inorganic emissions to agricultural soil]	Mass	1,29E-11	kg	(No statement)
Barium [Inorganic emissions to fresh water]	Mass	2,04E-05	kg	Literature
Barium (Ba140) [Radioactive emissions to fresh water]	Activity	1,64E-05	Bq	(No statement)
Barium (Ba140) [Radioactive emissions to air]	Activity	6,31E-06	Bq	(No statement)
Barytes [Inorganic emissions to sea water]	Mass	3,60E-06	kg	(No statement)
Benomyl [Pesticides to agricultural soil]	Mass	8,87E-09	kg	(No statement)
Benomyl [Pesticides to air]	Mass	5,89E-17	kg	Calculated
Benomyl [Pesticides to fresh water]	Mass	3,68E-18	kg	Calculated
Bentazone [Pesticides to agricultural soil]	Mass	1,80E-07	kg	(No statement)
Benzal chloride [Halogenated organic emissions to air]	Mass	6,08E-18	kg	(No statement)
Benzaldehyde [Group NMVOC to air]	Mass	3,46E-11	kg	(No statement)
Benzene [Hydrocarbons to sea water]	Mass	2,17E-06	kg	Literature
Benzene [Hydrocarbons to fresh water]	Mass	7,64E-06	kg	Literature
Benzene [Group NMVOC to air]	Mass	1,78E-05	kg	(Literature)
Benzo{a}anthracene [Group PAH to air]	Mass	2,48E-11	kg	Literature
Benzo{a}anthracene [Hydrocarbons to sea water]	Mass	1,07E-10	kg	Literature
Benzo{a}anthracene [Hydrocarbons to fresh water]	Mass	3,73E-10	kg	Literature
Benzo{a}pyrene [Group PAH to air]	Mass	1,19E-09	kg	(Literature)
Benzo{ghi}perylene [Group PAH to air]	Mass	2,21E-11	kg	Literature
Benzofluoranthene [Hydrocarbons to fresh water]	Mass	4,54E-11	kg	Literature
Benzofluoranthene [Group PAH to air]	Mass	4,42E-11	kg	Literature
Benzofluoranthene [Hydrocarbons to sea water]	Mass	1,31E-11	kg	Literature
Beryllium [Inorganic emissions to air]	Mass	8,86E-10	kg	Calculated
Beryllium [Inorganic emissions to industrial soil]	Mass	6,72E-17	kg	Literature
Beryllium [Inorganic emissions to fresh water]	Mass	2,15E-10	kg	Literature
Beryllium [ecoinvent long-term to fresh water]	Mass	5,49E-08	kg	(No statement)
Beryllium [Inorganic emissions to sea water]	Mass	2,47E-16	kg	Literature
Biological oxygen demand (BOD) [Analytical measures to fres	Mass	0,000461997	kg	Literature
Biological oxygen demand (BOD) [Analytical measures to sea	Mass	2,60E-05	kg	Literature
Biological oxygen demand, BSB5 (Ecoinvent) [ecoinvent long	Mass	4,46E-05	kg	(No statement)
Borate [Inorganic emissions to fresh water]	Mass	4,80E-09	kg	(No statement)
Boron [Inorganic emissions to sea water]	Mass	1,88E-09	kg	Literature
Boron [Inorganic emissions to fresh water]	Mass	9,77E-07	kg	Literature
Boron [ecoinvent long-term to fresh water]	Mass	5,14E-06	kg	(No statement)
Boron [Inorganic emissions to air]	Mass	2,11E-07	kg	Literature
Boron compounds (unspecified) [Inorganic emissions to air]	Mass	4,99E-07	kg	(Calculated)
Boron trifluoride [Inorganic emissions to air]	Mass	1,35E-17	kg	(No statement)
Bromate [Inorganic emissions to fresh water]	Mass	9,15E-08	kg	Literature
Bromide [Inorganic emissions to fresh water]	Mass	1,80E-06	kg	(No statement)
Bromide [Inorganic emissions to industrial soil]	Mass	7,59E-14	kg	Literature
Bromine [Inorganic emissions to fresh water]	Mass	4,98E-07	kg	Literature
Bromine [ecoinvent long-term to fresh water]	Mass	2,33E-08	kg	(No statement)

Bromine [Inorganic emissions to air]	Mass	1,98E-07	kg	(Calculated)
Bromine [Inorganic emissions to sea water]	Mass	1,57E-07	kg	(No statement)
Butadiene [Group NMVOC to air]	Mass	5,43E-11	kg	Measured
Butane [Group NMVOC to air]	Mass	1,07E-06	kg	(No statement)
Butane (n-butane) [Group NMVOC to air]	Mass	9,25E-05	kg	(Calculated)
Butanone (methyl ethyl ketone) [Group NMVOC to air]	Mass	1,52E-07	kg	(No statement)
Butene [Hydrocarbons to fresh water]	Mass	6,05E-10	kg	(No statement)
Butene [Group NMVOC to air]	Mass	2,49E-08	kg	Estimated
Butylene glycol (butane diol) [Hydrocarbons to fresh water]	Mass	3,23E-10	kg	(No statement)
Butylene glycol (butane diol) [Group NMVOC to air]	Mass	8,07E-10	kg	(No statement)
Butyrolactone [Group NMVOC to air]	Mass	5,08E-13	kg	(No statement)
Butyrolactone [Hydrocarbons to fresh water]	Mass	1,22E-12	kg	(No statement)
Cadmium (+II) [Heavy metals to sea water]	Mass	2,91E-07	kg	Literature
Cadmium (+II) [Heavy metals to air]	Mass	2,47E-08	kg	(Calculated)
Cadmium (+II) [Heavy metals to fresh water]	Mass	1,12E-06	kg	Literature
Cadmium (+II) [Heavy metals to industrial soil]	Mass	4,21E-11	kg	Calculated
Cadmium (+II) [Heavy metals to agricultural soil]	Mass	2,20E-08	kg	Calculated
Calcium (+II) [Inorganic emissions to industrial soil]	Mass	8,31E-06	kg	Literature
Calcium (+II) [Inorganic emissions to fresh water]	Mass	0,000957641	kg	Literature
Calcium (+II) [Inorganic emissions to sea water]	Mass	0,000494301	kg	Literature
Caprolactam [Group NMVOC to air]	Mass	1,22E-11	kg	Literature
Carbetamide [Pesticides to agricultural soil]	Mass	6,37E-08	kg	(No statement)
Carbofuran [Pesticides to agricultural soil]	Mass	4,86E-06	kg	(No statement)
Carbon (C14) [Radioactive emissions to air]	Activity	45,37498877	Bq	(Literature)
Carbon (C14) [Radioactive emissions to fresh water]	Activity	0,003269644	Bq	(Literature)
Carbon (C14) [Radioactive emissions to sea water]	Activity	1,783407939	Bq	Literature
Carbon (unspecified) [Organic emissions to industrial soil]	Mass	1,12E-06	kg	(No statement)
Carbon (unspecified) [Organic emissions to agricultural soil]	Mass	2,71E-06	kg	(No statement)
Carbon dioxide [Inorganic emissions to air]	Mass	1,734394808	kg	(Literature)
Carbon dioxide (biotic) [Inorganic emissions to air]	Mass	0,202118852	kg	Literature
Carbon dioxide, land transformation [Inorganic emissions to ai	Mass	0,058915974	kg	(No statement)
Carbon disulphide [Inorganic emissions to fresh water]	Mass	6,85E-11	kg	(No statement)
Carbon disulphide [Inorganic emissions to air]	Mass	5,34E-07	kg	Literature
Carbon monoxide [Inorganic emissions to air]	Mass	0,003876323	kg	(Literature)
Carbon monoxide (biotic) [Inorganic emissions to air]	Mass	6,30E-06	kg	(No statement)
Carbon tetrachloride (tetrachloromethane) [Halogenated organ	Mass	1,89E-10	kg	(No statement)
Carbon, organically bound [Organic emissions to fresh water]	Mass	1,88E-05	kg	Literature
Carbonate [Inorganic emissions to fresh water]	Mass	0,001254268	kg	Literature
Carbonate [Inorganic emissions to sea water]	Mass	0,000359944	kg	Literature
Cerium (Ce141) [Radioactive emissions to air]	Activity	1,53E-06	Bq	(No statement)
Cerium (Ce141) [Radioactive emissions to fresh water]	Activity	6,56E-06	Bq	(No statement)
Cerium (Ce144) [Radioactive emissions to fresh water]	Activity	2,00E-06	Bq	(No statement)
Cesium [Heavy metals to sea water]	Mass	2,24E-10	kg	(No statement)
Cesium [Heavy metals to fresh water]	Mass	5,65E-10	kg	(No statement)
Cesium (Cs134) [Radioactive emissions to sea water]	Activity	0,021422318	Bq	Literature
Cesium (Cs134) [Radioactive emissions to fresh water]	Activity	0,010494444	Bq	(Literature)
Cesium (Cs134) [Radioactive emissions to air]	Activity	0,000182243	Bq	(Literature)
Cesium (Cs136) [Radioactive emissions to fresh water]	Activity	1,17E-06	Bq	(No statement)
Cesium (Cs137) [Radioactive emissions to fresh water]	Activity	0,059730267	Bq	(Literature)
Cesium (Cs137) [Radioactive emissions to sea water]	Activity	0,423215198	Bq	Literature

