Analysis of The Energy Consumption Structure and Evaluation of Energy Performance Indicators of The Italian Ceramic Industry

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Abstract:

The Italian ceramic manufacturing sector is made up of industrial-level companies producing ceramic tiles and slabs, sanitaryware, porcelain and tableware, refractory materials, technical ceramics, bricks and roof tiles. According to [1] in 2019, the sector includes a total of 279 companies operating in Italy, with a workforce of more than 27,500 employees and revenues of 6.5 billion euros. Ceramics is an energy –intensive sector and its electric energy consumption in Italy amounts to about 1.800 GWh/year while the natural gas consumption to about 1.500 million of cubic meters per year. Furthermore, less than 30% of electricity is self-produced through cogeneration, while the remaining is acquired [1]. The primary energy use in ceramic manufacturing is for kiln firing and, in many processes, drying of intermediates or shaped ware is also energy intensive.

The aim of this work is to analyse the energy consumption structure of ceramic industry in Italy in order to define updated global and specific energy performance indicators related to the production process and to the auxiliary and general services with the final objective to promote targeted actions and measures to improve energy efficency of the sector, reducing costs and greenhouse gas emissions. The analysis is based on 197 Energy Audits [2] from ceramics sector received by ENEA (National Agency for New Technologies, Energy and Sustainable Economic Development) at December 2019 and conducted pursuant to art. 8 of Legislative Decree 102/2014 (updated by D.Lgs. 73/2020), which requires all large companies and energy-intensive companies (Ministerial Decree of 21 december 2017) to carry out an energy audit on their more representative productive sites at least every four years.

The analysis is focused on NACE (Nomenclature of Economic Activities) sectors C23.3.1 (103 EAs) and C23.3 (54 EAs) corresponding respectively to the production of ceramic tiles and bricks. All the energy performance indicators will be analysed for each energetic vector (electricity, natural gas etc.) consumed at the site.

Keywords:

Energy Efficiency; Ceramic Industry; Energy Audit; KPI; Energy Indicators.

1. Introduction

The Energy Efficiency Directive 2012/27/EU (EED) is a solid cornerstone of Europe's energy legislation. It includes a balanced set of binding measures planned to help the EU reach its 20% energy efficiency target by 2020. The EED establishes a common framework of measures for the promotion of energy efficiency (EE) in order to ensure the achievement of the European targets and to pave the way for further EE improvements beyond 2020. The Italian Government transposed the EED in 2014 (by issuing the legislative Decree n. 102/2014, recently updated by legislative Decree n. 73/2020 to make it compliant with new European Directive 2018/2002) assigning to ENEA (Italian National Agency for New Technologies, Energy, and the Sustainable Economic Development) the management of EED article 8 obligation [2]. The article 8 is dedicated to Energy Audits (EAs), a necessary tool to assess the existing energy consumption and identify the whole range of opportunities to save energy.

In the EED Energy Audit is definited as a systematic procedure with the purpose of obtaining adequate knowledge of the existing energy consumption profile of a building or group of buildings, an industrial or commercial operation or installation or a private or public service, identifying and quantifying cost-effective energy savings opportunities, and reporting the findings. According to Art. 8 of Lgs. D. 102/14, two categories of companies have been targeted as obliged to carry out energy audits on their production sites, firstly by the 5th of December 2015, and then at least every four years: large enterprises and Energy intensive enterprises.

Pursuant to article 8 of Lgs. D.102/2014 at 31 December 2019 ENEA received 11,172 energy audits of production sites relating to 6,434 companies [2].

Over 53% of the audits were carried out on sites related to the manufacturing sector (8% Plastic, 9% Iron and Steel, 2% Paper, 1,8% Ceramics, 3% Textile, 6% Food Industry) and over 14% in trade. 70% of the audits collected by ENEA are equipped with specific monitoring of energy consumption.

In the ceramic sector 197 EAs, carried out from 143 companies, have been collected by ENEA at December 2019 [2] and 162 EA are characterized by the presence of a monitoring plan for energy consumption (18 companies are equipped with the ISO 50001 energy management system). 95% of sectorial energy audit is carried out by Energy Intensive Enterprises.

The analysis developed, therefore, is based on updated process data relating to a specific sector of the Italian manufacturing context. In the literature there are no recent data relating to the Italian ceramic sector, in terms of global consumption and reference performance indices.

More than 50% of the energy audit relate to the production of ceramic tile, more than 28% relate to brick production. The total primary energy consumption covered by the analyzed 197 Energy Audits is 1,67 Mtoe.

