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6.2 Life Cycle Inventory (LCI) analysis of the Sicilian artistic and traditional ceramics as a tool for sustainable manufacturing

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Abstract

In the last few decades, greater attention is being paid by the Italian industrial ceramics sector to the environmental impacts related to ceramics production cycle and many companies have acquired voluntary environmental certifications (ISO 14001 or EMAS) or labeling (Ecolabel or EPD). This is not the case with the artistic ceramics sector in which few companies are certified. One of the most common and used tool for evaluating the environmental impact of products is the Life Cycle Assessment (LCA) methodology. This paper presents the preliminary results from a Life Cycle Inventory (LCI) analysis of the artistic ceramics sector in Caltagirone (Italy). Representative life cycle inventories are essential for any good quality LCA. They represent the fundamental blocks for compiling the full LCA of the ceramics production process, hence promoting environmental sustainability.

Keywords:

Ceramics, Environmental hotspots, Inventory, Sicily

1 INTRODUCTION

The Italian ceramics sector mainly produces the following five main products: floor and wall tiles, product for domestic and ornamental purpose (ceramics for daily or interior decoration use), terracotta products (such as bricks, roof tiles), refractory materials (for industrial technological use) and saniratyware. Besides these “official” product areas, it is possible to identify another one: the artistic and traditional ceramics products. For certain Italian regions, it characterises (sometimes also in a significant way) the local economy, giving the sector great importance even if the statistical data are not comparable to those of the other products.

The Italian ceramic tile industry, in particular, enjoys an unrivalled world leadership position, accounting for 9% of world and 40% of the European Union's tile production. Investment levels are at 5.5% of turnover, confirming the Italian ceramic industry's commitment to carry on its supremacy into the new millennium. These results are built on the Italian ceramic tile industry's tradition, constantly fuelled by technological innovation and product developments.

Due to the accumulated side-effects of its activities, (energy, water and non-renewable raw materials consumption, water, air and soil pollution) this industry was one of the first to develop a strong environmental awareness and to seek to combine environment protection, health and safety with sustained market competitiveness. Over the past decade the industry has shown a shift towards sustainable development projects through integrated and comprehensive standards and regulations (ISO 14001 and EMAS Regulation; environmental labels such as Ecolabel or Environmental Product Declaration, EPD) that take account of the causes of environmental impact and the tools to be used for preventing or, at least, minimising it. The Italian ceramic industry’s world leadership position is, therefore, not limited to production but includes also a commitment to achieving extremely low levels of environmental impact and to fully respecting the ecological equilibrium [1].

The Life Cycle Analysis (LCA) methodology, which is the most common internationally accepted and acknowledged tool for assessing and demonstrating the environmental behaviour of a system meets the needs of both production and the environment. This methodology can be specifically tailored to the ceramic tile sector and can be used to identify and evaluate the positive and negative effects that the various production techniques have on the environment and, hence, researchers can draw up new prevention and protection measures. The parameters analysed on the basis of the LCA are materials, energy, gaseous emissions and waste.

The literature review shows many examples of the application of LCA to the industrial ceramic sector. For example, the following studies have been conducted:

- Nicoletti et al. focused on the comparative Life Cycle Assessment of flooring materials (marble vs. tiles) [2];
- Bovea et al. analysed the environmental performance of ceramic tiles and the possible improvements related to the productive cycle [3];
- Bovea et al. evaluated the environmental performance of the process currently used to package and palletize ceramic floor and wall tiles and proposed and analysed improvements from an environmental point of view [4];
- Bovea et al. conducted a Cradle – to – Gate study of red clay for use in the ceramic industry [5];
- Breedveld et al presented a simplified LCA to assess the overall environmental effects of fabric filter in Italian ceramic tiles production. Furthermore, they calculated the eco-efficiency of such filters, the additional cost per unit reduction of emissions [6];

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- Mahalle, conducted a comparative LCA to compare and contrast the environmental performance of hardwood flooring with some alternative flooring types: carpet, ceramic floor tiles, vinyl flooring, cork, and linoleum. [7];
- Almeida et al. proposed the application of the Environmental Product Declaration (EPD) in ceramics materials as a sustainability tool [8].