Cesium (Cs137) [Radioactive emissions to air]	Activity	0,00016817	Bq	(Literature)
Chemical oxygen demand (COD) [Analytical measures to fresh	Mass	0,001158934	kg	Literature
Chemical oxygen demand (COD) [Analytical measures to sea v	Mass	5,83E-05	kg	Literature
Chloramine [Group NMVOC to air]	Mass	9,53E-11	kg	(No statement)
Chloramine [Organic emissions to fresh water]	Mass	8,76E-10	kg	(No statement)
Chlorate [Inorganic emissions to fresh water]	Mass	7,06E-07	kg	Literature
Chloride [Inorganic emissions to industrial soil]	Mass	5,80E-06	kg	Literature
Chloride [Inorganic emissions to fresh water]	Mass	0,104669802	kg	Literature
Chloride [ecoinvent long-term to fresh water]	Mass	0,004045179	kg	(No statement)
Chloride [Inorganic emissions to sea water]	Mass	0,028541603	kg	Literature
Chloride (unspecified) [Inorganic emissions to air]	Mass	7,96E-06	kg	(Literature)
Chlorinated hydrocarbons (unspecified) [Halogenated organic	Mass	3,26E-09	kg	(No statement)
Chlorinated hydrocarbons (unspecified) [Halogenated organic	Mass	1,26E-16	kg	Literature
Chlorine [Inorganic emissions to agricultural soil]	Mass	3,64E-07	kg	(No statement)
Chlorine [Inorganic emissions to air]	Mass	3,45E-07	kg	Literature
Chlorine [Inorganic emissions to industrial soil]	Mass	4,22E-05	kg	Literature
Chlorine [Inorganic emissions to fresh water]	Mass	1,42E-12	kg	(No statement)
Chlorine (dissolved) [Inorganic emissions to fresh water]	Mass	2,16E-06	kg	Literature
Chloroacetic acid [Group NMVOC to air]	Mass	1,76E-08	kg	(No statement)
Chloroacetic acid [Organic emissions to fresh water]	Mass	3,90E-06	kg	(No statement)
Chloroacetyl chloride [Organic emissions to fresh water]	Mass	7,65E-11	kg	(No statement)
Chlorobenzene [Halogenated organic emissions to fresh water]	Mass	5,09E-08	kg	(No statement)
Chloromethane (methyl chloride) [Halogenated organic emissi	Mass	3,29E-12	kg	Literature
Chloromethane (methyl chloride) [Halogenated organic emissi	Mass	1,60E-12	kg	Literature
Chlorosilane, trimethyl- [Group NMVOC to air]	Mass	1,35E-11	kg	(No statement)
Chlorosulfonic acid [Group NMVOC to air]	Mass	2,82E-10	kg	(No statement)
Chlorosulfonic acid [Organic emissions to fresh water]	Mass	7,03E-10	kg	(No statement)
Chlorothalonil [Pesticides to agricultural soil]	Mass	2,11E-10	kg	(No statement)
Chlorous dissolvent [Halogenated organic emissions to sea wat	Mass	4,49E-17	kg	(No statement)
Chlorous dissolvent [Halogenated organic emissions to fresh w	Mass	3,43E-10	kg	(No statement)
Chromium (+III) [Heavy metals to agricultural soil]	Mass	2,93E-08	kg	Calculated
Chromium (+III) [Heavy metals to industrial soil]	Mass	3,96E-12	kg	Calculated
Chromium (+III) [Heavy metals to fresh water]	Mass	6,35E-09	kg	Literature
Chromium (+III) [Heavy metals to air]	Mass	2,33E-10	kg	Literature
Chromium (+VI) [Heavy metals to fresh water]	Mass	6,27E-07	kg	Literature
Chromium (+VI) [Heavy metals to industrial soil]	Mass	2,99E-08	kg	Literature
Chromium (+VI) [Heavy metals to sea water]	Mass	4,22E-09	kg	(No statement)
Chromium (+VI) [ecoinvent long-term to fresh water]	Mass	1,46E-06	kg	(No statement)
Chromium (+VI) [Heavy metals to air]	Mass	6,40E-09	kg	Literature
Chromium (Cr51) [Radioactive emissions to air]	Activity	9,80E-08	Bq	(No statement)
Chromium (Cr51) [Radioactive emissions to fresh water]	Activity	0,001265697	Bq	(No statement)
Chromium (unspecified) [Heavy metals to air]	Mass	3,62E-07	kg	(Calculated)
Chromium (unspecified) [Heavy metals to agricultural soil]	Mass	1,79E-07	kg	(No statement)
Chromium (unspecified) [Heavy metals to fresh water]	Mass	3,65E-06	kg	Literature
Chromium (unspecified) [Heavy metals to sea water]	Mass	1,03E-06	kg	Literature
Chromium (unspecified) [Heavy metals to industrial soil]	Mass	1,97E-09	kg	Literature
Chrysene [Group PAH to air]	Mass	6,09E-11	kg	Literature
Chrysene [Hydrocarbons to sea water]	Mass	3,92E-10	kg	Literature
Chrysene [Hydrocarbons to fresh water]	Mass	1,37E-09	kg	Literature
Clean gas [Other emissions to air]	Mass	0,000165313	kg	Literature

Cobalt [Heavy metals to agricultural soil]	Mass	2,11E-09	kg	(No statement)
Cobalt [ecoinvent long-term to fresh water]	Mass	9,83E-07	kg	(No statement)
Cobalt [Heavy metals to air]	Mass	3,68E-08	kg	(Calculated)
Cobalt [Heavy metals to fresh water]	Mass	3,51E-09	kg	Calculated
Cobalt [Heavy metals to sea water]	Mass	6,98E-12	kg	Literature
Cobalt [Heavy metals to industrial soil]	Mass	1,29E-11	kg	Literature
Cobalt (Co57) [Radioactive emissions to fresh water]	Activity	3,70E-05	Bq	(No statement)
Cobalt (Co58) [Radioactive emissions to fresh water]	Activity	0,158962012	Bq	(Literature)
Cobalt (Co58) [Radioactive emissions to air]	Activity	0,000453842	Bq	(Literature)
Cobalt (Co60) [Radioactive emissions to air]	Activity	0,000958705	Bq	(Literature)
Cobalt (Co60) [Radioactive emissions to sea water]	Activity	0,034275708	Bq	Literature
Cobalt (Co60) [Radioactive emissions to fresh water]	Activity	0,115228573	Bq	(Literature)
Copper (+II) [Heavy metals to sea water]	Mass	9,70E-07	kg	Literature
Copper (+II) [Heavy metals to fresh water]	Mass	3,59E-06	kg	Literature
Copper (+II) [Heavy metals to industrial soil]	Mass	2,04E-08	kg	Calculated
Copper (+II) [Heavy metals to air]	Mass	3,11E-07	kg	(Calculated)
Copper (+II) [ecoinvent long-term to fresh water]	Mass	1,41E-06	kg	(No statement)
Copper (+II) [Heavy metals to agricultural soil]	Mass	-9,87E-07	kg	Calculated
Cresol (methyl phenol) [Hydrocarbons to sea water]	Mass	1,41E-17	kg	Literature
Cresol (methyl phenol) [Hydrocarbons to fresh water]	Mass	1,84E-17	kg	Literature
Cumene (isopropylbenzene) [Organic emissions to fresh water]	Mass	3,24E-08	kg	(No statement)
Cumene (isopropylbenzene) [Group NMVOC to air]	Mass	1,35E-08	kg	Literature
Curium (Cm alpha) [Radioactive emissions to fresh water]	Activity	6,31E-05	Bq	(Calculated)
Cyanide [Inorganic emissions to sea water]	Mass	1,02E-08	kg	(No statement)
Cyanide [Inorganic emissions to fresh water]	Mass	1,87E-07	kg	(Literature)
Cyanide (unspecified) [Inorganic emissions to air]	Mass	7,07E-06	kg	(Literature)
Cyanoacetic acid [Group NMVOC to air]	Mass	2,31E-10	kg	(No statement)
Cycloalkanes (unspec.) [Group NMVOC to air]	Mass	1,70E-06	kg	(No statement)
Cyclohexane (hexahydro benzene) [Group NMVOC to air]	Mass	5,41E-11	kg	Literature
Cypermethrin [Pesticides to agricultural soil]	Mass	6,88E-07	kg	(No statement)
Deltamethrin [Pesticides to fresh water]	Mass	6,68E-16	kg	Calculated
Deltamethrin [Pesticides to air]	Mass	1,07E-14	kg	Calculated
Detergent (unspecified) [Other emissions to fresh water]	Mass	4,20E-20	kg	(Literature)
Dibenz(a)anthracene [Group PAH to air]	Mass	1,38E-11	kg	Literature
Dicamba [Pesticides to air]	Mass	1,53E-16	kg	Calculated
Dicamba [Pesticides to fresh water]	Mass	9,54E-18	kg	Calculated
Dichlorobenzene (o-DCB; 1,2-dichlorobenzene) [Halogenated	Mass	4,11E-09	kg	(No statement)
Dichlorobenzene (o-DCB; 1,2-dichlorobenzene) [Halogenated	Mass	7,38E-10	kg	(No statement)
Dichloroethane (ethylene dichloride) [Halogenated organic em	Mass	1,03E-08	kg	Literature
Dichloroethane (ethylene dichloride) [Halogenated organic em	Mass	1,04E-08	kg	Literature
Dichloromethane (methylene chloride) [Halogenated organic e	Mass	1,04E-08	kg	(No statement)
Dichloromethane (methylene chloride) [Halogenated organic e	Mass	4,55E-10	kg	Calculated
Dichloropropane [Halogenated organic emissions to fresh wate	Mass	2,61E-21	kg	Literature
Dichromate [Inorganic emissions to fresh water]	Mass	7,80E-10	kg	(No statement)
Diethylamine [Organic emissions to fresh water]	Mass	2,89E-09	kg	(No statement)
Diethylamine [Group NMVOC to air]	Mass	1,21E-09	kg	Measured
Different pollutants [Other emissions to agricultural soil]	Mass	5,22E-05	kg	(No statement)
Different pollutants [Other emissions to industrial soil]	Mass	2,85E-06	kg	Estimated
Dimethenamid [Pesticides to fresh water]	Mass	2,83E-17	kg	Calculated
Dimethenamid [Pesticides to air]	Mass	4,52E-16	kg	Calculated