The paper is organized as follows: in Section 2 a synthetic description of the ceramic tiles and bricks production processes is presented. The research method, data collection and energy performance indexes, defined for the purpose of this analysis, are outlined in Section 3. Section 4 presents and discusses the main results of the study. Finally, in Section 5 conclusions of the study are highlighted along with the future steps of the project.

2. The ceramics manufacturing production process

The generalised ceramics manufacturing process consists of four basic stages (Fig1):

- preparation of raw materials,
- shaping,
- drying ,
- firing.

The differences among each particular sector, especially with respect to shaping process, to the raw materials used and to the firing temperatures employed, depend on the specific needs for the particular products (shape, dimensions, required properties, etc)[3].

The analysis is focused on the production of ceramic tiles and bricks.

Ceramic tiles are the result of a process that is strongly influenced by raw materials and firing temperature: as function of these two parameters different type of tiles can be obtained (porcelain tile, single-firing tile, double-firing tile, etc.).

Porcelain tiles are the most common type of tiles in the analysed production sites (about 85% of EAs of NACE sector C23.3.1) and thus the analysis will be focused on this type and their manufacturing process will be described with details.

The preparation of the mixture for porcelain stoneware tiles involves two phases: grinding (wet milling) and subsequent atomization. The raw materials are mixed and wet ground in continuous rotary mills, until a liquid called *slip* is obtained. This is then stored in tanks, equipped with agitators. The slip is colored in mass through the addition of dyes and in this phase the most varied chromatic compositions are formed. Special pumps collect the colored liquid and put it in the atomizer where the high temperature (500°C) cause the drop of slip to explode and the water to evaporate, producing a very fine and homogeneous powder, ready to be pressed. The powders are then conveyed to the hydraulic presses, which exert a pressure of about 350-450 kg/cm^2 on the atomised powders to allow, during cooking, the oxidation of organic substances and the removal of the generated gases. At this point, the pressed tile is dried, so that the humidity level reaches values suitable for firing in roller kilns at a temperature that reaches a maximum between 1180 and 1240 °C. The duration of the firing cycle and the high temperature are the necessary conditions established to obtain a vitrified porcelain stoneware tile, compact, non-porous and therefore non-absorbent. After cooling, tiles can be treated by several mechanical processes such as cutting, grinding, lapping and polishing, after which they are sorted and packed.

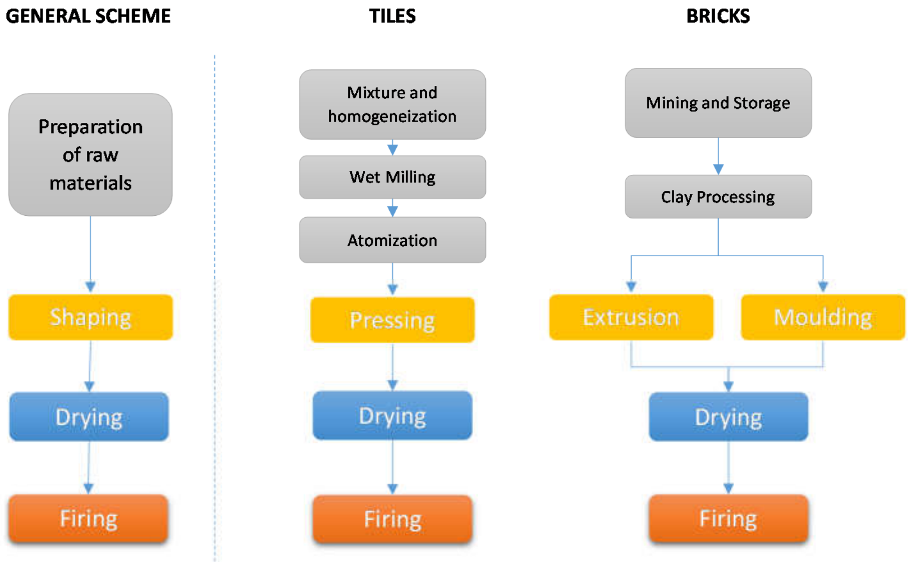

Figure 1 Ceramic manufacturing process: general scheme, tiles and bricks.

The basic principles of ceramic bricks manufacturing are uniform however manufacturing plants tailor their production to fit their particular raw materials and operation. Essentially, bricks are produced by mixing ground clay with water, forming the clay into the desired shape, drying and firing.