The huge environmental commitment highlighted in the industrial ceramics sector cannot be found as yet among the artistic and traditional ceramics sector despite the fact not only it is an economic and productive sub-sector but that it also has historical and artistic value.

Very few enterprises working in this sector have adhered to ISO 14001/EMAS environmental certification for their productive processes. Regarding the product certification, such as EPD, no examples can be recorded in the Italian sub-sector, even though there is a growing interest coming from the stakeholders regarding this type of voluntary environmental labels. If well managed, product certification can represent a valid instrument of enhancing and differentiation of the sub-sector's products on the market.

In this context the aim of this paper is to develop life cycle inventories one of the most common artistic and traditional ceramic products: the ceramic dishes. The current literature review shows no examples of the application of the LCA methodology to this sector.

2 THE ARTISTIC AND TRADITIONAL CERAMICS SECTOR: THE DISTRIC OF THE CERAMICS OF CALTAGIRONE

The "First National conference on ceramics" held in Rome in 2008 highlighted that the Italian artistic and traditional ceramic sector is going through an evident decline measured in terms of the reduction in the number of employees and of enterprises.

Italy has a big tradition of artistic and traditional ceramics production. The ceramic art craft plays an important role in contributing to local production volume, and culture and the territory that are related to it. While the art of ceramics is widespread among all the Italian regions most of them are located in Sicily, Campania, Veneto, Tuscany, Emilia Romagna and Umbria [9].

In Sicily, despite the crisis in the industry, the arts and traditional ceramics industry still plays a crucial role in the Sicilian economy. It is one of the few production systems considered an area of excellence in the region, together with the marble, agri-food, engineering and electronics industry. Two industrial districts in Sicily are most important and have gained recognition in the industry. These are: the "*District of the Sicilian ceramics*" and the "*District of the ceramics of Caltagirone*". In particular the *District of the ceramics of Caltagirone* is one of the most best ceramics district not only at regional and Italian level but also at international level. Caltagirone has been renowned since ancient times for its excellent and pleasant ceramics, for the elegance of its traditional design and for the creativity of its craftsmen. It is a small industrial district with almost 150 workers working in fewer than 90 very small enterprises located in the territory of the city of Caltagirone. Two enterprises located in the province of Messina (Patti e Taormina) and one in the province of Palermo (Monreale). The enterprises working in the sector base their activities on the last two phases of the production chain: the processing of the "raw product" (called "verde") and its decoration. Among these two phases, the last one has higher economic relevance. This is because most of the "raw material" used by the artisan comes from national (Deruta, Faenza, Vicenza) or regional (Santo Stefano di Camastra) ceramics districts. Nowadays, however, few artisans have begun producing "raw material" in the territory of Caltagirone.

Caltagirone ceramics have been used for centuries to decorate houses, public and private parks, churches, streets and squares. Nowadays, besides the traditional and lively production of ceramics, both functional and decorative, Caltagirone is also famous for the ceramic whistles and the Presepi, nativity scenes made with terracotta or ceramic characters and accessories. which carefully revive the daily life of simple people over the centuries. One of the most common art craft, accounting at times for almost 50% of the entire production of an enterprise, is the ceramic plate which can have both domestic and ornamental purpose.

