Chapter N 120

Definition of indicators relating to the extraction of minerals used in the ceramic sector for an LCA

**Abstract.** Among the main criticalities that the ceramic supply chain has to deal with in the logic of industrial symbiosis, there is the difficulty of finding primary data relating to the processes of supplying raw materials and the distribution and use of the final product. As part of the Mise Redirect project (https://www.redirect.gresmalt.it/) which aims to design and validate a Circular Industry 4.0 model, the environmental sustainability of the extraction processes of raw materials used in ceramic production was evaluated using the Life Cycle Assessment methodology.

The study was based on the definition of new indicators related to the depletion of the mineral Eurite in the IMPACT 2002+ calculation method, which allow the environmental damage due to the extraction of the mineral resource to be attributed dynamically. Finally, through an environmental impact assessment using the Life Cycle Assessment methodology, it was shown that the damage categories obtained from the new indicators affect the total damage related to the extraction and processing of the resource by a value within the range [0.20%; 1.96%].

**Keywords.** Life Cycle Assessment, Mineral extraction, Circular Industry 4.0, Mining, Depletion of natural resources.

# Introduction

In Life Cycle Assessment (LCA) studies related to the building sector, analysts encounter a difficulty in finding primary data for raw material extraction processes.

This lack of data is nowadays addressed by the adoption of secondary data, mainly through the use of database processes, which are fundamental in the representation of background processes, but which may, however, deviate from the reality under investigation.

Consequently, a large amount of secondary data can greatly influence the final result of an environmental assessment.

Furthermore, in the literature, LCA analyses are not available for minerals used in the ceramics sector, as well as LCA evaluations of national mining sites.

In order to handle this gap in relation to the supply of raw materials, within the framework of the Mise Redirect project (https://www.redirect.gresmalt.it/), which aims to design and validate a Circular Enterprise 4.0 model, the environmental sustainability of the mining processes of raw materials used in ceramic production was assessed by means of the LCA methodology, according to ISO 14040 and ISO 14044 (UNI EN ISO, 2006).

Specifically, this work focused on the extraction and processing of the mineral Eurite, used in the ceramic sector as a replacement or partial replacement for common feldspars, obtained from the "La Crocetta" mine located in Porto Azzurro on the Island of Elba (LI) by the mining company Eurit S.r.l.

In particular, in order to create a site-specific inventory with a high level of representativeness of the reality, not only the mining processes specific to the reality analysed were modeled, but also new indicators relative to the depletion of the mineral Eurite were introduced in the IMPACT 2002+ calculation method (Jolliet et al., 2003), used by the authors for the environmental impact assessment.

This modification to the calculation method should have concerned the *Mineral extraction* category, which allows environmental damage to be attributed to the inventory data relating to the extracted resource, but instead a new dynamic and time-varying category was created, i.e. dependent on the year in which the resource was extracted. Indeed, it is the authors' belief that environmental damage should increase as the availability of the resource decreases over time.

Finally, by the Life Cycle Assessment (LCA) analysis, the incidence of the damage categories thus created was analysed with respect to the total damage due to the entire mineral extraction and processing process.

It should be noted that for reasons of confidentiality it was not possible to report the numerical values of the inventory data, so the procedures adopted are only illustrated qualitatively.

# Material and methods

## Introduction of Eurite mining indicators within the IMPACT 2002+ method

The function of the calculation method is to connect the inventory data, i.e. the quantity of extracted resource, with the corresponding damage, i.e. the depletion of the resource (generally expressed by the *Mineral extraction* category).

This conversion is done by defining appropriate factors, which are applied successively in the various steps of impact analysis.

First of all, as many impact categories, expressed in ton of extractable resource, as the years of extraction license were introduced to account for the variability of the increasing damage to the rarefaction of the resource, and a new resource, *Eurite x year*, not previously evaluated by the method, was included within the categories.

This new resource was associated with an initial factor, called characterization factor (FC), equal to 1 ton of extractable resource/ton of extracted resource. As a precaution, the unit value was set as the resource extracted in the inventory corresponds to the extractable resource according to the impact category created. Related damage categories were also created.

