

1 Article

## 2 Life Cycle Sustainability Assessment (LCSA) of 3 Sassuolo Industrial District (Italy)

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14 **Abstract:** One of the biggest challenges for European industry is to introduce sustainability principles  
15 into business models. This is particularly important in raw material and energy intensive  
16 manufacturing sectors such as the ceramic industry. The present state of knowledge lacks a  
17 comprehensive operational tool for industry to support decision-making processes geared towards  
18 sustainability. In the ceramic sector, the economic and social dimensions of the product and processes  
19 have not yet been given sufficient importance. Moreover, the traditional research on industrial  
20 districts lacks an analysis of the relations between firms and the territory with a view to sustainability.  
21 Finally, the attention of scholars in the field of economic and social sustainability, has not yet turned  
22 to the analysis of the Sassuolo district. Therefore, in this paper we introduce the Life Cycle  
23 Sustainability Assessment (LCSA), as a method that can be a suitable tool to fill this gap, because  
24 through a mathematical model it is possible to obtain the information useful for decision makers to  
25 integrate the principles of sustainability both at the microeconomic level in enterprises, and at the  
26 meso-economic level for the definition of economic policies and territorial governance.  
27 Environmental and socio-economic analysis was performed from the extraction of raw materials to  
28 the packaging of the product on different product categories manufactured by the Italian ceramic  
29 industries of the Sassuolo district (northern Italy). For the first time the LCSA model, usually applied  
30 to unitary processes, is extended to the economic and industrial activities of the entire district,  
31 extending the prospect of investigation from the enterprise and its value chain to the integrated  
32 network of district enterprises.

33 **Keywords:** sustainability; Life Cycle Sustainability Assessment (LCSA); Sassuolo industrial district;  
34 Italian ceramic industry; meso-economic level; interpretative method.  
35

### 36 1. Introduction

37 The challenge of sustainable development embraces both environmental aspects and issues of  
38 social and economic sustainability. Sustainable development is understood to mean economic and  
39 social development compatible with social equity, environmental protection and the rights of future  
40 generations. The concept of sustainable development therefore refers to economic growth that meets  
41 the welfare needs of societies in the short, medium and, above all, long term [1]. The introduction of  
42 rules for safeguarding the environment and tools for monitoring company activities are important  
43 not only for protecting consumers and for defending principles of civilization but should also be an

44 important opportunity for companies that are striving to produce high-quality products.  
45 Accordingly, this capacity can be considered a strategic factor with great impact on competitive  
46 advantage building. Above and beyond short-term economic expediencies, companies are historic  
47 players whose actions influence the social life of the surrounding community. In addition, such  
48 community will evaluate firms' actions and behaviors according to the impacts they may provoke.  
49 Following the Institutional Theory [2] the consequences of entrepreneurial decisions are not limited  
50 to the company itself but extend to the various spheres of social life and affect the various economic  
51 and social parties and territories which are no longer neutral places. Therefore, as long as firms'  
52 impacts do not fit norms, values or game rules of the society, companies will be poorer evaluated.

53 This paper will conceptually develop the theme of relationships and interdependencies between  
54 companies organized in industrial districts (ID) and the territories in which they operate, and  
55 empirically will determine the environmental, economic and social impact of the main products of  
56 the ceramic district of Sassuolo in Italy, using the Life Cycle Sustainability Assessment (LCSA)  
57 structure with a territorial extension what supposes an innovative contribution to the current  
58 literature.

## 59 **2. Theoretical framework and research aims**

### 60 *2.1 Environment and economic activity*

61 Economic activity, like all human activity, takes place within the natural environment. The  
62 economic system and the natural environment are therefore interdependent, which determines both  
63 the way in which the economic system affects the environment and the limits that the environment  
64 places on the evolution and expansion of the economic system [3]. The environmental limits that the  
65 economic system must consider are established by the laws of thermodynamics. The first law of  
66 thermodynamics is presented first in the form of the law of the conservation of matter: matter can  
67 neither be increased nor destroyed but only transformed [4]. The material flows from the  
68 environment to the economic system are the same as the flows that return from the economic system  
69 to the environment; the economic process can only transform the material extracted from the  
70 environment to eventually return the same material to the environment in the form of waste [5].

71 The processes of transformation of matter that take place in the economic system imply the use  
72 of energy, defined as the "capacity to do work". The first law of thermodynamics states that energy,  
73 like matter, can neither be created nor destroyed; energy can only be transformed, converted from  
74 one form to another [6]. This energy conversion has an important effect, highlighted by the second  
75 law of thermodynamics. This law states that in every energetic transformation a part of the energy is  
76 dispersed in a form that can no longer be used to perform further work [7]. The environment is an  
77 essential resource base for the functioning of the economic system. The scarcity of resources that is  
78 the fact that they are useful and at the same time available in limited quantities compared to the  
79 request, is the condition for the talk of economic resources [8].

80 If environmental resource activity is over-exploited beyond regeneration or assimilation  
81 capacity, environmental resources tend to run out and the ability of the environment to provide its  
82 services to the economy in the future is compromised. This creates a conflict between exploitation  
83 and conservation of the environment which is economically relevant as the environment performs  
84 important economic functions not only because the flows of services it offers are exploited, but also  
85 because there is an interest in the conservation of the stocks of goods it contains [9]. When  
86 environmental exploitation goes beyond the natural capacities of regeneration and assimilation, it is  
87 an alternative use of non-environmental economic resources (such as capital and labor) that goes  
88 against the objective of conservation. In this case, the exploitation and preservation of the  
89 environment become alternative purposes of resource allocation [10].

90 The essence of the concept of sustainable development is that the exploitation of environmental  
91 resources should be contained within the limits of regeneration capacity so that the stock of these  
92 resources is not depleted. If the stock of environmental resources is to remain constant in the long  
93 term, the exploitation flow of these resources must also be kept constant within the limits of their

94 natural regeneration capacity [11]. But the only way in which the flow of use of environmental  
95 resources can remain constant in the presence of a continuous growth of the domestic gross product  
96 of an economy is that the flow of use of the environment per unit of gross domestic product is  
97 continuously reduced over time [12]. This also requires a profound structural modification of  
98 production processes. For this reason, economic growth to be sustainable must be based more and  
99 more on the material recycling [13], on a non-dissipative form of energy use and on an increasing  
100 weight of the intangible production component in the gross domestic product [14].

101 The most recent strategic documents of the European Union and the relative EU policies aim at  
102 combining competitiveness of member countries' enterprises and economies, social cohesion and  
103 sustainable development [15]. Further intergovernmental programmes promote the same strategic  
104 objectives of economic, social and environmental sustainability [16]. These documents identify local  
105 authorities, businesses and civil society as the actors responsible for implementing the strategic  
106 objectives set, although the key role of local authorities as relevant players in the promotion and  
107 implementation of policies and governance tools for sustainable environmental, economic and social  
108 development is highlighted. About the role of companies in contributing to greater socio-economic  
109 and environmental sustainability, the European Union has recently promoted the approach and  
110 concept of Corporate Social Responsibility (CSR). This is a way of voluntary integration, beyond the  
111 legal obligations, by companies of the social and environmental implications in their commercial  
112 operations and in their relations with the various stakeholders [17]. In order to address  
113 environmental issues, adequate information and knowledge is needed to underpin the choice of the  
114 most effective actions. Moreover, knowledge must be effectively usable and meaningful. The purpose  
115 of this information should be to provide an overview of sustainability, to overcome a sectoral view  
116 of the issues and to focus as much as possible on key elements. Finally, the issues addressed should  
117 not be limited to strictly environmental issues but should also include social and economic concerns  
118 [18]. An appropriate indicator system based on the laws of thermodynamics can be used to assess the  
119 pressures that economic and social activities exert on the environment, the resulting changes in the  
120 state of the environment, the resulting impacts (e.g. on ecosystems, human health, resource  
121 availability) and the political and social responses to these impacts through improvement actions.  
122 Sustainability indicators should reflect the mutual links between the environmental, economic and  
123 social aspects of development [19]. The sustainability assessment may cover:

- 124 • territorial systems (cities, regions, states) [20], environmental components (the atmosphere,  
125 soil, water) [21] and, lastly, socio-economic components (economic sectors, population) [22];
- 126 • actions relating to development policies (in the fields of energy [23], transport [24], urban  
127 areas [25], the protection and valorization of ecosystems [26] and Cultural Heritage [27],  
128 actions aimed at social integration and cohesion).