3 METHODOLOGY

Life Cycle Assessment (LCA) methodology represents a very powerful tool in Industrial Ecology useful for estimating and assessing the environmental impacts attributable to the life cycle of a product/service (for example climate change, eutrophication, acidification, resources depletion, water or land use). The methodology, following the requirements of the ISO standards 14040 and 14044: 2006 is made up of four phases:

1. Goal and scope definition, which provides description of the purpose of the study, expected product object of the study, system boundaries, Functional Unit (FU) and all assumptions done;
2. Life cycle inventory (LCI) analysis, which is the phase where an estimation of the consumption of resources and of the quantities of waste flows and emissions caused by or otherwise attributable to a product's life cycle is done; The inventory results are presented in complete input-output tables that quantify inputs and outputs like raw materials, water consumption, electricity, emissions to air, soil, water and solid waste generation [10], [11]. By doing so, it is possible to realise the evaluation of the environmental loads associated with the life cycle of a product by the analysis of the true consumption of energy, the consumption of the natural capital and the emissions to the environment [12]. Representative life cycle inventories are essential for any good quality LCA study because they represent fundamental building blocks for its compilation. This LCI represents the starting point for the whole LCA and can be the basis for future decisions about the environmentally friendly management of the production of ceramics.
3. Life cycle impact assessment (LCIA), which is carried out on the basis of the inventory analysis data It provides indicators and the basis for analysing the potential contributions of the resource extractions and wastes/emissions in an inventory to a number of potential impacts;
4. Life cycle interpretation (LCI), in which the results from the impact assessment and the inventory analysis are

analyzed and conclusions are established in a way that is consistent with the goal and scope of the study.

Among the four phases, the most important one is the LCI because it allows the building of an analogue model of reality, representing, as close as possible, all the exchanges among the single actions belongings to the effective production chain.

This paper deals with only the first two steps of the LCA methodology, the goal definition and scoping phase and the inventory analysis one, with the aim of developing the LCI of decorative ceramic plates.

3.1 Goal definition and scoping

The purpose of this paper is to investigate the life cycle inventory of ornamental ceramic plates (variable diameter) during their life cycle and to identify the “input and output material and energy flow” inventories associated with their production. Decorative ceramic plates represent one of the most common and typical production of the ceramics of Caltagirone: they can be used both for domestic and ornamental purpose.

3.2 Functional Unit (FU)

The purpose of the Functional Unit (FU) is to provide a reference unit for which the inventory data are normalized. In order to calculate the material and energy flow, 1 kg of decorative ceramic plates of different diameter was chosen as the FU.

3.3 System boundaries

The system boundaries defined include the following phases: manufacturing of the plates; end of life of the plates; and transportation of the plates to the landfill. Details of the production system studied are shown in the process flow diagram in Figure 1, from which it can be possible to deduce how processes of the product system are interconnected through commodity flows.

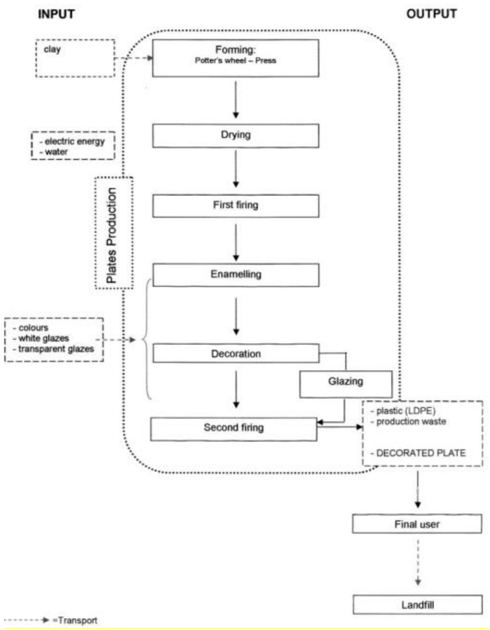

Figure 1: System boundaries.

It has to be highlighted that the use phase of the plates by the final user was excluded from the system boundaries and, with it, also the correlated environmental impacts due, for example, to water, detergents and electrical energy used for their cleaning. This is because, as said before, the examined plates have just ornamental purpose and it is assumed that they are rarely used.

3.4 Inventory analysis and data collection

For realizing the life cycle inventory of the FU it was necessary to represent the entire life cycle of it inside the software used for the analysis. In table 1 the input data related to the ceramic plates life cycle are reported, being referred to the phases: production, end of life and transportation: in particular it has to be noted that the first phase was computed for the share related to the FU.