For the normalization step, which consists of relating the characterized impact to a reference value, i.e. the annual consumption of the site, expressing it as extractable ton of resource/annual ton of resource consumed, a normalization factor Fnorm was inserted into the method for each year of extraction. In particular, the annual resource consumption was taken as the reference since it was assumed that resource extraction equals resource consumption. The annual consumption was estimated by assuming to add to the primary data provided of extracted finished product, a share of Eurite that is extracted but leaves the system as air emission or remaining trapped in the bag filters of the extraction equipment. The normalization factor was derived from the following equation (Eq. 1):

$F\_{norm} [\frac{year}{ton}]= \frac{1}{annual site-specific resource consumption [\frac{ton}{year}]}$ (1)

Therefore, it can be affirmed that Fnorm appears to be the inverse of the annual resource consumption for the site under analysis.

Furthermore, it was assumed that the annual consumption remains unchanged during the years of the mining license and, in particular, it was decided to consider an average value since the real one would only be obtained at the end of each specific year. Consequently, the Fnorm factor also remains unchanged during the mining license years, so there is only one normalization factor valid for each year of extraction.

For the weighing step, which aims to assign a weight to the category, the comparison was made between the annual resource consumption of the site under analysis compared to the total resource availability, which was assumed to be equal to the previous one multiplied by the number of years of the mining license. For the calculation, it was decided not to take into account the Eurite present on the site at the end of the mining works, as it is characterized by a considerably lower quality leading to its reduced application in the ceramic sector. Consequently, the weighting factor Fweight was derived from the following equation (Eq. 2):

$F\_{weight}[\frac{1}{year}]= \frac{annual site-specific resource consumption [year]}{total availability of the site resource [ton]}$ (2)

As many weighing factors as the years of extraction of the resource were included in the method. From the calculations it emerges that Fweight increases with the passing of the years; in fact, the damage resulting from the extraction and consumption of the resource should depend on the year of extraction, since the availability of the resource gradually decreases with the passage of time, e.g. the damage associated with Eurite extracted in the first year of activity should be less than that associated with Eurite extracted in the last year of the mining license.

As an example, the following is an application of the indicators thus derived to calculate the environmental damage associated with Eurite mining:

Characterization (Eq. 3):

$inventory data \left[ton\right]\*F\_{c} \left[\frac{ton}{tonn}\right]= extractable site-specific resource [ton]$ (3)

Normalization (Eq. 4):

$extractable site-specific resource \left[ton\right]\*F\_{norm} [\frac{year}{ton}]=normalised versus annual resource consumption[\frac{ton}{ton}\*year] $ (4)

Weighing (Eq. 5):

$normalised versus annual resource consumption \left[\frac{ton}{ton}\*year\right]\*F\_{weight}\left[\frac{1}{anno}\right]=annual resource consumption weighed versus resource availability [\frac{ton\*anno}{oton\*year}]$

(5)

## Life Cycle Assessement

### Goal and scope definition

The objective of the study is the environmental impact assessment, through the LCA methodology, of the damage due to the extraction and processing of the mineral Eurite, i.e. porphyritic aplite, i.e. a fine-grained magmatic rock composed of potassic feldspar, quartz and clay minerals, with possible carbonate alteration. It is a mineral obtained from the “La Crocetta” mine located on the Island of Elba (LI) and operated by the Eurit S.r.l. mining company.

### System, functional unit and function of the system to be studied

The function of the system is the production of Eurite for the ceramic industry as a replacement or partial replacement for common feldspars.

The system studied is the “La Crocetta” mine located on the island of Elba (LI).

The functional unit was set at one ton of Eurite extracted and processed. This unit quantity was chosen in order to respect the confidentiality constraint, so the analysis is only representative.

#### 1.2.2.2.3 The system boundaries

According to the cradle-to-gate approach, the system boundaries include all phases from the removal of the scotic on the Eurite cultivation area to the delivery of the finished product to the end customer.

#### 1.2.2.2.4 Data quality

In order to realize a site-specific LCI with a high level of representativeness of reality, a high percentage of primary data was used. In particular, the primary data provided included the quantity of finished product obtained annually, data on the mining site, and data on the individual processing stages in terms of energy consumption, machinery, and hours of use.

When absent, data were estimated or literature data or data taken from commercial websites were used.

The method used for the damage calculation is IMPACT 2002+ (Jolliet et al., 2003) modified by the study group (Pini et al., 2014) (Ferrari et al., 2019) and implemented with the damage indicators described in chapter 1.2.1.

The calculation code used is SimaPro 9.3 (Pré Sustainability SimaPro, 2022), while the database is Ecoinvent database v.3.8 (Ecoinvent Center, 2021).

# Results and discussions

In order to obtain a qualitative analysis, the functional unit used to calculate the damage was one ton of resource extracted.