## 129 *2.2 Environment and territory*

130 In Italy, the geographical concentration of supply chains (based on an integrated system of  
131 production, where the entire process is controlled and managed in close collaboration with the best  
132 local producers), has allowed many companies to share in the industrial risk linked to development  
133 in harmony with the local situation. The system of districts, in fact, has had the ability to create  
134 development by reducing the distortions of capitalist systems and enhancing the integration of the  
135 industrial reality with the social and environmental fabric [28]. Economic theory has long recognized  
136 that agglomeration economies are able to improve the productivity of enterprises and encourage  
137 processes of territorial concentration of productive activity in districts [29]. In the decade of the 1990s  
138 these ideas represented the starting point for numerous theoretical studies, which forcefully brought  
139 out the link between territory and economic development [30-34]. However, research has focused  
140 almost exclusively on the benefits of economic development without considering the social costs  
141 involved. Today, in economic analysis, space ceases to be considered only a source of cost for  
142 businesses, and increasingly assumes the role of a favorable (or unfavorable) milieu, creating

143 externalities (economic or non-economic) [35]. Space thus becomes the place where economic agents  
144 meet to organize forms of collaboration [36].

145 Industrial districts (ID) are the structures where the interaction between territories and firms in  
146 the supply chain is best observed [37]. The organizational structure of the industrial district explains  
147 the variables that are at the base of the localization and investment choices of the entrepreneurs and  
148 that therefore affect the local development [38]. The development process acquires definitively its  
149 character of "social process" and no longer only a technical process. Within an industrial district, the  
150 territory represents a determining factor in the processes of economic and social growth because the  
151 anthropological, historical, cultural and environmental factors that contradict it, affect the specificity  
152 of the models of productive organization of the district [39]. However, in the analysis of industrial  
153 districts, the relationship between companies and their local context has long lacked a fundamental  
154 dimension in the logic of sustainability: that of environmental protection, that is, the link that exists  
155 between productive activities and pollution phenomena related to them. This is inconsistent with the  
156 growing importance of sustainable development principles in business strategies and public decision  
157 makers' agendas. Only recently there has been a growing interest (both theoretically and empirically)  
158 in sustainability as a driver of growth in industrial districts [40-42]. Given the importance of the socio-  
159 territorial context to district businesses, it is inevitable that the issue of environmental sustainability  
160 will also become crucial from the point of view of competitive development [43]. A local district  
161 system can be seen as a network of locally concentrated enterprises whose stability derives from a  
162 dynamic yet balanced relationship with the community and the networks of interaction that  
163 characterize individual enterprises [44]. This balance is dynamic because even in local systems it is  
164 possible to highlight the presence of a life cycle whose trend follows that of the product, the greater  
165 the production specialization of a local system. This is the case of the Sassuolo ceramic district located  
166 in the provinces of Modena and Reggio Emilia in Italy, analyzed in this paper [45]. The dynamism of  
167 this balance can favour, both from a theoretical and managerial point of view, the adoption of a life-  
168 cycle methodological approach, to explain the dynamics of some of the most famous district systems  
169 and to describe the prevailing modes of interaction among economic operators [46-50]. However, the  
170 adoption of a life-cycle perspective requires that the main social actors do not limit their responsibility  
171 to the stages of the supply chain that they directly control but would constitute the prerequisite for a  
172 solid sustainability assessment, in order to identify opportunities for reducing environmental impact,  
173 industrial costs and, as a consequence, greater efficiency in the use of resources [51,52].

### 174 *2.3 Life-cycle paradigm from a territorial approach*

175 The implementation of sustainability policies requires the development of increasingly refined  
176 quantitative and qualitative tools for analyzing the environmental, economic and social impacts, the  
177 Triple Bottom Line (TBL) associated with collective and individual choices, both with more limited  
178 effects and with more complex medium and long-term implications [53]. Life Cycle Sustainability  
179 Assessment (LCSA) can be a suitable tool for this purpose, since through a mathematical model, it  
180 describes the set of business solutions that integrate into the decision-making processes supporting  
181 the development of a product (from its conception to its withdrawal from the market), both the view  
182 of the life cycle and the economic, environmental and social assessments necessary for the  
183 management of processes, with a total sharing of data related to it between the various company  
184 functions [54]. This quantitative analysis tool allows to implement the principles of sustainability in  
185 business practices through the integration of three different impact assessment tools: Environmental  
186 Life Cycle Assessment (LCA) for the environmental dimension [55]; Life Cycle Costing (LCC) for the  
187 economic dimension [56]; and Social Life Cycle Assessment (S-LCA) for the social dimension [57].  
188 The integration of the three impact assessment methods is expressed in Klöpffer's conceptual formula  
189 [58]:

$$190 \quad (1) \quad LCSA = LCA + LCC + S-LCA$$

191 The life-cycle paradigm based on the three pillars of sustainability offers a systemic perspective for  
192 decision making [59]. The strategic choice between alternative options should be made by looking at  
193 the "*pluses*" and "*minuses*" that characterize a product, process or activity "from the cradle to the

194 grave", reconciling, as far as possible, the environmental, economic and social concerns of economic  
195 operators within the supply chain and the territory [60]. Sustainability Analysis, as a tool to monitor  
196 a production process, or an integrated supply chain and to develop and valorize a territory, is a topic  
197 that is having growing interest in the literature [61]. To this end, the LCA guidelines have recently  
198 been adapted to carry out an environmental assessment of a territory. The expectations of this  
199 framework, called "*Territorial LCA*", are in line with the European Directive (2001/42/EC) on Strategic  
200 Environmental Assessment applied to spatial planning programmes, i.e. to provide an environmental  
201 reference basis and compare spatial planning scenarios [62]. However, there is still no empirical  
202 evidence in the literature of the integration of the territorial factor into the assessment of economic  
203 and social impact, since studies are limited to the environmental dimension. Integrating the territorial  
204 dimension in the impact assessment means moving the field of observation from the microeconomic  
205 level (the company and its processes and products) to the meso-economic level, then to the entire  
206 supply chain with its flows of materials, energy resources, semi-finished and finished products [63].  
207 Meso-economic systems are dynamic, complex and open systems with dynamic elements that reflect  
208 the complexity of the ways in which macro-targets are achieved [64]. The purpose of their operation  
209 is to achieve maximum efficiency from the use of their resources and know-how. Their efficient  
210 network structure of interdependent microeconomic agents connected through a division of task,  
211 promotes the rational use of the available economic potential of the macro-system, balancing  
212 development and minimizing operational risks [65]. According to this definition, the concept of  
213 industrial district (ID) can be described as localized meso-economic systems, consisting of  
214 interconnected heterogeneous, but complementary, microeconomic agents and specific local  
215 institutions that determine the role of these agents and stimulate the innovative development of these  
216 systems [66].

#### 217 **2.4 Aim and scope**

218 This work presents an empirical study conducted with the Life Cycle Sustainability Assessment  
219 (LCSA) approach for the analysis at mesoeconomic level of the environmental, economic and social  
220 performance of the Sassuolo ceramic district in Italy. The research integrates the elements of an  
221 evolutionary industrial approach, the life cycle one, with economic-environmental theories, which  
222 are interested in the process of forming organizations, their growth and evolution. Based on the  
223 literature analysis, for the first time an evaluation of the economic and social impact of the Italian  
224 ceramic industry is carried out, as well as for the first time the integrated approach of LCSA is  
225 applied. In fact, there are no published studies by LCC and/or S-LCA concerning the Sassuolo ceramic  
226 district. The only known study is the sectorial Environmental Product Declaration (EPD) based on an  
227 analysis of the environmental data of Italian ceramic tile manufacturers, promoted by the Italian  
228 ceramic industry association (Confindustria Ceramica) [67]. To fill this gap, we propose the following  
229 main objectives:

- 230 • Assessment of the environmental and socio-economic impacts associated with the entire  
231 production life cycle for different types of ceramic tiles located in the Sassuolo industrial  
232 district.
- 233 • Verification of the usefulness of LCSA as a tool to support decision-making processes from a  
234 sustainable supply chain management perspective.

### 235 **3. Materials and Assumptions**

236 The Sassuolo industrial district is made up of a network of 79 companies that manufacture  
237 ceramic tiles, located in ten municipalities straddling the provinces of Modena and Reggio Emilia.  
238 During 2016, ceramic companies produced about 341 million square meters, equal to 82% of Italian  
239 production, with a turnover of 5.4 billion euros [68]. Of the ceramic companies that make up the

240 district, six have a turnover of more than 200 million euro, nine have a turnover of between 200 and  
241 100 million euro, and the rest are below 100 million euro. These data have been elaborated by  
242 consulting the financial statements of the firms of the district, filed with the local Chambers of  
243 Commerce.