Table 1: Input data for LCA of 1 kg of ceramic plates.

Functional Unit (FU)	1	kg	Ceramic plates of variable diameter (10 - 90 cm)
Input flow	**Physic amount**	**Measure unit**	**Comment**
Production	1	kg	This phase has been represented creating the “production” life cycle, then computing it for the share associated to the FU
End of life	1	kg	Treatment of the FU at the landfill.
Trasport	50	kg*km	Trasport by the final user of the FU to the landfill

Production phase

Forming (Potter’s wheel – Press): the clay undergoes shaping processes and this can be performed manually or with the help of special machines.

Drying: the shaped clay pieces are dried by letting the residual water contained in the clay to evaporate. This phase can be natural or forced (using dryers). Usually the small ceramics enterprises adopt the first method, the industrial ones the second. It is important to pay attention to the drying phase of the clay pieces: they have to dry slowly, especially in the first phase, since the quantity of water contained in the pieces is still excessive. In fact, if the drying occurs rapidly at this stage, distortions, cracks and detachment of parts added (as handles or other elements) can occur.

First firing (“ceramic bisque” firing): bisque firing is the first firing, and sometimes is also the last firing, if no transparent glaze is added. Firing is necessary in order to transform the clay so that it will no longer “melt” if left in water. The “bisque” is ceramics which has been fired once, without glaze, to a temperature just before vitrification. This stage is carried out at a temperature between 900 - 950°C using wood, gases, gasoline, kerosene, coke, electric kilns. Recently experiments applying solar energy for alimenting the kilns have been done.

Enamelling: after the first firing, the bisque is dipped into a bath of fast drying liquid white glaze. When dry, the glazed piece is ready to be hand painted. The ceramics of Caltagirone is renowned for its use of enamels which, when applied to terracotta, give origin to majolica. The most commonly used enamel is white, lustrous, matt for the tin oxide and it is able to form the coating of the majolica. In the tradition of the ceramics of Caltagirone, the enamel is applied on the bisque and it is used for coating the piece that will undergo the decorating stage. The glazing can be carried out, manually, by immersion of the object in an aqueous solution of enamel or brush (on small objects or when you want to give the effect of casting) or by spraying by means of spray gun in a special booth.

Decoration: ceramic crafts decoration is hand made by skilled decorators, using ceramic colours that are made by mixing one or more pigmented oxides with fluxes, plasticizers and hardeners, bearing in mind the chemical properties of the colorant used and its expansion and controlling the operating temperature.

Glazing (optional phase): it consists of the application on the decorated ceramic piece of a transparent glaze for obtaining, after the second firing, a lucid effect.

Second firing: final firing at 920-950°C will make the glaze interact with the metal oxides used by the painter to create the deep and brilliant translucent colours specific to majolica.

As has been clearly described, the production phase includes some stages that provide the use of white glaze (frit), transparent glazes (crystalline) and colours. For each of them, it was necessary to create the relative life cycle data because they do not exist in the software used for the analysis. For each of them 1kg was chosen as the FU and they are presented in tables 2, 3,and 4.

Every process was, then, computed in the life cycle of the ceramic plates for the share related to the FU (Table 5).

The inventory data were collected from various sources, paying attention to data quality and integrity. Most of the data were collected from people working in the sector. Thus, it was possible to measure the quantity of electricity, water, clay, white and transparent glaze and colour used in the production of the ceramic plates. The Ecoinvent database was used for assessing the impact of white and transparent glaze and colour production and also for all the transportation.

Table 2: Input data for 1kg of white glaze production.