Dimethyl malonate [Group NMVOC to air]	Mass	2,89E-10	kg	(No statement)
Dimethylamine [Group NMVOC to air]	Mass	2,71E-14	kg	Calculated
Dimethylamine [Organic emissions to fresh water]	Mass	2,99E-09	kg	(No statement)
Dioxins (unspec.) [Halogenated organic emissions to air]	Mass	1,46E-13	kg	Literature
Dipropylamine [Group NMVOC to air]	Mass	7,57E-10	kg	(No statement)
Dipropylamine [Organic emissions to fresh water]	Mass	1,82E-09	kg	(No statement)
Dissolved organic carbon, DOC (Ecoinvent) [ecoinvent long-te	Mass	5,42E-05	kg	(No statement)
Dust (> PM10) [Particles to air]	Mass	0,000149066	kg	(Calculated)
Dust (PM10) [Particles to air]	Mass	2,59E-08	kg	Calculated
Dust (PM2,5 - PM10) [Particles to air]	Mass	0,000179655	kg	(Calculated)
Dust (PM2.5) [Particles to air]	Mass	0,00032919	kg	Literature
Ethane [Group NMVOC to air]	Mass	0,000316048	kg	(Calculated)
Ethanol [Group NMVOC to air]	Mass	9,24E-07	kg	Literature
Ethanol [Hydrocarbons to fresh water]	Mass	6,73E-08	kg	(No statement)
Ethene (ethylene) [Group NMVOC to air]	Mass	4,51E-05	kg	(Literature)
Ethene (ethylene) [Hydrocarbons to fresh water]	Mass	9,41E-09	kg	(No statement)
Ethine (acetylene) [Group NMVOC to air]	Mass	9,32E-06	kg	(No statement)
Ethyl benzene [Hydrocarbons to sea water]	Mass	1,22E-07	kg	Literature
Ethyl benzene [Hydrocarbons to fresh water]	Mass	4,20E-07	kg	Literature
Ethyl benzene [Group NMVOC to air]	Mass	6,37E-07	kg	(Calculated)
Ethyl cellulose [Particles to air]	Mass	3,08E-10	kg	(No statement)
Ethylamine [Organic emissions to fresh water]	Mass	1,41E-10	kg	(No statement)
Ethylamine [Group NMVOC to air]	Mass	5,89E-11	kg	(No statement)
Ethylene acetate (ethyl acetate) [Group NMVOC to air]	Mass	1,54E-07	kg	(No statement)
Ethylene acetate (ethyl acetate) [Hydrocarbons to fresh water]	Mass	3,03E-09	kg	(No statement)
Ethylene oxide [Hydrocarbons to fresh water]	Mass	1,17E-08	kg	(No statement)
Ethylene oxide [Group NMVOC to air]	Mass	3,88E-10	kg	(No statement)
Ethylenediamine [Organic emissions to fresh water]	Mass	2,73E-11	kg	(No statement)
Ethylenediamine [Group NMVOC to air]	Mass	1,14E-11	kg	(No statement)
Exhaust [Other emissions to air]	Mass	5,068046912	kg	Calculated
Fatty acids (calculated as total carbon) [Hydrocarbons to fresh	Mass	2,08E-06	kg	(No statement)
Fatty acids (calculated as total carbon) [Hydrocarbons to sea w	Mass	1,28E-06	kg	(No statement)
Fenpiclonil [Pesticides to agricultural soil]	Mass	1,22E-08	kg	(No statement)
Fipronil [Pesticides to air]	Mass	1,55E-17	kg	Calculated
Fipronil [Pesticides to fresh water]	Mass	9,71E-19	kg	Calculated
Fluoranthene [Hydrocarbons to fresh water]	Mass	4,23E-10	kg	Literature
Fluoranthene [Group NMVOC to air]	Mass	1,60E-10	kg	Literature
Fluoranthene [Hydrocarbons to sea water]	Mass	1,21E-10	kg	Literature
Fluorene [Group NMVOC to air]	Mass	5,09E-10	kg	Literature
Fluoride [ecoinvent long-term to fresh water]	Mass	3,20E-05	kg	(No statement)
Fluoride [Inorganic emissions to air]	Mass	1,10E-07	kg	(Literature)
Fluoride [Inorganic emissions to fresh water]	Mass	0,000229583	kg	Literature
Fluoride [Inorganic emissions to sea water]	Mass	5,08E-06	kg	Literature
Fluoride [Inorganic emissions to industrial soil]	Mass	4,52E-08	kg	Literature
Fluorine [Inorganic emissions to fresh water]	Mass	2,83E-09	kg	(Literature)
Fluorine [Inorganic emissions to air]	Mass	7,07E-08	kg	Literature
Formaldehyde (methanal) [Hydrocarbons to fresh water]	Mass	1,29E-08	kg	Literature
Formaldehyde (methanal) [Group NMVOC to air]	Mass	2,78E-05	kg	(Literature)
Formamide [Group NMVOC to air]	Mass	2,49E-11	kg	(No statement)
Formamide [Organic emissions to fresh water]	Mass	5,97E-11	kg	(No statement)

Formate [Organic emissions to fresh water]	Mass	5,45E-08	kg	(No statement)
Formic acid [Organic emissions to fresh water]	Mass	1,73E-11	kg	(No statement)
Formic acid (methane acid) [Group NMVOC to air]	Mass	2,77E-05	kg	(No statement)
Furan [Group NMVOC to air]	Mass	7,88E-06	kg	(No statement)
Glutaraldehyde [Hydrocarbons to sea water]	Mass	4,44E-10	kg	(No statement)
Glyphosate [Pesticides to fresh water]	Mass	2,33E-17	kg	Calculated
Glyphosate [Pesticides to agricultural soil]	Mass	9,64E-06	kg	(No statement)
Glyphosate [Pesticides to air]	Mass	3,73E-16	kg	Calculated
Glyphosate [Pesticides to industrial soil]	Mass	3,30E-09	kg	(No statement)
Halon (1211) [Halogenated organic emissions to air]	Mass	4,11E-10	kg	(No statement)
Halon (1301) [Halogenated organic emissions to air]	Mass	5,27E-10	kg	(Literature)
Hazardous waste (deposited) [Stockpile goods]	Mass	0,001271143	kg	(No statement)
Heavy metals to air (unspecified) [Heavy metals to air]	Mass	8,58E-09	kg	Literature
Heavy metals to water (unspecified) [Heavy metals to fresh wa	Mass	8,43E-13	kg	Literature
Helium [Inorganic emissions to air]	Mass	5,43E-08	kg	Literature
Heptane (isomers) [Group NMVOC to air]	Mass	2,85E-06	kg	Calculated
Hexachlorobenzene (Perchlorobenzene) [Halogenated organic	Mass	1,69E-11	kg	(No statement)
Hexaflourosilicates [Inorganic emissions to air]	Mass	2,48E-09	kg	(No statement)
Hexaflourosilicates [Inorganic emissions to fresh water]	Mass	4,47E-09	kg	(No statement)
Hexamethylene diamine (HMDA) [Group NMVOC to air]	Mass	2,99E-19	kg	Measured
Hexane (isomers) [Hydrocarbons to sea water]	Mass	1,54E-18	kg	Literature
Hexane (isomers) [Group NMVOC to air]	Mass	0,000181888	kg	(Calculated)
Hexane (isomers) [Hydrocarbons to fresh water]	Mass	2,04E-18	kg	Calculated
Hydrocarbons (unspecified) [Organic emissions to air (group V	Mass	7,05E-06	kg	Literature
Hydrocarbons (unspecified) [Hydrocarbons to fresh water]	Mass	1,35E-06	kg	Literature
Hydrocarbons (unspecified) [Hydrocarbons to sea water]	Mass	6,76E-08	kg	(No statement)
Hydrocarbons, aromatic [Group NMVOC to air]	Mass	2,61E-07	kg	Calculated
Hydrocarbons, chloro-/fluoro- [Halogenated organic emissions	Mass	3,44E-13	kg	Calculated
Hydrocarbons, halogenated [Halogenated organic emissions to	Mass	7,85E-14	kg	Literature
Hydrogen [Inorganic emissions to air]	Mass	8,88E-07	kg	(Calculated)
Hydrogen arsenic (arsine) [Heavy metals to air]	Mass	1,97E-11	kg	Measured
Hydrogen bromine (hydrobromic acid) [Inorganic emissions to	Mass	5,12E-12	kg	Calculated
Hydrogen chloride [Inorganic emissions to fresh water]	Mass	4,27E-10	kg	Estimated
Hydrogen chloride [Inorganic emissions to air]	Mass	2,29E-05	kg	(Calculated)
Hydrogen cyanide (prussic acid) [Inorganic emissions to air]	Mass	1,74E-10	kg	(Literature)
Hydrogen cyanide (prussic acid) [Inorganic emissions to fresh	Mass	2,84E-16	kg	Literature
Hydrogen fluoride [Inorganic emissions to air]	Mass	1,31E-06	kg	(Calculated)
Hydrogen fluoride (hydrofluoric acid) [Inorganic emissions to	Mass	1,80E-10	kg	(Measured)
Hydrogen iodide [Inorganic emissions to air]	Mass	1,02E-18	kg	Literature
Hydrogen peroxide [Inorganic emissions to air]	Mass	2,28E-10	kg	(No statement)
Hydrogen peroxide [Inorganic emissions to fresh water]	Mass	2,36E-07	kg	Calculated
Hydrogen phosphorous [Inorganic emissions to air]	Mass	2,87E-12	kg	Measured
Hydrogen sulphide [Inorganic emissions to air]	Mass	9,76E-05	kg	(Calculated)
Hydrogen sulphide [Inorganic emissions to fresh water]	Mass	2,19E-09	kg	(No statement)
Hydrogen sulphide [ecoinvent long-term to fresh water]	Mass	2,62E-07	kg	(No statement)
Hydrogen-3, Tritium [Radioactive emissions to air]	Activity	142,4257568	Bq	(Literature)
Hydrogen-3, Tritium [Radioactive emissions to fresh water]	Activity	3032,090135	Bq	(Literature)
Hydrogen-3, Tritium [Radioactive emissions to sea water]	Activity	2627,065486	Bq	Literature
Hydroxide [Inorganic emissions to fresh water]	Mass	6,57E-09	kg	Estimated
Hypochlorite [Inorganic emissions to fresh water]	Mass	5,35E-09	kg	(No statement)