244 Four main types of product are manufactured in the Sassuolo district:

- 245 • **Porous double-fired wall tiles:** the tiles are obtained by a process divided into two distinct  
246 phases: a first phase of firing of the support which is then glazed and then fired again to  
247 obtain the fusion of the glaze. Two different kilns are used. The product, mainly intended for  
248 wall coverings, is characterized by high porosity (greater than 10 wt% water absorption),  
249 brilliance of the glazes and definition of colours. This typology corresponds to 6% of the total  
250 production.
- 251 • **Porous single-fired wall tiles (or "monoporosa"):** The tiles are obtained through a technique  
252 that involves single firing of the product: both bisque and glaze are fired in a single process,  
253 only one kiln is used. The product is porous (greater than 7 wt% water absorption) with  
254 aesthetic effects of smoothness and brightness on the surface and it is suitable for indoor wall  
255 covering. This typology corresponds to 3% of the total production.
- 256 • **Glazed porcelain stoneware:** the tiles are obtained by a single high-temperature firing cycle  
257 (1220°C) to obtain complete sintering of the ceramic body, which therefore has frost-hardy  
258 properties (water absorption less than 0.5% by weight). The glazing and surface decoration  
259 give the product valuable aesthetic effects, as well as resistance to staining agents and  
260 chemical reagents, facilitating cleaning operations. For these properties glazed porcelain  
261 stoneware tiles are particularly suitable for indoor use. This typology corresponds to 60% of  
262 the total production.
- 263 • **Unglazed porcelain stoneware:** the tiles are obtained by a single firing process at a very high  
264 temperature (1220-1230°C) capable of reaching the complete vitrification of the product. For  
265 this reason, porcelain stoneware is the most performing type of ceramic from a technological  
266 point of view and is above all used in solutions for use where high mechanical resistance,  
267 absolute frost and chemical inertia are required. Porcelain stoneware is available in various  
268 surface finishes. This typology corresponds to 31% of the total production.

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270 The production of ceramic tiles requires large quantities of raw materials that can be  
271 schematically divided into at least four fundamental components:

- 272 • **Clay raw materials:** clays and kaolin which give sufficient plasticity to ensure good  
273 formability.
- 274 • **Melting raw materials:** such as feldspars, which produce the glass phases necessary to  
275 promote solid-solid sintering reactions.
- 276 • **Inert raw materials:** feldspar sand and sand which have the function of balancing the  
277 composition of ceramic bodies, also containing the cost, as these are the cheapest raw  
278 materials.
- 279 • **Additives raw materials:** calcite and/or dolomite used mainly in the production of  
280 porous types of, or in smaller quantities as promoters of eutectic to facilitate the melting  
281 of feldspars into porcelain stoneware.

282 Using this classification, it is essential to refer to the composition of the ceramic bodies from  
283 which the different types of tiles are obtained. To this end, 15 industrially spray-dried powders [69]  
284 of ceramic body, corresponding to the four main product categories of the Sassuolo district, were  
285 collected from the main ceramic companies of the district. Chemical analyses were carried out on  
286 these powders to determine their composition and establish a compositional range that defines each  
287 type of ceramic in a representative way (Table 1a). From the average chemical compositions, through  
288 a reverse engineering (RE) process [70], it was possible to reconstruct the formulation of a "medium"  
289 body, typical for each product category, using the main raw materials available on the market (Table  
290 1b).

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|                                | POROUS       |              | GLAZED    | UNGLAZED  |
|--------------------------------|--------------|--------------|-----------|-----------|
|                                | DOUBLE-FIRED | SINGLE-FIRED | PORCELAIN | PORCELAIN |
| SiO <sub>2</sub>               | 53÷57        | 60÷65        | 69÷72     | 65÷68     |
| Al <sub>2</sub> O <sub>3</sub> | 13÷16        | 15÷18        | 17÷19     | 18÷20     |
| Fe <sub>2</sub> O <sub>3</sub> | 0,5÷0,7      | 0,5÷0,7      | 0,6÷0,8   | 0,4÷0,6   |
| TiO <sub>2</sub>               | 0,5÷0,7      | 0,5÷0,7      | 0,5÷0,7   | 0,3÷0,6   |
| MgO                            | 0÷4          | 0÷4          | 0,2÷0,4   | 0,2÷0,7   |
| CaO                            | 5÷12         | 4÷6          | 0,2÷0,4   | 0,3÷1,2   |
| Na <sub>2</sub> O              | 1÷1,5        | 1,5÷2,5      | 2,5÷4,0   | 3,5÷4,5   |
| K <sub>2</sub> O               | 2÷3          | 2,5÷3,5      | 2,5÷3,5   | 2÷3,5     |
| LOI                            | 11÷14        | 7÷10         | 3,3÷3,9   | 3÷5       |

(a)

|                         | POROUS       |              | GLAZED       | UNGLAZED     |
|-------------------------|--------------|--------------|--------------|--------------|
|                         | DOUBLE FIRED | SINGLE-FIRED | PORCELAIN    | PORCELAIN    |
| Ukrainian ball clay     | 24           | 26           | 24           | 25           |
| German ball Clay        | 17           | 17           | 18           | 19           |
| Turkish Na-Feldspar     | 12           | 20           | 24           | 30           |
| Italian Na,K-Feldspar   |              |              | 7            | 13           |
| Italian K-Feldspar      | 11           | 12           | 7            |              |
| Italian Feldspar Sand   | 16           | 15           | 20           | 11,5         |
| Italian Calcite         |              | 10           |              |              |
| Italian Dolomite        | 20           |              |              | 1,5          |
| <b>Kg/m<sup>2</sup></b> | <b>16+18</b> | <b>16+18</b> | <b>18+22</b> | <b>21+24</b> |

(b)

**Table 1:** (a) compositional intervals of the ceramic bodies analyzed (wt%); (b) ceramic body compositions for each category expressed as wt% of raw material and quantity of dough to produce 1 m<sup>2</sup> of tiles [71-74].

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The compositions of the ceramic bodies shown in Table 1b show that in all product categories, the import raw materials represent more than 50% of the total. This data is an indication of how vulnerable the district and its member companies are in their production processes, due to the criticality of the supply markets.

### 3.1 Definition of industrial processes

In order to configure a "standard" production plant that could be taken as a reference for the various product categories, it was based on the concept that the plants for the production of ceramic products all have the same plant characteristics, the main differences consist of the particularity of the machinery. The possible differences between the machines can be considered irrelevant for the analysis of aggregate average quantities as in this study. In this respect, it should be noted that the great differences between the various product categories do not lie in the machinery used, but in the different grinding and firing cycles and pressing loads, which have a clear impact on energy consumption per m<sup>2</sup> of finished product. Table 2a shows the data relating to the average weight of the various product categories and the relative loss on ignition (L.O.I) from which it was possible to derive the firing efficiency and then determine the value of the surplus of raw material, expressed in kg per m<sup>2</sup>, to be added to the theoretical value. During the input phase of the dough creation data on the impact assessment software, the values in the fourth column were considered to determine the amount of raw material to be input.

|                     | Theoretical weight. (Kg/m <sup>2</sup> ) | Loss on Ignition (%) | Firing efficiency Index | Real weight (Kg/m <sup>2</sup> ) |
|---------------------|--|----------------------|-------------------------|----------------------------------|
| POROUS DOUBLE-FIRED | 16                                       | 12,15                | 0,878                   | 18,21                            |
| POROUS SINGLE-FIRED | 16                                       | 7,88                 | 0,921                   | 17,37                            |
| GLAZED PORCELAIN    | 21                                       | 3,52                 | 0,964                   | 21,77                            |
| UNGLAZED PORCELAIN  | 23                                       | 4,01                 | 0,959                   | 23,96                            |

(a)

|                     | Cost of electricity (€/m <sup>2</sup> ) | Consumption of electrical energy (kWh/m <sup>2</sup> ) | Thermal energy cost (€/m <sup>2</sup> ) | Thermal energy consumption (kcal/m <sup>2</sup> ) |
|---------------------|---|--|---|---|
| POROUS DOUBLE-FIRED | 0,29                                    | 2,64   | 0,40                                    | 14,642  |
| POROUS SINGLE-FIRED | 0,17                                    | 1,55   | 0,38                                    | 13,910  |
| GLAZED PORCELAIN    | 0,30                                    | 2,73   | 0,58                                    | 21,232  |
| UNGLAZED PORCELAIN  | 0,44                                    | 4,00   | 0,72                                    | 26,357  |

(b)

**Table 2:** (a) firing efficiency of the compositions studied and quantity of ceramic body per m<sup>2</sup> needed for production; (b) Consumption of electricity and methane gas (expressed as thermal energy) per m<sup>2</sup> of product.