Functional Unit (FU)	1	kg	White glaze (frit)
Input flow	**Physical amount**	**Measure unit**	**Comment**
Resources			
Water process, well in ground	**0.404**	kg	Amount of water for the production of 1 kg of white glaze used for enamelling
Raw materias and fossil fuels			
Zinc oxide, at plant/RER S	**0.073**	kg	
Zirconuim oxide, at plant/AU S	**0.0317**	kg	
Dolomite, at plant)	**0,157**	kg	
Aluminium oxide, at plant/RER S	**0.067**	kg	
Titanium dioxide, production mix, at plant/RER S	**0.00192**	kg	
Feldspar, at plant/RER S	**0.213**	kg	
Calcium borates, at plant/TR S	**0.125**	kg	
Sodium perborate, tetrahydrate, powder, at plant/RER S	**0.106**	kg	
Silica sand, at plant/DE S	**0,241**	kg	
Barite, at plant/RER S	**0.00962**	kg	
Tin, at regional storage/RER S	**0.000962**	kg	
Lead, at regional storage/RER S	**0.124**	kg	
Electric and thermal energy			
Electricity LV use in I + import S	**0.16**	kWh	Amount of electrical energy for white glaze production
Transport, lorry 7.5-16t, EURO5/RER S	**57.5**	kg*km	Raw materials transport to the company producing the white glaze (Montelupo Fiorentino - ITALY). Average distance 50 km for a total of 1,15 kg of raw material

Table 3: Input data for 1kg of transparent glaze production.

Functional Unit (FU)	1	kg	Transparent glaze
Input flow	**Physical amount**	**Measure unit**	**Comment**
Raw materias and fossil fuels			
Production 1 kg frit	**0.956**	kg	95% of transparent glaze is made of frit
Kaolin, at plant/RER S	**0.04**	kg	
Cobalt, at plant/GLO S	**0.001**	kg	
Sodium chloride, powder, at plant/RER S	**0.03**	kg	
Electric and thermal energy			
Electricity LV use in I + import S	**0.16**	kWh	Amount of electrical energy for the transparent glaze
Transport, lorry 3.5-7.5t, EURO5/RER S	**3.3**	kg*km	Raw materials transport to the company producing the crystalline (Montelupo Fiorentino – ITALY). Average distance = 75 km

Table 4: Input data for 1kg of colour production.

Functional Unit	1	kg	Colour
Input flow	**Physical amount**	**Measure unit**	**Comment**
Raw materias and fossil fuels			
Production 1 kg transparent glaze	**0.91**	kg	
Zinc oxide, at plant/RER S	**0.00405**	kg	
Zirconuim oxide, at plant/AU S	**0.00115**		
Aluminium oxide, at plant/RER S	**0.003**		
Titanium dioxide, production mix, at plant/RER S	**0.0001**		
Lime B250	**0.00455**		
Magnesium oxide, at plant/RER S	**0.0003**		
Boric oxide, at plant/GLO S	**0.0057**		
Potassium chloride, as K2O, at regional storehouse/RER S	**0.00065**		
Silica sand, at plant/DE S	**0.021**		
Barite, at plant/RER S	**0.00055**		
Tin, at regional storage/RER S	**0.0001**		
Lead, at regional storage/RER S	**0.0069**		
Soda, powder, at plant/RER S	**0.00195**	kg	
Kaolin, at plant/RER S	**0.01**	kg	
Zirconuim oxide, at plant/AU S	**0.01**		
Boric oxide, at plant/GLO S	**0.02**		
Electric and thermal energy			
Transport, lorry 7.5-16t, EURO5/RER S	**1500**	kg*km	Colour transport from the company producing it (Montelupo Fiorentino – ITALY) to the ceramics company (SICILY, d= 1500 km)
Transport, lorry 3.5-7.5t, EURO5/RER S	**4.5**	kg*km	Raw materials transport to the company producing the colour (Montelupo Fiorentino – ITALY). Average distance = 75 km