Hypochlorite [Inorganic emissions to sea water]	Mass	5,64E-09	kg	(No statement)
Indeno[1,2,3-cd]pyrene [Group PAH to air]	Mass	1,65E-11	kg	Literature
Inert gases [Radioactive emissions to air]	Activity	7056,915	Bq	Literature
Inorganic dissolved matter (unspecified) [Inorganic emissions t	Mass	1,54E-16	kg	(No statement)
Inorganic salts and acids (unspecified) [Inorganic emissions to	Mass	1,57E-22	kg	Literature
Iodide [Inorganic emissions to fresh water]	Mass	1,51E-07	kg	(No statement)
Iodide [ecoinvent long-term to fresh water]	Mass	1,39E-14	kg	(No statement)
Iodide [Inorganic emissions to sea water]	Mass	2,24E-08	kg	(No statement)
Iodine [Inorganic emissions to air]	Mass	1,06E-08	kg	(No statement)
Iodine (I129) [Radioactive emissions to air]	Activity	0,00083844	Bq	(Literature)
Iodine (I129) [Radioactive emissions to fresh water]	Activity	0,006890279	Bq	(Literature)
Iodine (I131) [Radioactive emissions to air]	Activity	0,658881265	Bq	(Literature)
Iodine (I131) [Radioactive emissions to fresh water]	Activity	0,004396022	Bq	(Literature)
Iodine (I131) [Radioactive emissions to sea water]	Activity	0,313301395	Bq	Literature
Iodine (I133) [Radioactive emissions to air]	Activity	8,90E-06	Bq	(No statement)
Iodine (I133) [Radioactive emissions to fresh water]	Activity	1,03E-05	Bq	(No statement)
Iodine-135 [Radioactive emissions to air]	Activity	2,93E-06	Bq	(No statement)
Iron [Heavy metals to sea water]	Mass	1,22E-08	kg	Literature
Iron [Heavy metals to industrial soil]	Mass	6,98E-06	kg	Literature
Iron [Heavy metals to agricultural soil]	Mass	3,63E-06	kg	(No statement)
Iron [Heavy metals to air]	Mass	1,37E-06	kg	(Literature)
Iron [ecoinvent long-term to fresh water]	Mass	0,000103818	kg	(No statement)
Iron [Heavy metals to fresh water]	Mass	9,86E-05	kg	Literature
Iron (Fe59) [Radioactive emissions to fresh water]	Activity	2,83E-06	Bq	(No statement)
Iron ion (+III) [Heavy metals to fresh water]	Mass	3,11E-15	kg	(No statement)
iso-Butanol [Group NMVOC to air]	Mass	1,39E-10	kg	(No statement)
iso-Butanol [Organic emissions to fresh water]	Mass	3,34E-10	kg	(No statement)
Isocyanide acid [Inorganic emissions to air]	Mass	6,17E-10	kg	(No statement)
Isoprene [Group NMVOC to air]	Mass	3,65E-07	kg	(No statement)
Isopropanol [Group NMVOC to air]	Mass	3,56E-08	kg	(Estimated)
Isopropylamine [Group NMVOC to air]	Mass	2,93E-11	kg	(No statement)
Isopropylamine [Organic emissions to fresh water]	Mass	7,03E-11	kg	(No statement)
Krypton (Kr85) [Radioactive emissions to air]	Activity	1801,321396	Bq	(Literature)
Krypton (Kr85m) [Radioactive emissions to air]	Activity	109,9239512	Bq	(Literature)
Krypton (Kr87) [Radioactive emissions to air]	Activity	0,022313955	Bq	(No statement)
Krypton (Kr88) [Radioactive emissions to air]	Activity	0,02835645	Bq	(No statement)
Krypton (Kr89) [Radioactive emissions to air]	Activity	0,01150545	Bq	(No statement)
Lactic acid [Organic emissions to fresh water]	Mass	1,42E-09	kg	(No statement)
Lactic acid [Organic emissions to air (group VOC)]	Mass	5,93E-10	kg	(No statement)
Lanthanides [Heavy metals to air]	Mass	2,37E-15	kg	(Calculated)
Lanthanum (La140) [Radioactive emissions to fresh water]	Activity	1,75E-05	Bq	(No statement)
Lanthanum-140 [Radioactive emissions to air]	Activity	5,39E-07	Bq	(No statement)
Lead (+II) [Heavy metals to sea water]	Mass	1,96E-07	kg	Literature
Lead (+II) [Heavy metals to industrial soil]	Mass	9,05E-10	kg	Calculated
Lead (+II) [Heavy metals to air]	Mass	3,91E-07	kg	(Calculated)
Lead (+II) [Heavy metals to agricultural soil]	Mass	8,77E-08	kg	Calculated
Lead (+II) [Heavy metals to fresh water]	Mass	7,91E-07	kg	Literature
Lead (+II) [ecoinvent long-term to fresh water]	Mass	1,86E-07	kg	(No statement)
Lead (Pb210) [Radioactive emissions to fresh water]	Activity	0,001129221	Bq	(No statement)
Lead (Pb210) [Radioactive emissions to air]	Activity	0,013738744	Bq	Literature

Lead (Pb210) [Radioactive emissions to sea water]	Activity	1,269433994	Bq	(No statement)
Lead dioxide [Inorganic emissions to air]	Mass	1,88E-14	kg	Literature
Linuron [Pesticides to agricultural soil]	Mass	2,72E-06	kg	(No statement)
Lithium [Inorganic emissions to fresh water]	Mass	1,04E-08	kg	(No statement)
Magnesium [Inorganic emissions to sea water]	Mass	1,32E-06	kg	Literature
Magnesium [Inorganic emissions to fresh water]	Mass	0,000440574	kg	Literature
Magnesium [Inorganic emissions to air]	Mass	7,55E-07	kg	(No statement)
Magnesium [Inorganic emissions to industrial soil]	Mass	6,40E-09	kg	Literature
Magnesium chloride [Inorganic emissions to fresh water]	Mass	7,55E-10	kg	Literature
Magnesium ion (+II) [Inorganic emissions to fresh water]	Mass	3,85E-12	kg	(No statement)
Mancozeb [Pesticides to fresh water]	Mass	4,09E-17	kg	Calculated
Mancozeb [Pesticides to agricultural soil]	Mass	2,74E-10	kg	(No statement)
Mancozeb [Pesticides to air]	Mass	6,54E-16	kg	Calculated
Manganese (+II) [Heavy metals to industrial soil]	Mass	1,50E-08	kg	Literature
Manganese (+II) [Heavy metals to sea water]	Mass	2,76E-08	kg	Literature
Manganese (+II) [Heavy metals to air]	Mass	3,44E-07	kg	Calculated
Manganese (+II) [Heavy metals to agricultural soil]	Mass	2,28E-06	kg	(No statement)
Manganese (+II) [Heavy metals to fresh water]	Mass	1,03E-06	kg	Literature
Manganese (+II) [ecoinvent long-term to fresh water]	Mass	3,59E-05	kg	(No statement)
Manganese (Mn54) [Radioactive emissions to air]	Activity	5,02E-08	Bq	(No statement)
Manganese (Mn54) [Radioactive emissions to fresh water]	Activity	0,011318316	Bq	(Literature)
Mercaptan (unspecified) [Group NMVOC to air]	Mass	2,78E-09	kg	Literature
Mercury (+II) [Heavy metals to industrial soil]	Mass	6,17E-14	kg	Calculated
Mercury (+II) [Heavy metals to sea water]	Mass	1,55E-09	kg	Literature
Mercury (+II) [Heavy metals to agricultural soil]	Mass	2,63E-09	kg	Calculated
Mercury (+II) [Heavy metals to air]	Mass	1,95E-08	kg	(Calculated)
Mercury (+II) [Heavy metals to fresh water]	Mass	1,59E-08	kg	Literature
meta-Cresol [Group NMVOC to air]	Mass	1,75E-13	kg	Calculated
Metal ions (unspecific) [Inorganic emissions to fresh water]	Mass	9,83E-09	kg	Estimated
Metal ions (unspecific) [ecoinvent long-term to fresh water]	Mass	8,74E-05	kg	(No statement)
Metaldehyde [Organic emissions to agricultural soil]	Mass	1,20E-08	kg	(No statement)
Metals (unspecified) [Particles to fresh water]	Mass	8,66E-13	kg	Literature
Metals (unspecified) [Particles to air]	Mass	2,62E-14	kg	Literature
Methacrylate [Group NMVOC to air]	Mass	9,64E-11	kg	Literature
Methane [Organic emissions to air (group VOC)]	Mass	0,006636665	kg	(Literature)
Methane (biotic) [Organic emissions to air (group VOC)]	Mass	1,72E-06	kg	(No statement)
Methanesulfonic acid [Group NMVOC to air]	Mass	2,33E-10	kg	(No statement)
Methanol [Hydrocarbons to sea water]	Mass	5,48E-09	kg	(No statement)
Methanol [Group NMVOC to air]	Mass	4,91E-05	kg	(Calculated)
Methanol [Hydrocarbons to fresh water]	Mass	9,62E-06	kg	(Literature)
Methomyl [Pesticides to fresh water]	Mass	1,66E-18	kg	Calculated
Methomyl [Pesticides to air]	Mass	2,66E-17	kg	Calculated
Methyl acetate [Organic emissions to fresh water]	Mass	2,30E-11	kg	(No statement)
Methyl acetate [Group NMVOC to air]	Mass	9,57E-12	kg	(No statement)
Methyl acrylate [Organic emissions to fresh water]	Mass	2,08E-09	kg	(No statement)
Methyl amine [Organic emissions to fresh water]	Mass	1,18E-09	kg	(No statement)
Methyl amine [Group NMVOC to air]	Mass	4,91E-10	kg	(No statement)
Methyl borate [Group NMVOC to air]	Mass	6,69E-12	kg	(No statement)
Methyl bromide [Halogenated organic emissions to air]	Mass	9,31E-17	kg	Calculated
Methyl formate [Group NMVOC to air]	Mass	6,95E-12	kg	(No statement)