Surface clays, shales and fire clays are mined in open pits with power equipment and then the transported to plant storage areas. To break up large clay lumps and stones, the material is processed through size-reduction machines before mixing the raw material.. Depending on the type of brick to be produced, the mixture is placed, together with the sand, inside the caissons, where the hoppers will provide for mixing. Clay is then thoroughly mixed with water to reach the humidity rate needed for the subsequent forming phase. There are two main processes for forming bricks: extrusion process and moulding process. In extrusion process water in the range of 10 to 15 percent is mixed into the clay to produce plasticity and then the clay is extruded through a die to produce a column of clay. An automatic cutter then slices through the clay column to create the individual brick. The molded process is particularly suitable for clays containing too much water to be extruded by the extruded process. Wet brick from molding or cutting machines contain 7 to 30 percent moisture, depending upon the forming method. Before the firing process begins, most of this water is evaporated in dryer chambers with a drying time between 24 to 48 hours. Although heat may be generated specifically for dryer chambers, it usually is supplied from the exhaust heat of kilns to maximize thermal efficiency.

Bricks are then fired between 10 to 40 hours, depending upon kiln type and other variables. There are several types of kilns used by manufacturers. The most common type is a tunnel kiln, followed by periodic kilns. Fuel may be natural gas, coal, sawdust, methane gas from landfills or a combination of these fuels.

3. Energy consumption and energy performance indicators

As illustrated in the previous section ceramics, both tiles and bricks, acquire their specific properties thanks to the application of high temperature heat which takes place inside kilns usually for a long period of time. Firing is responsible for about 53% of the ceramic manufacturing thermal consumption, followed by spray drying (35%) and drying (10%) [4].

Ceramic manufacturing is an energy intensive sector and therefore a high amount of energy is consumed during the process and energy cost is a significant share of the total production cost. For the manufacturing of Italian ceramic tiles, for example, the energy item accounts for 20% of the total cost of production [1]. Energy sources used in the ceramic process are natural gas and electricity, with roughly 80% of the energy consumption credited to gas.

The implementation of energy saving technologies is therefore a requirement directly related with both production cost and emissions reduction.

In 2016 Confindustria Ceramica, the association of Italian ceramic industries, conducted a research on thermal efficiency strategies developed to optimize the energy consumption of ceramic tiles industry [5]. The research analyzed a sample of 64 production sites covering 59.6% of national production. A first energy saving solution, started in the early '80s, was the recovery of the indirect cooling air of kilns to the dryers. In 2016, this strategy concerned 43.2% of vertical dryers and 35.2% of horizontal dryers. The second and most effective energy efficiency measure was the introduction of the CHP units in the '90s, and their diffusion had another strong impulse around 2008, thanks to the establishment in Italy of the WhC (White Certificates or Energy Efficiency Shares).

Sectorial scientific literature related to specific energy consumption is not very up-to-date and the most recent data on Italian Ceramic industry are included in [6] and [7]. Thermal energy consumption and carbon dioxide emissions in the Spanish ceramic tile manufacturing process are presented in [8], both overall and broken down by production stages and by products manufactured.

A practical guidance for improving the sustainability of the ceramic tiles manufacturing process through the selection of most appropriate BAT for this sector is given in [9].Comprehensive information on the best available technologies and specific energy consumption indexes for the production of ceramics are given in the EU Bref reference document elaborated within the IIIP and IED directives [10] and, for the Italian case, in the D.M. January 29, 2007 [11]. Energy saving opportunities in this sector include the installation of waste heat recovery systems [12], use of renewable energy [13] and cogeneration systems [14,15].

The reference energy consumption per tonne of product for the manufacturing of porcelain ceramic tile is equal to 6,37 GJ/t for the complete production cycle and 3,12 GJ/t for the partial production cycle (from pressing to firing)[10]. The reference energy consumption per tonne of product for the manufacturing of bricks (walls, facing and roof tiles) is in the range 1.5 – 3 GJ/t [10].

In this study updated sectorial Energy Performance Indexes (EPI) have been evaluated using the Italian Mandatory Energy Audits database. The purpose of defining the energy performance indices is to identify the reference values that allow companies to plan their energy policy appropriately. These values can be related to the entire production site, to a single production process, to a company area / department, to a single phase of the production process.

The EPI can be defined as:

$$EPI = \frac{Energy\ Consumption}{Production\ [\ kg, m^3, etc]}$$

and takes the form of a specific consumption, having as its denominator the specific production and the energy consumption as its numerator.

Comparing the value of corporate EPIs to industry standards allows for a comparison called industry benchmarking.

Energy performance benchmarking allows to:

- Quantify trends in energy consumption (fixed and variable) with respect to production levels
- Compare the energy performance of the sector against various levels of production
- Identify industry best practices
- Quantify the available margins for reducing energy costs

It also forms the basis for setting the monitoring plan and the energy targets to be achieved.