In particular, the damage assessment showed a total damage of 3.24E-2 Pt, of which 61.65% was due to the delivery of the Eurite to the end customer.

The end-point analysis shows that 30.83% of the total damage is due to the damage category *Human health* in particular for the substance *Particulates, < 2.5 μm* (29.78%). The second largest contribution is provided by *Resources* with 20.85% mainly due to the substance *Coal, hard, in raw* (36.40%), followed by *Climate change* for 20.62% with the substance *Carbon, dioxide, fossil* (92.76%), *Ecosystem quality* affects 12.03% for the substance *Zinc, in soil* (42.46%). These damage categories are mainly affected by the transport process of the finished product to the final customer located in the Sassuolo ceramic district. While the damage categories referring to the depletion of the Eurite resource, identified in the present work, are characterized respectively by environmental damage within the range [6.35E-05 Pt; 6.35E-04 Pt]. On a percentage level, these damage categories affect the total damage by range values [0.20%; 1.96%]. The reason why it was decided to report a range of values is because the damage referred to the depletion of the resource is dynamic and varies depending on the year the resource was extracted, however, as mentioned in Chapter 1.1, for reasons of data confidentiality it was not possible to indicate the number of years the resource was extracted and consequently the number of damage categories referred to the depletion of the resource specific to each year of extraction.

Finally, entering more specifically into the mining activity and excluding the process relating to the transport of the finished product to the end customer, it emerged that, at end-point level, 30.64% of the total damage was due to *Human health* for the substance *Particulates, <2. 5μm, in air* (31.52%) due to the emission of fine particulate generated during the particle size reduction.

# Conclusions and future developments

This work focused on the identification and introduction of new indicators referring to the depletion of the Eurite resource, a mineral intended for the ceramic sector as a replacement or partial replacement for common feldspars, not assessed by the IMPACT 2002+ damage calculation method, in order to attribute environmental damage to the inventory data referring to the extracted resource.

In particular, these new indicators allow to connect the extracted resource inventory data with the relative damage caused by the depletion of the resource. This was made possible through the use of parameters, such as the annual site-specific resource consumption, assumed to be equal to the annual quantity of extracted resource, and the availability of the resource estimated on the basis of the years of extraction license.

The variability of this damage over time is the result of the authors' belief that environmental damage should increase as the availability of the resource decreases.

Damage assessment analysis was performed using the LCA methodology, which showed that one ton of Eurite mined and processed produces an environmental damage of 3.24E-2 Pt and the damage categories related to the depletion of the Eurite resource affect the percentage level in the range [0.20%; 1.96%] with a value in terms of damage point varying in the range [6.35E-05 Pt; 6.35E-04 Pt].

The present work also includes a number of significant limitations that may translate into possible future perspectives, such as the assumption of an unchanged annual resource consumption over the years of the mining licence. This assumption was made since the actual figure could only be known at the end of each specific year. It follows that a possible future development could be to introduce the realistic resource consumption figure for each year of extraction into the method.

Another assumption was to calculate the availability of Eurite as the amount of ore mined annually multiplied by years of mining licence, without taking into account the Eurite remaining on site at the end of mining. This assumption stems from the fact that all Eurite with characteristics suitable for the ceramic sector is mined during the set time frame, so the remaining resource may no longer be applicable in the ceramic sector.

# References and Citations

Ferrari AM, Volpi L, Pini M, Siligardi C, García-Muiña FE, Settembre-Blundo D (2019). Building a Sustainability Benchmarking Framework of Ceramic Tiles Based on Life Cycle Sustainability Assessment (LCSA). Resources 8:11. <https://doi.org/10.3390/resources8010011>.

Jolliet, O, Margni, M, Charles, R, Humbert, S, Payet, J, Rebitzer, G, Rosenbaum, R (2003). IMPACT2002+: A new life cycle impact assessment methodology, Int. J. LCA 8: 324–330. <https://link.springer.com/article/10.1007/BF02978505>.

Pini M, Ferrari AM, Gamberini R, Neri P, Rimini B (2014). Life cycle assessment of a large, thin ceramic tile with advantageous technological properties. Int J Life Cycle Assess 19:1567–80. <https://doi.org/10.1007/s11367-014-0764-8>.

 Pré Sustainability SimaPro 9.1. Available online: <https://www.pre-sustainability.com/simapro>.

UNI EN ISO, 2006. ISO 14040:2006 - Environmental management — Life cycle assessment — Principles and framework.