Methyl isobutyl ketone [Organic emissions to fresh water]	Mass	3,61E-14	kg	(No statement)
Methyl lactate [Organic emissions to air (group VOC)]	Mass	6,51E-10	kg	(No statement)
Methyl methacrylate (MMA) [Group NMVOC to air]	Mass	5,87E-12	kg	Literature
Methyl tert-butylether [Hydrocarbons to sea water]	Mass	1,49E-09	kg	(No statement)
Methyl tert-butylether [Group NMVOC to air]	Mass	1,27E-10	kg	(No statement)
Methyl tert-butylether [Hydrocarbons to fresh water]	Mass	2,32E-12	kg	(No statement)
Methylformat [Organic emissions to fresh water]	Mass	2,78E-12	kg	(No statement)
Metolachlor [Pesticides to agricultural soil]	Mass	1,97E-05	kg	(No statement)
Metribuzin [Pesticides to agricultural soil]	Mass	9,63E-12	kg	(No statement)
Molybdenum [Heavy metals to fresh water]	Mass	1,03E-07	kg	Literature
Molybdenum [Heavy metals to sea water]	Mass	4,69E-11	kg	Literature
Molybdenum [Heavy metals to agricultural soil]	Mass	4,57E-10	kg	(No statement)
Molybdenum [Heavy metals to air]	Mass	2,87E-08	kg	(Literature)
Molybdenum [ecoinvent long-term to fresh water]	Mass	2,01E-07	kg	(No statement)
Molybdenum (Mo99) [Radioactive emissions to fresh water]	Activity	6,03E-06	Bq	(No statement)
Monoethanolamine [Group NMVOC to air]	Mass	1,56E-08	kg	(No statement)
Naphthalene [Organic emissions to sea water]	Mass	6,75E-08	kg	Literature
Naphthalene [Group PAH to air]	Mass	5,17E-09	kg	Literature
Naphthalene [Hydrocarbons to fresh water]	Mass	2,35E-07	kg	Literature
Napropamide [Pesticides to agricultural soil]	Mass	2,12E-08	kg	(No statement)
n-Butyl acetate [Organic emissions to fresh water]	Mass	7,23E-10	kg	(No statement)
n-Butyl acetate [Group NMVOC to air]	Mass	5,48E-14	kg	Measured
Nickel (+II) [Heavy metals to industrial soil]	Mass	4,14E-10	kg	Calculated
Nickel (+II) [Heavy metals to sea water]	Mass	3,81E-07	kg	Literature
Nickel (+II) [Heavy metals to agricultural soil]	Mass	1,71E-08	kg	Calculated
Nickel (+II) [Heavy metals to air]	Mass	9,28E-07	kg	(Calculated)
Nickel (+II) [Heavy metals to fresh water]	Mass	4,41E-06	kg	Literature
Niobium (Nb95) [Radioactive emissions to air]	Activity	5,96E-09	Bq	(No statement)
Nitrate [Inorganic emissions to sea water]	Mass	1,28E-06	kg	Literature
Nitrate [Inorganic emissions to fresh water]	Mass	0,00414308	kg	Literature
Nitrate [Inorganic emissions to air]	Mass	4,73E-09	kg	(No statement)
Nitrate [ecoinvent long-term to fresh water]	Mass	2,07E-05	kg	(No statement)
Nitric acid [Inorganic emissions to industrial soil]	Mass	2,35E-15	kg	(No statement)
Nitrite [Inorganic emissions to sea water]	Mass	1,16E-08	kg	Literature
Nitrite [ecoinvent long-term to fresh water]	Mass	3,65E-10	kg	(No statement)
Nitrite [Inorganic emissions to fresh water]	Mass	1,32E-07	kg	Literature
Nitrobenzene [Organic emissions to fresh water]	Mass	1,46E-08	kg	(No statement)
Nitrobenzene [Group NMVOC to air]	Mass	3,63E-09	kg	(No statement)
Nitrogen [Inorganic emissions to sea water]	Mass	1,08E-09	kg	(No statement)
Nitrogen [Inorganic emissions to fresh water]	Mass	0,000103	kg	Literature
Nitrogen [Inorganic emissions to industrial soil]	Mass	6,74E-14	kg	(No statement)
Nitrogen (as total N) [Inorganic emissions to fresh water]	Mass	5,59E-09	kg	Literature
Nitrogen (atmospheric nitrogen) [Inorganic emissions to air]	Mass	0,000197996	kg	(Calculated)
Nitrogen dioxide [Inorganic emissions to air]	Mass	3,98E-07	kg	Literature
Nitrogen monoxide [Inorganic emissions to air]	Mass	2,52E-06	kg	Calculated
Nitrogen organic bounded [Inorganic emissions to sea water]	Mass	4,69E-08	kg	(No statement)
Nitrogen organic bounded [ecoinvent long-term to fresh water]	Mass	1,10E-08	kg	(No statement)
Nitrogen organic bounded [Inorganic emissions to fresh water]	Mass	4,20E-05	kg	(Literature)
Nitrogen oxides [Inorganic emissions to air]	Mass	0,00275688	kg	(Literature)
Nitrogenous Matter (unspecified, as N) [Analytical measures tc	Mass	6,68E-07	kg	(No statement)

Nitrogentriflouride [Inorganic emissions to air]	Mass	5,12E-12	kg	Measured
Nitrous oxide (laughing gas) [Inorganic emissions to air]	Mass	0,000272637	kg	Literature
NMVOC (unspecified) [Group NMVOC to air]	Mass	0,001216067	kg	Literature
Octane [Group NMVOC to air]	Mass	1,29E-06	kg	Calculated
Oil (unspecified) [Hydrocarbons to sea water]	Mass	1,90E-05	kg	Literature
Oil (unspecified) [Organic emissions to industrial soil]	Mass	1,46E-06	kg	(Literature)
Oil (unspecified) [Organic emissions to agricultural soil]	Mass	4,79E-05	kg	(No statement)
Oil (unspecified) [Hydrocarbons to fresh water]	Mass	0,000194814	kg	Literature
o-Nitrotoluene [Group NMVOC to air]	Mass	3,57E-11	kg	(No statement)
Orbencarb [Pesticides to agricultural soil]	Mass	5,20E-11	kg	(No statement)
Organic chlorine compounds [Organic emissions to air (group	Mass	2,65E-14	kg	Literature
Organic chlorine compounds (unspecified) [Organic emissions	Mass	8,30E-14	kg	Literature
Organic compounds (dissolved) [Organic emissions to fresh wa	Mass	3,66E-14	kg	Literature
Organic compounds (unspecified) [Organic emissions to fresh	Mass	2,25E-06	kg	Literature
Overburden (deposited) [Stockpile goods]	Mass	1,085730459	kg	Literature
Oxygen [Inorganic emissions to air]	Mass	0,00733629	kg	Literature
Ozone [Inorganic emissions to air]	Mass	2,39E-07	kg	(No statement)
Palladium [Heavy metals to air]	Mass	1,30E-15	kg	Literature
para-Cresol [Group NMVOC to air]	Mass	1,73E-13	kg	Literature
Pentachlorobenzene [Halogenated organic emissions to air]	Mass	1,76E-12	kg	(No statement)
Pentachlorophenol (PCP) [Halogenated organic emissions to fr	Mass	2,40E-13	kg	(No statement)
Pentachlorophenol (PCP) [Halogenated organic emissions to ai	Mass	1,28E-10	kg	(No statement)
Pentane (n-pentane) [Group NMVOC to air]	Mass	3,85E-05	kg	(Calculated)
Phenanthrene [Group PAH to air]	Mass	1,62E-09	kg	Literature
Phenol (hydroxy benzene) [Hydrocarbons to sea water]	Mass	2,20E-06	kg	Literature
Phenol (hydroxy benzene) [Group NMVOC to air]	Mass	1,44E-07	kg	(Literature)
Phenol (hydroxy benzene) [Hydrocarbons to fresh water]	Mass	7,87E-06	kg	Literature
Phosphate [Inorganic emissions to sea water]	Mass	2,14E-05	kg	(No statement)
Phosphate [ecoinvent long-term to fresh water]	Mass	8,21E-05	kg	(No statement)
Phosphate [Inorganic emissions to fresh water]	Mass	3,22E-05	kg	Literature
Phosphorus [Inorganic emissions to industrial soil]	Mass	2,05E-08	kg	Literature
Phosphorus [Inorganic emissions to sea water]	Mass	2,02E-09	kg	Literature
Phosphorus [Inorganic emissions to agricultural soil]	Mass	1,11E-06	kg	(No statement)
Phosphorus [Inorganic emissions to air]	Mass	2,68E-07	kg	(No statement)
Phosphorus [Inorganic emissions to fresh water]	Mass	5,19E-06	kg	Literature
Pirimicarb [Pesticides to agricultural soil]	Mass	1,70E-08	kg	(No statement)
Platinum [Heavy metals to air]	Mass	1,14E-14	kg	(No statement)
Plutonium (Pu alpha) [Radioactive emissions to fresh water]	Activity	0,00018921	Bq	(Literature)
Plutonium (Pu alpha) [Radioactive emissions to air]	Activity	2,11E-09	Bq	(Calculated)
Plutonium (Pu238) [Radioactive emissions to air]	Activity	1,00E-10	Bq	(No statement)
Polonium (Po210) [Radioactive emissions to sea water]	Activity	1,93727292	Bq	(No statement)
Polonium (Po210) [Radioactive emissions to air]	Activity	0,022097786	Bq	Literature
Polonium (Po210) [Radioactive emissions to fresh water]	Activity	0,001145858	Bq	(No statement)
Polychlorinated biphenyls (PCB unspecified) [Halogenated org	Mass	6,48E-11	kg	Literature
Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD) [Halogen	Mass	5,03E-20	kg	(Estimated)
Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD) [Halogen	Mass	8,51E-14	kg	Literature
Polycyclic aromatic hydrocarbons (PAH, carcinogenic) [Group	Mass	9,57E-08	kg	(Literature)
Polycyclic aromatic hydrocarbons (PAH, unspec.) [Hydrocarbo	Mass	1,78E-09	kg	(No statement)
Polycyclic aromatic hydrocarbons (PAH, unspec.) [Hydrocarbo	Mass	7,33E-09	kg	(Literature)
Polycyclic aromatic hydrocarbons (unspecified) [Organic emis	Mass	1,92E-11	kg	Literature