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### 3.2 Energy consumption estimation

For the quantification of average energy consumption, the data for 2016 was used. Table 2b shows the cost of electricity (expressed in euro/m<sup>2</sup>) and heat for each product category. When entering the data in the calculation software, it was decided to enter the average electricity consumption for each m<sup>2</sup> of product; it was therefore considered appropriate to convert the unit of measurement in kWh/m<sup>2</sup>. The average electricity consumption, expressed in kWh/m<sup>2</sup>, has been calculated using a conversion factor that considers 0.11 €/kWh as the cost of electricity for users of the order of at least 20 GWh/year. The same procedure was adopted for quantifying the average thermal energy consumption (methane gas) per m<sup>2</sup> of product. The total cost therefore amounts to 0.224 euro/Nm<sup>3</sup> of methane gas and dividing the cost per square meter by this value, the energy consumption expressed in Nm<sup>3</sup>/m<sup>2</sup> was obtained.

### 3.3 Air pollutant emissions

For the calculation of emission factors of the main pollutants present in gaseous emissions deriving from production processes, reference was made to the data calculated based on the measurements made by ARPAE (Regional Agency for the Environment and Energy of Emilia-Romagna) [75]. For the bodies in which carbonates were introduced (Porous single-fired: 10% of calcite; Porous double-fired: 20% of calcite; Unglazed porcelain stoneware: 1.5% of dolomite and Glazed porcelain stoneware: 0.5% of calcite), CO<sub>2</sub> emissions deriving from the decarbonization process had to be calculated. The reasoning followed to reach the CO<sub>2</sub> emission value per m<sup>2</sup> of product is based on molar ratios and on the approximation that all the Carbon released is fully bound to oxygen. Having calculated the Kg of calcite, CaCO<sub>3</sub>, and dolomite, CaMg(CO<sub>3</sub>)<sub>2</sub>, present in one m<sup>2</sup> of product, and having their weights and molar ratios, CO<sub>2</sub> emissions were calculated.

### 3.4 Water consumption

The ceramic tile industry has a relatively high-water requirement, associated with the various functions that water must perform (grinding of raw materials and glazes, cooling, washing of lines, etc.). A large proportion of the incoming water is, however, destined to be re-entered into the environment through gaseous emissions (evaporated water). While the use of water as a washing fluid generally corresponds to the production of waste water. Based on the data collected, it was established that average water consumption was 11 kg/m<sup>2</sup>.

### 3.5 Cost of raw materials

Table 3a shows the average market prices of the main raw materials used in the manufacture of tiles, including the costs incurred for transport from the suppliers' mines to the Sassuolo district area. Based on the compositions shown in Table 1b, the cost of each ceramic body was obtained for all the product categories considered (Table 3b).

| RAW MATERIAL          | MARKET PRICE |
|-----------------------|--------------|
| Ukrainian ball clay   | 70-75        |
| German ball Clay      | 45-50        |
| Turkish Na-Feldspar   | 40-45        |
| Italian Na,K-Feldspar | 35-40        |
| Italian K-Feldspar    | 30-35        |
| Italian Feldspar Sand | 30-35        |
| Italian Calcite       | 27-29        |
| Italian Dolomite      | 58-63        |

(a)

|                     | QUANTITY<br>(Kg/m <sup>2</sup> ) | COST<br>(€/Kg) | COST<br>(€/m <sup>2</sup> ) |
|---------------------|----------------------------------|----------------|-----------------------------|
| Porous double-fired | 18,21                            | 0,0445         | 0,81                        |
| Porous single-fired | 17,37                            | 0,0456         | 0,79                        |
| Glazed porcelain    | 21,77                            | 0,0464         | 1,01                        |
| Unglazed porcelain  | 23,96                            | 0,0484         | 1,16                        |

(b)

**Table 3:** (a) cost of raw materials in the Sassuolo area (€/Ton.); (b) cost per kg and per m<sup>2</sup> of ceramic bodies for each product category.

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### 3.6 Production costs

The cost analysis was based on the "value chain" developed by Porter, which disaggregates a company according to its strategically relevant activities [76].

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| COSTS             | POROUS DOUBLE-FIRED WALL TILES |               | POROUS SINGLE-FIRED WALL TILES |               | GLAZED PORCELAIN STONEWARE |               | UNGLAZED PORCELAIN STONEWARE |               |
|-------------------|--------------------------------|---------------|--------------------------------|---------------|----------------------------|---------------|------------------------------|---------------|
|                   | Value                          | %             | Value                          | %             | Value                      | %             | Value                        | %             |
| Raw Materials     | 0,96                           | 15,6%         | 1,24                           | 16,1%         | 1,35                       | 19,7%         | 1,89                         | 23,4%         |
| Inks & Glazes     | 0,85                           | 13,8%         | 0,98                           | 12,7%         | 0,65                       | 9,5%          | 0,41                         | 5,1%          |
| Electrical Energy | 0,17                           | 2,8%          | 0,29                           | 3,8%          | 0,3                        | 4,4%          | 0,44                         | 5,5%          |
| Thermal Energy    | 0,38                           | 6,2%          | 0,4                            | 5,2%          | 0,58                       | 8,5%          | 0,72                         | 8,9%          |
| Consumables       | 0,5                            | 8,1%          | 0,7                            | 9,1%          | 0,7                        | 10,2%         | 0,84                         | 10,4%         |
| Packages          | 0,21                           | 3,4%          | 0,23                           | 3,0%          | 0,28                       | 4,1%          | 0,34                         | 4,2%          |
| Production Staff  | 1,61                           | 26,2%         | 2,02                           | 26,2%         | 1,64                       | 23,9%         | 1,69                         | 21,0%         |
| Accessories       | 1,13                           | 18,4%         | 1,38                           | 17,9%         | 0,87                       | 12,7%         | 1,02                         | 12,7%         |
| Amortizations     | 0,34                           | 5,5%          | 0,48                           | 6,2%          | 0,48                       | 7,0%          | 0,71                         | 8,8%          |
| <b>TOTAL</b>      | <b>6,15</b>                    | <b>100,0%</b> | <b>7,72</b>                    | <b>100,0%</b> | <b>6,85</b>                | <b>100,0%</b> | <b>8,06</b>                  | <b>100,0%</b> |

**Table 4:** average production costs by product type in euro/m<sup>2</sup> and percentage on total incidence.

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Two areas have been identified: one closely linked to the transformation of raw materials into finished products, valued based on costs. The other one called "staff costs" is subdivided into average commercial costs and average general, administrative and financial costs. Charged according to the



357 functional logic of "cost centers" [77]. A survey carried out recently by Confindustria Ceramica  
 358 (Association of Italian Ceramic Producers) on the dynamics of costs has involved 60 production units  
 359 concentrated for 89% in the district of Sassuolo and divided into the four types of this study.  
 360 Employment of the sample companies accounts for 46% of the total number of employees in the  
 361 sector. Just under 45%, the weight of production. It is therefore a representative sample and the  
 362 results are shown in Table 4.

### 363 3.7 Social issues

364 The collection of social data was carried out through the adoption of the Participatory Process  
 365 [78] of social agents operating in the district. From the methodological point of view, the same  
 366 procedure has been followed as that already used by the authors themselves for a study concerning  
 367 the restoration of an architectural work of historical and artistic value [79]. As socioeconomic  
 368 indicators relevant to ceramic production on Sassuolo District, the expectations of the main  
 369 Stakeholder have been adopted.  
 370

| STAKEHOLDER CATEGORIES   | STAKEHOLDER SUBCATEGORIES           | STAKEHOLDER DETAILS                                      |                                   |
|--------------------------|-------------------------------------|--|-----------------------------------|
| 1.Human Resources        | 1.1 Staff Personnel                 | 1.1.1 Blue-collar Workers                                |                                   |
|                          |                                     | 1.1.2 Employees  |                                   |
|                          | 1.2 Trade Unions                    | 1.1.3 Managers   |                                   |
|                          |                                     | 1.1.4 Top Management                                     |                                   |
| 2.Local Community        | 2.1 Local Public Institutions       | 1.2.1 Confederal Trade Unions                            |                                   |
|                          |                                     | 1.2.2 Independent Trade Unions                           |                                   |
|                          |                                     | 2.1.1 Regional Governments                               |                                   |
| 3.Society                | 3.1 Private Business                | 2.1.2 Provincial Governments                             |                                   |
|                          |                                     | 2.1.3 Municipalities                                     |                                   |
|                          |                                     | 3.1.1 Company's Shareholders                             |                                   |
|                          | 3.2 Public and Private Organization | 3.1.2 Association of Manufacturing and Service Companies |                                   |
|                          |                                     | 3.1.3 Chambers of Commerce                               |                                   |
|                          |                                     | 3.2.1 Regulatory Authorities                             |                                   |
|                          |                                     | 3.2.2 Research Community                                 |                                   |
|                          | 3.3 Environment                     | 3.2.3 National and International Public Institutions     | 3.2.4 Civil Society Organizations |
|                          |                                     |  | 3.3.1 Natural Environment         |
|                          | 3.4 Media                           | 3.3.2 Future Generations                                 | 3.3.1 Natural Environment         |
|                          |                                     |  | 3.4.1 Newspapers                  |
|                          |                                     |  | 3.4.2 Professional Magazines      |
| 3.4.3 TV and Radio       |                                     |  |                                   |
| 4.Consumers              | 4.1 Trade Channel Operators         | 3.4.4 Internet   |                                   |
|                          |                                     | 4.1.1 Resellers  |                                   |
|                          | 4.2 Final Consumer                  | 4.1.2 Trading Partners                                   |                                   |
|                          |                                     | 4.1.3 Business Customers                                 |                                   |
| 5.Value Chain Actors     | 5.1 Suppliers                       | 4.2.1 Private Customers                                  |                                   |
|                          |                                     | 4.2.2 Consumers Associations                             |                                   |
|                          | 5.2 Partners                        | 5.1.1 Large-Scale Suppliers                              |                                   |
|                          |                                     | 5.1.2 Small-Scale- Suppliers                             |                                   |
|                          | 5.3 Competitors                     | 5.2.1 Practitioners and Professionals                    |                                   |
| 5.3.1 Direct Competitors |                                     |  |                                   |