Table 5: Input data 1 kg ceramic plates production

Functional Unit (FU)	1	kg	Ceramics plates of variable diameterse (10 - 90 cm)
Input flow	**Physical amount**	**Measure unit**	**Comment**
Resources			
Water process, well in ground	**4**	kg	Amount obtained comparing the total used amount of water (40m^3 of water for 12000 kg of clay) to 1.2 kg of clay used for the FU
Raw materias and fossil fuels			
Clay, at mine/CH S	**1.2**	kg	Amount of clay for 1 kg of plates (taking into account a weight loss of 20%)
Production 1 kg white glaze	**0.0521**	kg	Amount of glaze, computing it for the share associated to the FU.
Production 1 kg di colour	**0.0104**	kg	Colour, computing it for the share associated to the FU
Production1 kg di transparent glaze	**0.00521**	kg	Crystalline, computing it for the share associated to the FU. (its use is optional)
Electric and thermal energy			
Electricity LV use in I + import	**1.73**	KWh	Amount obtained comparing the total used amount of electric energy (17.3 MWh of electric energy for 12000 kg of clay) to 1.2 kg of clay used for the FU
Transport, lorry 3.5-7.5t, EURO 5	**78.15**	kg*km	Transport of the white glaze form supplier (Montelupo Fiorentino – ITALY) to ceramics company (SICILY, d = 1500 km)
Transport, lorry 3.5-7.5t, EURO 4	**7.815**	kg*km	Transport of transparent glaze form supplier (Montelupo Fiorentino – ITALY) to ceramics company (SICILY, d = 1500 km)

4 DISCUSSION

The aim of this paper was to realise the LCIA of decorative ceramic plates (variable diameter) and to identify the material and energy flow inventories associated with their production. This allows the identification of all the raw materials and the energetic resources linked to the ceramics plates' life cycle, facilitating the quantification of the resources which is necessary for the next LCA steps: the Life Cycle Impacts Assessment and the Life Cycle Interpretation phases.

The study results show that for among the three phases taken into account in the system boundaries (manufacturing, end of life and transportation of the ceramics plates), the most inventories are in the manufacturing phase (for more than 90% of the total damage). There is a huge amount of electrical energy used during the manufacturing of the ceramics plates: this is because the first and the second firing occur in an electrical kiln at very high temperatures. On the contrary, the raw materials, glazes, colours is almost negligible.

5 CONCLUSION

As stated at the beginning of this paper, the Sicilian artistic and traditional ceramic production (and so the ceramic art craft) can be seen as a medium for enhancing the local production, the culture and the territory related to it. The industry is economic and productive and also has historical and artistic value. It is an industry in crisis and the difficulties that the sector is going trough are the ones typical of sectors characterised by a low technological and organizational level, such as, for example, few opportunities of experimenting new materials and new manufacturing/firing techniques or scarce orientation to activities with a higher environmental sustainability level (for example, the use of renewable energy or eco-friendly materials). A good way for overcoming this crisis and enhancing the ceramics production could be by focusing on high quality, innovation and sustainability of the manufacturing process, respecting, at the same time, the tradition of the cultural productive processes. This could be achieved by obtained looking for new and more sustainable material and technologies or by finding new ways for recycling the waste from the production processes.

As highlighted in the last paragraph, the most of the inventory occurring during the life cycle of the ceramic plates is due to the large amount of electrical energy consumed by the kiln used for the manufacturing of the ceramics plates. Kilns are an essential part of the manufacturing of all ceramics, since they require heat treatment, often at high temperatures: during this process, chemical and physical reactions occur that permanently alter the clay. In this context, one possible improvement could be trying to reduce the amount of energy used for the firing stage and finding more sustainable ways of feeding the kiln. This could be obtained using, for example, kilns supplemented by solar energy or gas, such as methane. A second improvement could be the possibility of using recycled raw materials.

Future work needs to conduct a full assessment and to provide further interpretation of the results obtained. Furthermore, even if the developed topic is very specific the papers helps to show what the possible applications of the methodology are. The LCI structure and the results can be usable in case studies among the ceramic sector focusing other items.

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