Potassium [Inorganic emissions to sea water]	Mass	9,47E-07	kg	(No statement)
Potassium [ecoinvent long-term to fresh water]	Mass	0,000256327	kg	(No statement)
Potassium [Inorganic emissions to fresh water]	Mass	3,26E-05	kg	Literature
Potassium (+I) [Inorganic emissions to industrial soil]	Mass	4,98E-09	kg	Literature
Potassium (K40) [Radioactive emissions to sea water]	Activity	0,153431944	Bq	(No statement)
Potassium (K40) [Radioactive emissions to air]	Activity	0,001982403	Bq	(No statement)
Potassium (K40) [Radioactive emissions to fresh water]	Activity	0,001372852	Bq	(No statement)
Propane [Group NMVOC to air]	Mass	0,000429329	kg	(Calculated)
Propanol (iso-propanol; isopropanol) [Hydrocarbons to fresh w	Mass	4,83E-10	kg	(No statement)
Propene [Hydrocarbons to fresh water]	Mass	5,37E-08	kg	(No statement)
Propene (propylene) [Group NMVOC to air]	Mass	3,16E-05	kg	(Calculated)
Propionaldehyde [Organic emissions to fresh water]	Mass	4,73E-11	kg	(No statement)
Propionaldehyde [Group NMVOC to air]	Mass	1,59E-09	kg	(No statement)
Propionic acid [Organic emissions to fresh water]	Mass	1,18E-09	kg	(No statement)
Propionic acid (propane acid) [Group NMVOC to air]	Mass	6,16E-09	kg	(Literature)
Propylamine [Organic emissions to fresh water]	Mass	1,89E-11	kg	(No statement)
Propylamine [Group NMVOC to air]	Mass	7,88E-12	kg	(No statement)
Propylene glycol methyl ether acetate [Group NMVOC to air]	Mass	3,26E-10	kg	Literature
Propylene oxide [Hydrocarbons to fresh water]	Mass	6,23E-09	kg	(No statement)
Propylene oxide [Group NMVOC to air]	Mass	2,59E-09	kg	(No statement)
Protactinium (Pa234m) [Radioactive emissions to fresh water]	Activity	0,011952197	Bq	Literature
Protactinium (Pa234m) [Radioactive emissions to air]	Activity	0,000120328	Bq	Literature
R 11 (trichlorofluoromethane) [Halogenated organic emissions	Mass	4,57E-14	kg	Literature
R 113 (trichlorotrifluoroethane) [Halogenated organic emissio	Mass	4,03E-12	kg	(No statement)
R 114 (dichlorotetrafluoroethane) [Halogenated organic emissi	Mass	5,49E-10	kg	Literature
R 116 (hexafluoroethane) [Halogenated organic emissions to a	Mass	2,89E-09	kg	(Estimated)
R 12 (dichlorodifluoromethane) [Halogenated organic emissio	Mass	2,52E-11	kg	Literature
R 124 (chlorotetrafluoroethane) [Halogenated organic emissio	Mass	1,90E-16	kg	Estimated
R 125 (pentafluoroethane) [Halogenated organic emissions to a	Mass	3,17E-11	kg	Literature
R 13 (chlorotrifluoromethane) [Halogenated organic emissions	Mass	3,44E-16	kg	Literature
R 134a (tetrafluoroethane) [Halogenated organic emissions to a	Mass	4,00E-08	kg	(Literature)
R 143 (trifluoroethane) [Halogenated organic emissions to air]	Mass	2,83E-11	kg	(Literature)
R 152a (difluoroethane) [Halogenated organic emissions to air]	Mass	2,02E-11	kg	(No statement)
R 21 (Dichlorofluoromethane) [Halogenated organic emissions	Mass	2,66E-14	kg	(No statement)
R 22 (chlorodifluoromethane) [Halogenated organic emissions	Mass	1,67E-09	kg	Literature
R 23 (trifluoromethane) [Halogenated organic emissions to air]	Mass	2,26E-10	kg	Literature
R 245fa [Halogenated organic emissions to air]	Mass	5,64E-10	kg	Literature
R32 (difluoromethane) [Halogenated organic emissions to air]	Mass	4,76E-12	kg	Literature
Radioactive emissions (general) [Radioactive emissions to air]	Activity	0,000151231	Bq	Literature
Radioactive isotopes (unspecific) [Radioactive emissions to fre	Activity	0,716505879	Bq	(No statement)
Radioactive isotopes (unspecific) [Radioactive emissions to air	Activity	0,030756686	Bq	(No statement)
Radium (Ra224) [Radioactive emissions to sea water]	Activity	0,01120545	Bq	(No statement)
Radium (Ra224) [Radioactive emissions to fresh water]	Activity	0,02827335	Bq	(No statement)
Radium (Ra226) [Radioactive emissions to sea water]	Activity	1,4474367	Bq	(No statement)
Radium (Ra226) [Radioactive emissions to fresh water]	Activity	35,23697348	Bq	Literature
Radium (Ra226) [Radioactive emissions to air]	Activity	0,03107952	Bq	Literature
Radium (Ra228) [Radioactive emissions to sea water]	Activity	0,02241105	Bq	(No statement)
Radium (Ra228) [Radioactive emissions to fresh water]	Activity	0,056562897	Bq	(No statement)
Radium (Ra228) [Radioactive emissions to air]	Activity	0,007036583	Bq	(No statement)
Radon (Rn220) [Radioactive emissions to air]	Activity	0,025120301	Bq	(No statement)