Table 5: stakeholder mapping involved in the ceramic production of Sassuolo District (Source: our elaboration based on the SETAC/UNEP guidelines and the AA1000 standard).

371  
 372 The first step of the Participatory Approach consists of selecting stakeholders. For the  
 373 operational identification of the Stakeholder we have used an adaptation of the tools contained in the  
 374 guidelines of the AA1000 "Stakeholder Engagement Standard" (AA1000SES). These guidelines were  
 375 published in 2015 and provide a framework for organizations to identify, respond and prioritize their  
 376 sustainability challenges [80]. The AA1000 standard is a liability standard focused on ensuring the  
 377 quality of social and ethical accounting, auditing and reporting [81]. In this way and in accordance  
 378 with the SETAC/UNEP guidelines, we have identified the stakeholder involved in the ceramic  
 379 production adopting the principles of Responsibility, Influence, Proximity, Dependency and  
 380 Representation described in AA1000 standard. Table 5 shows the correspondences between the  
 381 categories defined by the SETAC/UNEP guidelines and sub categories of stakeholder of Sassuolo  
 382 District.

### 383 4. Method and data processing

384 The procedure we propose for the Life Cycle Sustainability Assessment (LCSA), provides for the  
 385 integration between the three tools of impact assessment (LCA, LCC, S-LCA), so in accordance with

386 ISO 14040, ISO 14044 and ISO 15686 standards we will adopt the same main phases for each  
387 dimension (environment, economy and society): goal and scope, inventory analysis, impact  
388 assessment and interpretation. We will also upscale the traditional LCSA to the ceramic district,  
389 considering the territorial component by processing data relating to the management of the entire  
390 supply chain.

#### 391 *4.1 Goal and scope definition*

392 The objective of the study is to assess the environmental and socio-economic impact of ceramic  
393 production in the Sassuolo district.

##### 394 4.1.1 System Studied

395 Ceramic tiles, produced by the companies belonging to the District of Sassuolo, which extends  
396 territorially between the provinces of Modena and Reggio Emilia in Italy and includes the  
397 municipalities of Sassuolo, Fiorano Modenese, Formigine, Maranello, Castelvetro, Castellarano,  
398 Scandiano, Casalgrande, Viano and Rubiera.

##### 399 4.1.2 Function of the system

400 For this study four types of medium ceramic products were identified and adopted, representing  
401 the entire district production: porous double-fired wall tiles, porous single-fired wall tiles, glazed  
402 porcelain stoneware and unglazed porcelain stoneware. The ceramic tiles under study are intended  
403 and applied for both floor and wall coverings, installed both in internal and external environments.

##### 404 4.1.3 Functional unit

405 For the purpose of this study, the functional unit chosen, is 1m<sup>2</sup> of each of the selected product  
406 categories.

##### 407 4.1.4 System boundary

408 The system boundaries include the whole life cycle of the product consistently with the LCA  
409 (cradle-to-grave) procedure: extraction, transport and grinding of raw materials; pressing, glazing,  
410 decoration, firing and packaging of tiles; in addition to the use, maintenance and disposal of  
411 equipment, emissions to air and water during manufacture and management of scrap and processing  
412 waste [82]. In this study, we have also adopted the spatialization of each phase of the LCA [61],  
413 considering also the flows of raw materials and their impacts that come from other territories both in  
414 Italy (Tuscany, Piedmont, Sardinia) and abroad (Germany, Turkey and Ukraine).

##### 415 4.1.5 Data quality and impact assessment methodology

416 Primary data on raw material extraction processes have been provided directly by mining  
417 companies, as well as data on inks, glazes and pigments production processes have been provided  
418 by the chemical companies producing these materials. Instead, the Ecoinvent database [83] was used  
419 as a secondary data source. For the study, the SimaPro 8.0.2 software and the IMPACT 2002  
420 evaluation method were adopted to calculate the environmental impacts.

#### 421 *4.2 Inventory analysis*

422 Life cycle inventory background data, costs including inputs and outputs in processes to  
423 produce ceramic tiles as well the emissions and social issues, have already been described in detail  
424 in paragraphs 3.

425

## 426 **5. Results and Discussion**

### 427 *5.1 LCA: Impact Assessment*

428 Table 6 shows the impact assessments for the four types of ceramic products, and the total  
429 corresponding weight factor (Pt), these values are represented in the graphic in Figure 1. The  
430 processes produce an impact due to 19,7% to the porous double firing wall tiles, 22,2% to porous  
431 single firing wall tiles, 25,7% to glazed porcelain stoneware and 32,3% to unglazed porcelain  
432 stoneware. In order to estimate the environmental damage that ceramic production has on the  
433 district, a further calculation was made by weighting the impacts with the square meters produced  
434 for each type of product considered. In this way we have passed from the level of microeconomic  
435 analysis (which refers only to the functional unit of 1 m<sup>2</sup> of ceramic tiles) to the level of meso-economic  
436 analysis which refers to the entire district. The results are shown in Figure 1a.

437

| LCA               |                         |                                 |                                 |                            |                              |                 |
|-------------------|-------------------------|---------------------------------|---------------------------------|----------------------------|------------------------------|-----------------|
| DAMAGE CATEGORIES | IMPACT CATEGORIES       | POROUS DOUBLE FIRING WALL TILES | POROUS SINGLE FIRING WALL TILES | GLAZED PORCELAIN STONEWARE | UNGLAZED PORCELAIN STONEWARE | TOTAL           |
| HUMAN HEALTH      | Carcinogenic agents     | 1,45E-05                        | 1,60E-05                        | 2,60E-05                   | 3,50E-05                     | 3,22E-03        |
|                   | Non-carcinogenic agents | 3,80E-05                        | 4,10E-05                        | 4,90E-05                   | 5,70E-05                     |                 |
|                   | Respiratory inorganic   | 6,10E-04                        | 7,10E-04                        | 7,10E-04                   | 9,10E-04                     |                 |
|                   | Respiratory organic     | 1,00E-06                        | 1,20E-06                        | 1,40E-06                   | 1,70E-06                     |                 |
| ECOSYSTEM QUALITY | Ozone depletion         | 2,40E-07                        | 3,00E-07                        | 3,60E-07                   | 4,70E-07                     | 4,07E-04        |
|                   | Aquatic ecotoxicity     | 6,50E-06                        | 1,00E-05                        | 8,30E-06                   | 1,10E-05                     |                 |
|                   | Terrestrial ecotoxicity | 6,50E-05                        | 8,20E-05                        | 7,70E-05                   | 8,00E-05                     |                 |
|                   | Aquatic acidification   | 0,00E+00                        | 0,00E+00                        | 0,00E+00                   | 0,00E+00                     |                 |
|                   | Soil acidification      | 9,80E-06                        | 1,20E-05                        | 1,20E-05                   | 1,40E-05                     |                 |
|                   | Land occupation         | 3,60E-06                        | 4,90E-06                        | 4,20E-06                   | 5,30E-06                     |                 |
| CLIMATE CHANGE    | Global warming          | 8,90E-04                        | 9,50E-04                        | 1,10E-03                   | 1,40E-03                     | 4,34E-03        |
| RESOURCES         | Nonrenewable energy     | 8,10E-04                        | 9,20E-04                        | 1,20E-03                   | 1,50E-03                     | 4,44E-03        |
|                   | Mineral extraction      | 3,20E-06                        | 4,80E-06                        | 2,70E-06                   | 3,60E-06                     |                 |
| <b>TOTAL</b>      |                         | <b>2,45E-03</b>                 | <b>2,75E-03</b>                 | <b>3,19E-03</b>            | <b>4,02E-03</b>              | <b>1,24E-02</b> |
|                   |                         | 19,7%                           | 22,2%                           | 25,7%                      | 32,3%                        |                 |

**Table 6:** results of environmental damage for the four product categories expressed in Pt and obtained with the Impact 2002 model.

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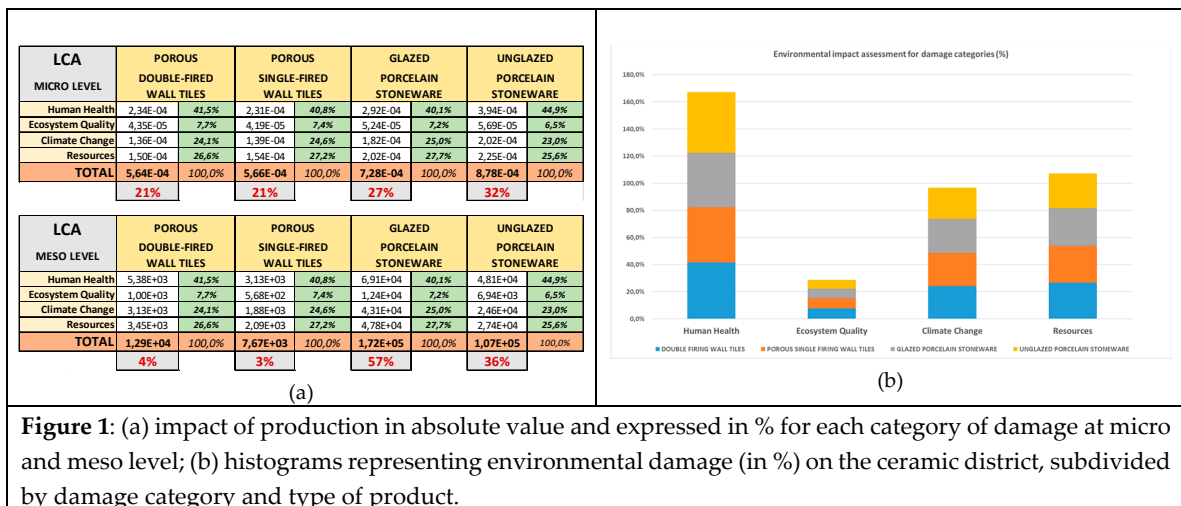
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The greatest impact for all products corresponds to the category of damage to human health. The detrimental effect on human health is mainly related to the NO<sub>x</sub> (nitrogen oxide) emissions associated with transportation of raw materials from the extraction sites to the factory sites at (41,9% overall). Clearly the same NO<sub>x</sub> emissions affect climate changes (24,2% in total). Figure 1b shows, in a comparative diagram, the results of the environmental impact of the production categories for the entire district in aggregate form.



**Figure 1:** (a) impact of production in absolute value and expressed in % for each category of damage at micro and meso level; (b) histograms representing environmental damage (in %) on the ceramic district, subdivided by damage category and type of product.

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## 5.2 LCA: Results Interpretation

The environmental impact analysis carried out at micro level, having as a reference 1 m<sup>2</sup> of ceramic tiles for each product category, showed that the types with the most moderate impact are unglazed porcelain stoneware and glazed porcelain stoneware, while no significant variations were observed in the category of damage between the various typologies. Changing the perspective of observation and moving on to meso level, then to the district level considering production volumes, takes the effect of weighting volumes downwind and, of course, the product category most impacting is glazed porcelain stoneware.

## 5.3 LCC: Inventory Costs

Consistent with the LCA analysis discussed before, the same functional unit was adopted for the assessment of costs, for the four product categories already described above: porous double-fired

458 wall tiles, porous single-fired wall tiles, glazed porcelain stoneware and unglazed porcelain  
459 stoneware (Paragraphs 3.5 and 3.6).

#### 460 5.4 LCC: Costs Assessment

461 In an integrated process for the manufacturing of a product, the life cycle of costs is the sum of  
462 the costs attributable to the individual life cycle stages [84]:

$$463 \text{LCC}_{\text{TOT}} = \text{Development Costs} + \text{Utilization Costs} + \text{Disposal Costs} \quad (2)$$

464 To adapt the above conceptual formula (2) to the specific case under study, we propose this new  
465 empirical formula:  
466

$$467 \text{LCC}_{\text{TOT}} = \text{Production Costs} + \text{Utilization Costs} + \text{Externalities} \quad (3)$$

470

| <b>LIFE CYCLE COSTING</b>                 | <b>POROUS<br/>DOUBLE-FIRED<br/>WALL TILES</b> | <b>POROUS<br/>SINGLE-FIRED<br/>WALL TILES</b> | <b>GLAZED<br/>PORCELAIN<br/>STONEWARE</b> | <b>UNGLAZED<br/>PORCELAIN<br/>STONEWARE</b> |
|---|---|---|---|---|
| <b>PRODUCTION COST</b>                    |   |   |   |   |
| Production (m <sup>2</sup> )              | 22.978.356                                    | 13.545.628                                    | 236.734.900                               | 121.954.343                                 |
| Production Costs (€/m <sup>2</sup> )      | 6,15  | 7,72  | 6,85                                      | 8,06  |
| <b>TOTAL PRODUCTION COSTS</b>             | <b>141.316.889</b>                            | <b>104.572.248</b>                            | <b>1.621.634.065</b>                      | <b>982.952.005</b>                          |
| <b>2.850.475.207</b>                      |   |   |   |   |
| <b>UTILIZATION COST</b>                   |   |   |   |   |
| Utilization Costs (€/m <sup>2</sup> )     | 6,56  | 6,85  | 8,99                                      | 10,01                                       |
| <b>TOTAL UTILIZATION COSTS</b>            | <b>150.738.015</b>                            | <b>92.787.552</b>                             | <b>2.128.010.016</b>                      | <b>1.220.762.973</b>                        |
| <b>3.592.298.557</b>                      |   |   |   |   |
| <b>EXTERNALITIES</b>                      |   |   |   |   |
| Human Health                              | 0,11  | 0,13  | 0,15                                      | 0,17  |
| Ecosystem Production Capacity             | 0,11  | 0,14  | 0,14                                      | 0,19  |
| Abiotic Stock Resource                    | 0,54  | 0,83  | 0,41                                      | 0,50  |
| Biodiversity                              | 0,0014  | 0,0015  | 0,0018                                    | 0,0023                                      |
| <b>TOTAL</b>                              | <b>0,76</b>                                   | <b>1,10</b>                                   | <b>0,71</b>                               | <b>0,86</b>                                 |
| <b>TOTAL EXTERNALITIES</b>                | <b>17.443.293</b>                             | <b>14.896.295</b>                             | <b>168.293.988</b>                        | <b>104.824.295</b>                          |
| <b>305.457.871</b>                        |   |   |   |   |
| <b>TOTAL PRODUCT COST €/m<sup>2</sup></b> | <b>13,47</b>                                  | <b>15,67</b>                                  | <b>16,55</b>                              | <b>18,93</b>                                |
| <b>TOTAL COSTS BY CATEGORY</b>            | <b>309.498.197,60</b>                         | <b>212.256.095,04</b>                         | <b>3.917.938.069,26</b>                   | <b>2.308.539.272,52</b>                     |
| <b>TOTAL</b>                              | <b>6.748.231.634</b>                          |   |   |   |

**Table 7:** LCC calculation scheme based on inventory data and applying the empirical formula (2). Externalities are expressed in euro/m<sup>2</sup>.

471

472 The calculation of production and utilization (distribution, installation and use phases) costs of  
473 the end product, were determined per m<sup>2</sup> and then projected on a "meso" scale on the basis of  
474 production volumes by category and total for the entire district (Table 7). The economic impact  
475 assessment (LCC), which is carried out in parallel with the environmental impact assessment (LCA),  
476 makes it possible to quantify environmental damage economically. The production of ceramic tiles,  
477 as well as other economic activities, uses resources that come from the environment without,  
478 however, considering the economic value of the environmental damage caused by the use of these  
479 factors of production. Costs incurred by some parts of society because of activities that affect the  
480 environmental balance of a territory are referred to as negative environmental externalities or  
481 external costs [85]. The EPS 2000 model has been used to estimate externalities. It estimates the  
482 economic cost of pollutant emissions based on the willingness to pay (WTP) of the entity responsible,  
483 in order to avoid a worsening of the situation created or to remedy a damage caused, attributing an  
484 economic value to the damage. Each impact category in the EPS 2000 model attributes a specific  
485 weight to the severity of the impact in environmental and social terms. This weight is defined as the  
486 ELU (Environmental Load Unit), whose value is 1 ELU = 1. Table 7 shows the costs of environmental  
487 externalities relating to the damage category for each type of ceramic product considered.