Radon (Rn222) [Radioactive emissions to air]	Activity	2001,68957	Bq	Literature
Radon (Rn222) [ecoinvent long-term to air]	Activity	15232,53	Bq	(No statement)
Rhodium [Heavy metals to air]	Mass	1,26E-15	kg	Measured
Rubidium [Inorganic emissions to fresh water]	Mass	7,90E-09	kg	(No statement)
Ruthenium (Ru103) [Radioactive emissions to fresh water]	Activity	1,27E-06	Bq	(No statement)
Ruthenium (Ru103) [Radioactive emissions to air]	Activity	1,31E-09	Bq	(No statement)
Ruthenium (Ru106) [Radioactive emissions to sea water]	Activity	0,964004291	Bq	Literature
Ruthenium (Ru106) [Radioactive emissions to fresh water]	Activity	0,011449413	Bq	(Calculated)
Scandium [Inorganic emissions to fresh water]	Mass	2,25E-09	kg	(No statement)
Scandium [ecoinvent long-term to fresh water]	Mass	9,60E-08	kg	(No statement)
Scandium [Inorganic emissions to air]	Mass	1,56E-09	kg	(Calculated)
Selenium [Heavy metals to industrial soil]	Mass	7,77E-14	kg	Literature
Selenium [Heavy metals to sea water]	Mass	7,03E-11	kg	(No statement)
Selenium [Heavy metals to fresh water]	Mass	5,00E-08	kg	Literature
Selenium [Heavy metals to air]	Mass	6,82E-08	kg	(Calculated)
Selenium [ecoinvent long-term to fresh water]	Mass	1,73E-07	kg	(No statement)
Silicate particles [Inorganic emissions to fresh water]	Mass	1,92E-11	kg	Measured
Silicium tetrafluoride [Inorganic emissions to air]	Mass	1,16E-10	kg	Calculated
Silicon dioxide (silica) [Particles to fresh water]	Mass	1,94E-11	kg	Literature
Silicon dioxide (silica) [Particles to air]	Mass	8,93E-11	kg	Literature
Silicon dust [Particles to air]	Mass	1,79E-06	kg	(No statement)
Silver [Heavy metals to fresh water]	Mass	9,52E-10	kg	Literature
Silver [Heavy metals to sea water]	Mass	1,34E-10	kg	Literature
Silver [Heavy metals to air]	Mass	1,01E-09	kg	Calculated
Silver [ecoinvent long-term to fresh water]	Mass	7,46E-09	kg	(No statement)
Silver (Ag110m) [Radioactive emissions to fresh water]	Activity	0,035919032	Bq	(Literature)
Silver (Ag110m) [Radioactive emissions to air]	Activity	1,30E-08	Bq	(No statement)
Sodium (+I) [Inorganic emissions to industrial soil]	Mass	4,92E-09	kg	Literature
Sodium (+I) [Inorganic emissions to sea water]	Mass	7,82E-05	kg	Literature
Sodium (+I) [ecoinvent long-term to fresh water]	Mass	0,00252312	kg	(No statement)
Sodium (+I) [Inorganic emissions to fresh water]	Mass	0,002495908	kg	Literature
Sodium (Na24) [Radioactive emissions to fresh water]	Activity	4,56E-05	Bq	(No statement)
Sodium chlorate [Inorganic emissions to air]	Mass	1,10E-10	kg	(No statement)
Sodium chloride (rock salt) [Inorganic emissions to fresh water	Mass	3,89E-08	kg	Literature
Sodium dichromate [Inorganic emissions to air]	Mass	2,13E-10	kg	(No statement)
Sodium formate [Hydrocarbons to fresh water]	Mass	1,11E-11	kg	(No statement)
Sodium formate [Inorganic emissions to air]	Mass	4,64E-12	kg	(No statement)
Sodium hydroxide [Inorganic emissions to air]	Mass	8,52E-10	kg	(No statement)
Sodium hypochlorite [Inorganic emissions to fresh water]	Mass	1,62E-06	kg	(Calculated)
Sodium sulphate [Inorganic emissions to fresh water]	Mass	4,88E-06	kg	Literature
Soil loss by erosion into water [Particles to fresh water]	Mass	0,00013409	kg	Literature
Solids (dissolved) [Analytical measures to fresh water]	Mass	0,000997722	kg	Literature
Solids (suspended) [Particles to sea water]	Mass	0,000395196	kg	Literature
Solids (suspended) [Particles to fresh water]	Mass	0,003060023	kg	Literature
Solids (suspended) [ecoinvent long-term to fresh water]	Mass	0,001501275	kg	(No statement)
Spoil (deposited) [Stockpile goods]	Mass	0,011705805	kg	Literature
Strontium [Inorganic emissions to fresh water]	Mass	3,24E-06	kg	Literature
Strontium [Inorganic emissions to industrial soil]	Mass	3,74E-09	kg	Literature
Strontium [Inorganic emissions to sea water]	Mass	4,17E-07	kg	Literature
Strontium [Inorganic emissions to agricultural soil]	Mass	3,03E-11	kg	(No statement)

Strontium [Inorganic emissions to air]	Mass	2,38E-08	kg	(Calculated)
Strontium [ecoinvent long-term to fresh water]	Mass	8,57E-06	kg	(No statement)
Strontium (Sr89) [Radioactive emissions to fresh water]	Activity	0,000108128	Bq	(No statement)
Strontium (Sr90) [Radioactive emissions to sea water]	Activity	0,063665709	Bq	Literature
Strontium (Sr90) [Radioactive emissions to fresh water]	Activity	0,614442705	Bq	(Literature)
Styrene [Group NMVOC to air]	Mass	4,61E-10	kg	Literature
Sulphate [Inorganic emissions to industrial soil]	Mass	4,56E-10	kg	Literature
Sulphate [Inorganic emissions to sea water]	Mass	0,001118973	kg	Literature
Sulphate [Inorganic emissions to fresh water]	Mass	0,001823243	kg	Literature
Sulphate [Inorganic emissions to air]	Mass	5,43E-06	kg	(No statement)
Sulphate [ecoinvent long-term to fresh water]	Mass	0,00368193	kg	(No statement)
Sulphide [Inorganic emissions to sea water]	Mass	6,55E-05	kg	Literature
Sulphide [Inorganic emissions to industrial soil]	Mass	1,06E-09	kg	Literature
Sulphide [Inorganic emissions to fresh water]	Mass	0,000230123	kg	Literature
Sulphite [Inorganic emissions to fresh water]	Mass	1,80E-07	kg	Literature
Sulphur [Inorganic emissions to industrial soil]	Mass	2,24E-07	kg	(No statement)
Sulphur [Inorganic emissions to sea water]	Mass	5,71E-09	kg	Literature
Sulphur [Inorganic emissions to fresh water]	Mass	3,08E-05	kg	Literature
Sulphur [Inorganic emissions to agricultural soil]	Mass	1,17E-06	kg	(No statement)
Sulphur [Inorganic emissions to air]	Mass	5,86E-10	kg	Literature
Sulphur dioxide [Inorganic emissions to air]	Mass	0,004814868	kg	(Literature)
Sulphur hexafluoride [Inorganic emissions to air]	Mass	2,79E-09	kg	(Estimated)
Sulphur trioxide [Inorganic emissions to fresh water]	Mass	1,09E-09	kg	Calculated
Sulphur trioxide [Inorganic emissions to air]	Mass	3,00E-08	kg	Literature
Sulphuric acid [Inorganic emissions to fresh water]	Mass	1,57E-10	kg	Estimated
Sulphuric acid [Inorganic emissions to air]	Mass	1,46E-09	kg	Calculated
Sulphuric acid [Inorganic emissions to agricultural soil]	Mass	1,10E-13	kg	(No statement)
Suspended solids, unspecified [Particles to fresh water]	Mass	2,87E-06	kg	(No statement)
Tailings (deposited) [Stockpile goods]	Mass	0,004195518	kg	Literature
Tantalum [Heavy metals to fresh water]	Mass	2,11E-15	kg	(No statement)
t-Butylamine [Organic emissions to fresh water]	Mass	4,24E-10	kg	(No statement)
t-Butylamine [Group NMVOC to air]	Mass	1,77E-10	kg	(No statement)
Tebutam [Pesticides to agricultural soil]	Mass	5,03E-08	kg	(No statement)
Technetium (Tc99m) [Radioactive emissions to fresh water]	Activity	0,000138595	Bq	(No statement)
Teflubenzuron [Pesticides to agricultural soil]	Mass	6,42E-13	kg	(No statement)
Tellurium [Heavy metals to air]	Mass	6,60E-12	kg	(Measured)
Tellurium (Te123m) [Radioactive emissions to fresh water]	Activity	2,31E-05	Bq	(No statement)
Tellurium (Te132) [Radioactive emissions to fresh water]	Activity	3,49E-07	Bq	(No statement)
Terbufos [Pesticides to fresh water]	Mass	1,07E-17	kg	Calculated
Terbufos [Pesticides to air]	Mass	1,72E-16	kg	Calculated
Terpenes [Group NMVOC to air]	Mass	3,46E-06	kg	(No statement)
Tetrachloroethene (perchloroethylene) [Halogenated organic e	Mass	1,31E-18	kg	(No statement)
Tetrachloroethene (perchloroethylene) [Halogenated organic e	Mass	3,19E-15	kg	(No statement)
Tetrachloroethene (perchloroethylene) [Halogenated organic e	Mass	2,80E-13	kg	Estimated
Tetrafluoromethane [Halogenated organic emissions to air]	Mass	2,40E-08	kg	Measured
Thallium [Heavy metals to fresh water]	Mass	8,72E-11	kg	(Measured)
Thallium [ecoinvent long-term to fresh water]	Mass	1,33E-08	kg	(No statement)
Thallium [Heavy metals to air]	Mass	2,36E-10	kg	(Literature)
Thiram [Pesticides to agricultural soil]	Mass	1,57E-08	kg	(No statement)
Thorium [Radioactive emissions to air]	Mass	2,03E-10	kg	(No statement)