### 488 5.5 LCC: Results Interpretation

489 The adoption of the external costs approach allowed us to monetize the environmental impact  
 490 of different ceramic tiles production. The LCC analysis integrates the directional accounting because  
 491 it introduces into it not only the industrial costs and those of use, but also those that the environment  
 492 and the company must pay in order to maintain the manufacturing conditions of the ceramic product.  
 493 The transformation of environmental externalities into internal costs makes it possible to go beyond  
 494 the individual production units and to consider the territory, switching from micro to the meso level.

### 495 5.6 S-LCA: Social Assessment

496 The three impact assessment systems S-LCA, LCA and LCC all refer to the guidelines set out in  
 497 ISO 14040 which provides for four phases. Therefore, for the determination of the social impact,  
 498 implementing the same Objective and Scope of LCA and LCC, using the so-called Participatory  
 499 Approach [78] already used for the engagement of stakeholders involved in the management of  
 500 Cultural Heritage [79]. In the case under consideration in this study, the expectations of the  
 501 Stakeholders involved in the value chain of the Sassuolo district were adopted as an indicator of  
 502 social impact. To determine the expectations of the main stakeholders, the qualitative analysis has  
 503 required the use of various data collection techniques, such as: structured online interviews and focus  
 504 groups. Subsequently, in order to define the degree of influence that the expectations of the  
 505 stakeholders have on the producers of ceramic tiles, it was necessary to assign to each stakeholder a  
 506 prioritization index, constructed with the criteria of power, urgency and proximity already described  
 507 in the AA1000 standard [80].  
 508

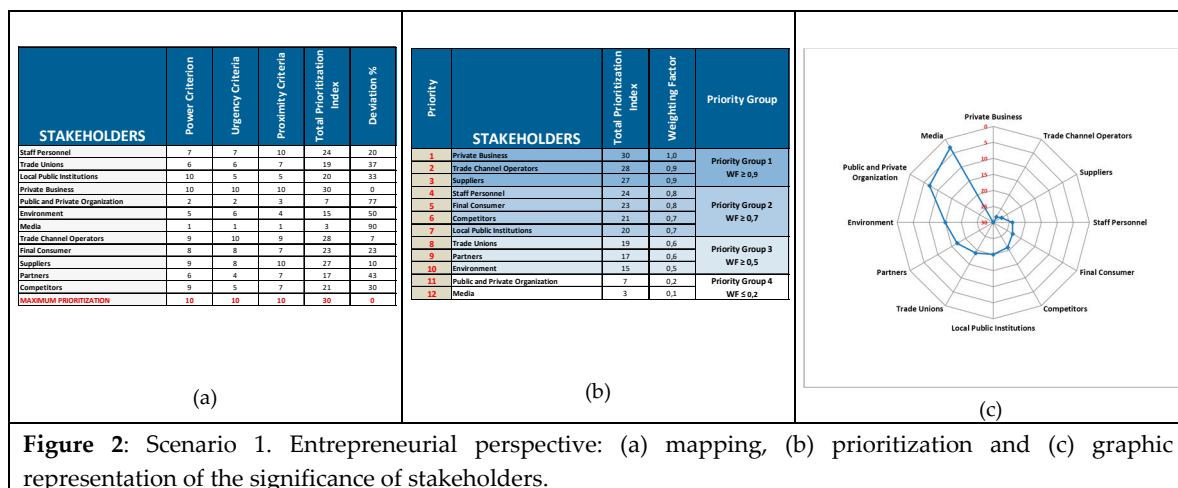


Figure 2: Scenario 1. Entrepreneurial perspective: (a) mapping, (b) prioritization and (c) graphic representation of the significance of stakeholders.

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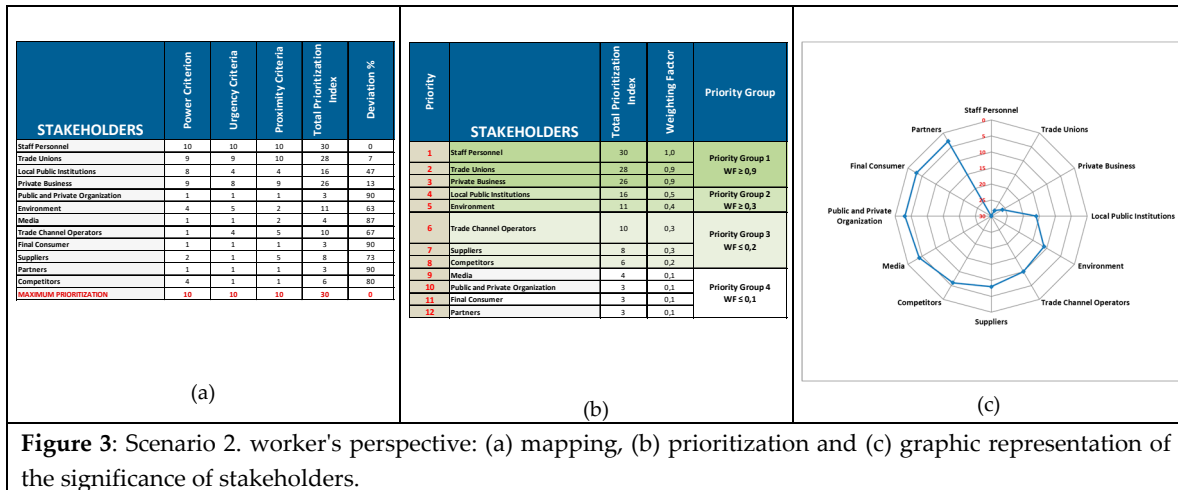
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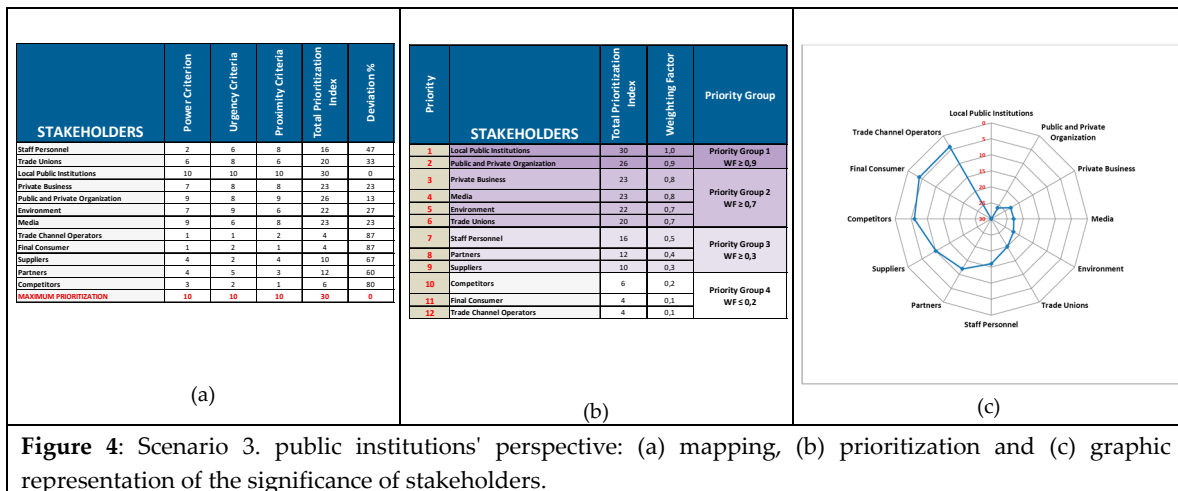
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The social research applied to this case study, raised relevant methodological questions. It has been verified that the analyst's position is not neutral, when he observes social events to infer conclusions, he "interprets" social phenomena based on his background (experience, knowledge and conscience) [86]. Therefore, the research team was confronted with the intrinsic partiality of each member when collecting, processing and analyzing social data [87]. The construction of knowledge is therefore done through a continuous exchange of points of view, including those of the research team, but not only. The interpretative process and the construction of reality is also influenced by the context in which the social event occurs. Converging multiple points of view, such as stakeholder expectations, is a way to build and describe reality. Through the interpretation of these different points of view, the background of the researcher/analysts merges with those of other social agents, creating a new and more complete understanding of the reality under examination [88].



**Figure 3:** Scenario 2. worker's perspective: (a) mapping, (b) prioritization and (c) graphic representation of the significance of stakeholders.

527 For this reason, the importance of Stakeholders was declined into three sets characterized by  
 528 three different perspectives of observation of reality. Scenario 1, entrepreneurial perspective (Figure  
 529 2); Scenario 2, worker's perspective (Figure 3) and Scenario 3 public institutions' perspective (Figure  
 530 4).  
 531



**Figure 4:** Scenario 3. public institutions' perspective: (a) mapping, (b) prioritization and (c) graphic representation of the significance of stakeholders.

532 Table "a" of each scenario considered (Figures: 2, 3 and 4), indicates that for each main  
 533 stakeholder category and each criterion, a priority index has been assigned (from 1 to 10). The total  
 534 index is obtained from their sum. Assuming the value 30 (10 + 10 + 10) as the maximum prioritization  
 535 index, the percentage deviation for each stakeholder indicates the "distance" of this value from the  
 536 maximum possible index. In the following Table "b" (Figures: 2,3 and 4) stakeholder groups are  
 537 ordered by total index of decreasing prioritization and by weighting factor obtained by dividing this  
 538 index with the maximum index of prioritization (30). In this way, it was possible to aggravate the  
 539 stakeholders in four priority groups. Finally, radial diagram "c" (Figures: 2, 3 and 4) graphically traces  
 540 the relative relevance of the stakeholders with respect to the index of maximum prioritization.  
 541

542 **5.7 S-LCA: Assessment Interpretation**

543 By merging the different perspectives and expectations of the stakeholders of the Sassuolo  
 544 ceramic district, it was possible to arrive at a new construction of the reality that has overcome the  
 545 subjection of each individual economic agent or stakeholder group, as well as to reduce the problem  
 546 of partiality of the members of the research team in the data collection and analysis phases. Figure 5  
 547 shows the interpretative process for the three scenarios considered: entrepreneurs, workers and  
 548 public institutions.  
 549

| Priority Group | SCENARIO 1<br>Entrepreneurial Perspective |       | SCENARIO 2<br>Worker's Perspective |       | SCENARIO 3<br>Public Institutions' Perspective |       |
|----------------|---|-------|------------------------------------|-------|--|-------|
|                | STAKEHOLDER                               | INDEX | STAKEHOLDER                        | INDEX | STAKEHOLDER                                    | INDEX |
| 1              | Private Business                          | 1,0   | Staff Personnel                    | 1,0   | Local Public Institutions                      | 1,0   |
|                | Trade Channel Operators                   | 0,9   | Trade Unions                       | 0,9   | Public and Private Organization                | 0,9   |
|                | Suppliers                                 | 0,9   | Private Business                   | 0,9   |  |       |
| 2              | Staff Personnel                           | 0,8   | Local Public Institutions          | 0,5   | Private Business                               | 0,8   |
|                | Final Consumer                            | 0,8   | Environment                        | 0,4   | Media  | 0,8   |
|                | Competitors                               | 0,7   |                                    |       | Environment                                    | 0,7   |
|                | Local Public Institutions                 | 0,7   |                                    |       | Trade Unions                                   | 0,7   |
| 3              | Trade Unions                              | 0,6   | Trade Channel Operators            | 0,3   | Staff Personnel                                | 0,5   |
|                | Partners                                  | 0,6   | Suppliers                          | 0,3   | Partners                                       | 0,4   |
|                | Environment                               | 0,5   | Competitors                        | 0,2   | Suppliers                                      | 0,3   |
| 4              | Public and Private Organization           | 0,2   | Media                              | 0,1   | Competitors                                    | 0,2   |
|                | Media                                     | 0,1   | Public and Private Organization    | 0,1   | Final Consumer                                 | 0,1   |
|                |   |       | Final Consumer                     | 0,1   | Trade Channel Operators                        | 0,1   |
|                |   |       | Partners                           | 0,1   |  |       |

**INTERPRETATION PROCESS FOR A NEW UNDERSTANDING**

|    |                                 |     |
|----|---------------------------------|-----|
| 1  | Private Business                | 1,0 |
| 2  | Staff Personnel                 | 1,0 |
| 3  | Local Public Institutions       | 1,0 |
| 4  | Trade Channel Operators         | 0,9 |
| 5  | Suppliers                       | 0,9 |
| 6  | Trade Unions                    | 0,9 |
| 7  | Public and Private Organization | 0,9 |
| 8  | Final Consumer                  | 0,8 |
| 9  | Media                           | 0,8 |
| 10 | Competitors                     | 0,7 |
| 11 | Environment                     | 0,7 |
| 12 | Partners                        | 0,6 |

**Figure 5:** Interpretative process of fusion of the different perspectives of entrepreneurs, workers and public institutions and construction of a new prioritization of the stakeholders of Sassuolo district.

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The table above in Figure 5 represents the logic of stakeholder prioritization for each scenario. Entrepreneurs, workers and public institutions have a different construction of reality depending on the specificity of their expectations. After collecting these different visions, the research team, through a hermeneutical process [89], has carried out the fusion of the three different interpretative horizons to arrive at a new construction of reality that is represented in the table below in Figure 5 [90]. It represents a new prioritization of the stakeholders of the Sassuolo district on the basis of the perspectives of the three scenarios that have been considered. The new stakeholder list was built by combining scenarios (in columns) with priority groups (in rows) across them and listing them in descending order of priority, switching from micro to meso level. The new list of stakeholders can be the basis for defining the most appropriate strategies for engagement.

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## 6. Conclusions

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In this paper it was shown that the LCSA approach helps to incorporate the full social cost of an environmental transaction into the price of products, avoiding attributing the external costs to the community and responding to market failures. The research bridges the gap between scholars and practitioners in the field of integrating sustainability principles into business models and economic and industrial policies for the governance of territories.

In a theoretical perspective, the change of the analysis unit, from the enterprise (at micro level) to the district (at meso level), allows to take into account those externalities that would otherwise remain outside the "gates" of the economic actors and allows to transform them into sector internalities. The LCSA model also highlighted that the transport of raw materials is one of the most impacting factors, but above all it showed that it is not only a transaction cost (the transport from the mine to the factories), but also an environmental cost not exclusively attributable to the individual company, but to the entire sector. The determination of the monetary value of externalities has questioned the hypothesis of the "isotropicity" of space considered in terms of "pure distance", that is, that spatial element that must be filled in order to transport people with raw materials and finished products. Distance is not only transaction cost, but also environmental cost. Externalities have the

577 consequence of creating situations of interdependence between subjects who are not among  
578 themselves in contractual relations. This vision raises the question of managing interactions between  
579 economic agents and internalizing externalities that cannot be left exclusively to market coordination.  
580 This is a problem of governance of the system and the implementation of appropriate economic  
581 policies aimed at attributing the cost of externalities to those who have been able to use public assets  
582 for the exercise of their economic activity. The economic quantification of external costs in aggregate  
583 terms, broadens the knowledge on the factors of pressure offering private decision makers and public  
584 administrators, useful information to prepare responses and targeted interventions of economic  
585 policies. We could therefore move from the coercive logic of "forbidding" to the positive logic of  
586 "doing better", in which the environment is no longer perceived as externality, a threat to the brake  
587 and obstacle to the development of businesses, but as an opportunity to stimulate product and  
588 process innovation.

589 From a managerial perspective, this experimental research has shown how the correct use of an  
590 appropriate scientific tool (the LCSA model) allows to quantify the economic, environmental and  
591 social impact, using process data normally available to economic agents and otherwise not always  
592 used profitably. Empirically, the study, adopting the holistic perspective of the life cycle, showed that  
593 the transport of raw materials constitutes about 20-25 % of the environmental damage produced by  
594 the entire life cycle, for all the production categories of the Sassuolo ceramic district. However, there  
595 are not great differences between the different processes of the product categories considered, in  
596 terms of environmental impact, as a demonstration of the standardization of the production phases.  
597 The process of technological standardization has also made less relevant the reduction of transaction  
598 costs related to the territorial proximity and the outsourcing of production phases and the efficiency  
599 of learning processes that are at the basis of innovation. The effects of the industrial activities of the  
600 Sassuolo district extend beyond the traditional concept of local territory to reach beyond national  
601 borders, to the countries from which the raw materials necessary to produce ceramic tiles are sourced.  
602 The social dimension of industrial activity in the district and the related costs has led us to ask  
603 ourselves about the ways in which economic actors interact and about the model of "government" of  
604 the territory. The interpretative study of the expectations of the various stakeholders, divided into  
605 three different scenarios, would evoke the creation of a district governance that guides the efforts and  
606 investments of all companies towards cost efficiency, value innovation, market presence with an  
607 adequate policy of brand, the ability to develop and integrate into international markets.

608  
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614 Davide Settembre Blundo wrote the paper.

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