Thorium (Th228) [Radioactive emissions to sea water]	Activity	0,06038655	Bq	(No statement)
Thorium (Th228) [Radioactive emissions to fresh water]	Activity	0,11308995	Bq	(No statement)
Thorium (Th228) [Radioactive emissions to air]	Activity	0,000693266	Bq	(No statement)
Thorium (Th230) [Radioactive emissions to fresh water]	Activity	1,058861072	Bq	Literature
Thorium (Th230) [Radioactive emissions to air]	Activity	0,009530573	Bq	Literature
Thorium (Th232) [Radioactive emissions to fresh water]	Activity	0,000255122	Bq	(No statement)
Thorium (Th232) [Radioactive emissions to air]	Activity	0,000572236	Bq	(No statement)
Thorium (Th234) [Radioactive emissions to fresh water]	Activity	0,011952483	Bq	Literature
Thorium (Th234) [Radioactive emissions to air]	Activity	0,000120385	Bq	Literature
Tin (+IV) [Heavy metals to fresh water]	Mass	5,80E-10	kg	Literature
Tin (+IV) [Heavy metals to sea water]	Mass	1,92E-17	kg	Literature
Tin (+IV) [ecoinvent long-term to fresh water]	Mass	1,22E-07	kg	(No statement)
Tin (+IV) [Heavy metals to agricultural soil]	Mass	1,54E-10	kg	(No statement)
Tin (+IV) [Heavy metals to air]	Mass	2,79E-08	kg	(Calculated)
Tin oxide [Inorganic emissions to air]	Mass	3,73E-20	kg	Literature
Titanium [Heavy metals to fresh water]	Mass	1,55E-07	kg	Literature
Titanium [Heavy metals to sea water]	Mass	1,72E-11	kg	Literature
Titanium [Heavy metals to agricultural soil]	Mass	1,57E-07	kg	(No statement)
Titanium [Heavy metals to air]	Mass	6,86E-08	kg	(Calculated)
Toluene (methyl benzene) [Hydrocarbons to sea water]	Mass	1,34E-06	kg	Literature
Toluene (methyl benzene) [Hydrocarbons to fresh water]	Mass	4,65E-06	kg	Literature
Toluene (methyl benzene) [Group NMVOC to air]	Mass	6,51E-06	kg	Literature
Total dissolved organic bounded carbon [Analytical measures t	Mass	8,33E-06	kg	(No statement)
Total dissolved organic bounded carbon [Analytical measures t	Mass	4,27E-05	kg	Literature
Total organic bounded carbon [Analytical measures to sea wat	Mass	8,81E-06	kg	Literature
Total organic bounded carbon [Analytical measures to fresh wa	Mass	9,44E-05	kg	Literature
Total organic carbon, TOC (Ecoinvent) [ecoinvent long-term t	Mass	5,42E-05	kg	(No statement)
Tributyltinoxide [Pesticides to sea water]	Mass	5,09E-09	kg	(No statement)
Trichloroethene (isomers) [Halogenated organic emissions to a	Mass	4,27E-11	kg	Calculated
Trichloromethane (chloroform) [Halogenated organic emission	Mass	6,48E-11	kg	(No statement)
Trichloromethane (chloroform) [Halogenated organic emission	Mass	6,35E-10	kg	(No statement)
Triethylene glycol [Hydrocarbons to sea water]	Mass	4,56E-09	kg	(No statement)
Triethylene glycol [Hydrocarbons to fresh water]	Mass	4,19E-17	kg	(No statement)
Trifluralin [Pesticides to fresh water]	Mass	4,27E-17	kg	Calculated
Trifluralin [Pesticides to air]	Mass	6,83E-16	kg	Calculated
Trimethylamine [Organic emissions to fresh water]	Mass	4,07E-11	kg	(No statement)
Trimethylamine [Group NMVOC to air]	Mass	1,70E-11	kg	(No statement)
Tungsten [Heavy metals to fresh water]	Mass	4,58E-09	kg	Calculated
Tungsten [ecoinvent long-term to fresh water]	Mass	1,67E-07	kg	(No statement)
Tungsten [Heavy metals to air]	Mass	1,61E-10	kg	(No statement)
Unused primary energy from geothermal [Other emissions to fi	Energy (ne	7,03E-09	MJ	Calculated
Unused primary energy from hydro power [Other emissions to	Energy (ne	0,120699712	MJ	Literature
Unused primary energy from solar energy [Other emissions to a	Energy (ne	0,156864409	MJ	(Literature)
Unused primary energy from wind power [Other emissions to a	Energy (ne	0,182498258	MJ	Calculated
Uranium [Radioactive emissions to fresh water]	Activity	0,159987005	Bq	Literature
Uranium (total) [Radioactive emissions to air]	Activity	0,006744502	Bq	Literature
Uranium (U234) [Radioactive emissions to sea water]	Activity	0,002851846	Bq	Literature
Uranium (U234) [Radioactive emissions to fresh water]	Activity	0,297260921	Bq	(Literature)
Uranium (U234) [Radioactive emissions to air]	Activity	0,024559572	Bq	(Literature)
Uranium (U235) [Radioactive emissions to fresh water]	Activity	0,005905241	Bq	Literature

Uranium (U235) [Radioactive emissions to air]	Activity	0,000371906	Bq	Literature
Uranium (U238) [Radioactive emissions to sea water]	Activity	0,654120808	Bq	Literature
Uranium (U238) [Radioactive emissions to fresh water]	Activity	0,300074721	Bq	(Literature)
Uranium (U238) [Radioactive emissions to air]	Activity	0,02872648	Bq	(Literature)
Urea [Inorganic emissions to fresh water]	Mass	7,58E-11	kg	(No statement)
Used air [Other emissions to air]	Mass	0,378619202	kg	Literature
Vanadium (+III) [Heavy metals to fresh water]	Mass	5,22E-08	kg	(Literature)
Vanadium (+III) [Heavy metals to sea water]	Mass	2,97E-15	kg	Literature
Vanadium (+III) [ecoinvent long-term to fresh water]	Mass	3,26E-06	kg	(No statement)
Vanadium (+III) [Heavy metals to agricultural soil]	Mass	4,49E-09	kg	(No statement)
Vanadium (+III) [Heavy metals to air]	Mass	1,14E-06	kg	(Calculated)
Vinyl chloride (VCM; chloroethene) [Halogenated organic em	Mass	5,45E-11	kg	Literature
Vinyl chloride (VCM; chloroethene) [Halogenated organic em	Mass	4,33E-09	kg	(Calculated)
VOC (unspecified) [Hydrocarbons to sea water]	Mass	7,84E-08	kg	(No statement)
VOC (unspecified) [Hydrocarbons to fresh water]	Mass	2,03E-07	kg	(No statement)
Waste (deposited) [Stockpile goods]	Mass	0,0037199	kg	Estimated
Waste heat [Other emissions to industrial soil]	Energy (ne	0,005666288	MJ	(No statement)
Waste heat [Other emissions to sea water]	Energy (ne	0,001684681	MJ	Literature
Waste heat [Other emissions to fresh water]	Energy (ne	1,13940179	MJ	Calculated
Waste heat [Other emissions to air]	Energy (ne	6,655771341	MJ	(Calculated)
Waste heat [ecoinvent long-term to fresh water]	Energy (ne	0,000122832	MJ	(No statement)
Water (evapotranspiration) [Inorganic emissions to air]	Mass	1,296696433	kg	(No statement)
Water (groundwater from technosphere, waste water) [Other er	Mass	2,18E-06	kg	Literature
Water (river water from technosphere, cooling water) [Other er	Mass	23,56588073	kg	Calculated
Water (river water from technosphere, turbined) [Other emissic	Mass	2767,042244	kg	Literature
Water (river water from technosphere, waste water) [Other emi	Mass	1,772886326	kg	Literature
Water (sea water from technosphere, cooling water) [Other em	Mass	2,208687466	kg	(Calculated)
Water (sea water from technosphere, waste water) [Other emis	Mass	0,041222438	kg	Literature
Water vapour [Inorganic emissions to air]	Mass	5,093020598	kg	(Estimated)
Xenon (Xe131m) [Radioactive emissions to air]	Activity	18,90303136	Bq	(Literature)
Xenon (Xe133) [Radioactive emissions to air]	Activity	367,7170356	Bq	(Literature)
Xenon (Xe133m) [Radioactive emissions to air]	Activity	13,94862536	Bq	(Literature)
Xenon (Xe135) [Radioactive emissions to air]	Activity	442,0277862	Bq	(Literature)
Xenon (Xe135m) [Radioactive emissions to air]	Activity	21,75257248	Bq	(Literature)
Xenon (Xe137) [Radioactive emissions to air]	Activity	68,5886547	Bq	(Literature)
Xenon (Xe138) [Radioactive emissions to air]	Activity	75,50006221	Bq	(Literature)
Xylene (dimethyl benzene) [Group NMVOC to air]	Mass	4,08E-06	kg	(Literature)
Xylene (isomers; dimethyl benzene) [Hydrocarbons to sea wate	Mass	4,93E-07	kg	Literature
Xylene (isomers; dimethyl benzene) [Hydrocarbons to fresh wa	Mass	1,68E-06	kg	Literature
Xylene (meta-Xylene; 1,3-Dimethylbenzene) [Hydrocarbons to	Mass	5,54E-11	kg	(No statement)
Xylene (meta-Xylene; 1,3-Dimethylbenzene) [Group NMVOC	Mass	9,99E-08	kg	(No statement)
Xylene (ortho-Xylene; 1,2-Dimethylbenzene) [Hydrocarbons t	Mass	1,90E-13	kg	(No statement)
Zinc (+II) [Heavy metals to fresh water]	Mass	7,13E-07	kg	Literature
Zinc (+II) [Heavy metals to industrial soil]	Mass	6,69E-08	kg	Calculated
Zinc (+II) [Heavy metals to sea water]	Mass	2,34E-07	kg	Literature
Zinc (+II) [Heavy metals to agricultural soil]	Mass	-2,38E-07	kg	Calculated
Zinc (+II) [Heavy metals to air]	Mass	7,96E-07	kg	(Calculated)
Zinc (+II) [ecoinvent long-term to fresh water]	Mass	9,35E-06	kg	(No statement)
Zinc (Zn65) [Radioactive emissions to fresh water]	Activity	0,000618518	Bq	(No statement)
Zinc (Zn65) [Radioactive emissions to air]	Activity	2,51E-07	Bq	(No statement)

Zinc chloride [Inorganic emissions to air]	Mass	1,16E-19	kg	Measured
Zinc oxide [Inorganic emissions to air]	Mass	7,47E-20	kg	Literature
Zinc sulphate [Inorganic emissions to air]	Mass	4,14E-10	kg	Measured
Zirconium (Zr) [Heavy metals to air]	Mass	4,17E-11	kg	(No statement)
Zirconium (Zr95) [Radioactive emissions to fresh water]	Activity	7,16E-06	Bq	(No statement)
Zirconium (Zr95) [Radioactive emissions to air]	Activity	2,45E-07	Bq	(No statement)