In this study the following energy performance indexes have been identified for both ceramic tiles and bricks manufacturing sites:

1) electrical energy performance index, EPI_{el}: it includes the electricity consumption of the production site, both grid consumption and self-production (as from renewables and cogeneration)

2) thermal energy performance index, EPI_{th}: it includes the consumption of natural gas, heat, cold, biomass, fuel oil, coke and other vectors with thermal uses in the production process.

3) global primary energy performance index, EPI_g: it includes all the energy consumption of the site as electricity, thermal energy and automotive fuels (diesel, petrol and LPG), as well as the specific consumption of transformation processes in terms of primary energy.

These indexes have been calculated on two levels: the energy consumption (electrical, thermal and general) related to the main activities of the production site and the total energy consumption including also auxiliaries and general services.

4. Methodology

The data collected through the EAs received by ENEA in December 2019 were the starting point for the evaluation of the reference EPIs for each sector. On this basis, a method has been developed based on the correlation, often linear, between energy consumption and production.

The first step of the proposed method consists in the identification of the correlation, supposed to be linear, between energy consumptions and site production.

Once the available data have been cleaned up by eliminating any outliers or non-homogeneous data, the linear regression line is identified in the form:

$$Energy\ Consumption(Production) = Variable\ energy\ consumption\ share\ \times Production + Fixed\ energy\ consumption\ share$$

Two statistical measures are then calculated to assess the reliability and significance threshold of the identified regression: R-squared and p-value. The R-squared measures the degree at which the data are explained by the model and the p-value is a test of hypothesis on the significance of the estimated model.

R-Squared (R^2 or the coefficient of determination) is a statistical measure in a regression model that determines the proportion of variance in the dependent variable that can be explained by the independent variable. In other words, R-squared shows how well the regression model fits the data (the goodness of fit). R-squared can take any values between 0 to 1.Generally, a higher R-squared indicates a better fit for the model [16].

Once the correlation between the quantities is assessed, the IPE model curve is constructed as:

$$EPI(production) = \frac{Energy\ Consumption\ (Production)}{Production}$$

The average deviation between the real EPI and the model values is then calculated to assess its reliability. The model is considered reliable if this value is lower than 30%.

In addition to the EPI model, the average EPIs are also calculated by evaluating their statistical distribution, the mean value and the relative standard deviations of the statistical sample.

5. Results and discussion

In this section the results obtained by the application of the previously explained method to the ceramic sector are presented. EPI models and reference values are presented for both ceramic tiles and bricks.

5.1 Ceramic tiles

The dataset used for the evaluation of EPIs consists of 103 EAs belonging to 68 companies. The dataset has been divided in two groups: the first group consists of 39 EAs where the products are measured in m^2, the second group consists of 64 EAs where the products are defined in tons of final products leaving the site. For the first group, the EPIs analysis was not carried out due to the variety of thicknesses of the tiles produced and therefore the non-homogeneity of the sample.

The second group of 64 energy audits has been classified on the basis of the type of production cycle: 23 EAs with Complete Cycle (in which all the processes phases from grinding to mechanical processing are present) and 15 EAs with Partial Cycle (involving only the steps from pressing and without considering spray-dried powders production). The remaining 26 EAs were not used because they were related to single sub-phases of the production process or because it was not possible to classify them in one of the two groups for lack of information. Production refers to the tons of stoneware produced.

The obtained regression lines for electrical energy and natural gas are presented in Figure 2.

Both total energy consumption and process energy consumption are represented for each energy vector.

In sites with complete process cycle the consumption of electricity is attributable, on the average, for about 70% to the production process while auxiliary (compressed air system, pumping etc) and general services (lighting, air conditioning etc) account for 24,8% and 5,2% respectively. For sites with partial process cycle the distribution of electrical energy consumption is: 62% process, 32% auxiliaries and 6% general services.

The consumption of natural gas, on the other hand, is almost entirely attributable to the production process for both complete and partial cycle. The natural gas used for the process represents 87% of the total gas used on the sites analyzed for the complete cycle sites and 99% for partial cycle sites.

The model parameters evaluated as explained in Section 4 are reported in Table 1 and Table 2. Regression lines obtained present a high reliability as indicated by the high R^2 and low p-value and the average percentage difference between real and modeled EPIs is lower than 16% for the complete cycle and 20% for the partial cycle (Table 3). Figure 3 shows an example of modeled and real EPIs as a function of site production.

For a direct comparison with the reference values reported in Section 3 average EPIs have been also calculated and included in Table 4. Comparing the results obtained from the analysis in terms of average global final energy consumption it can be seen that they are not very different from those present in scientific literature.

However additional insights related to primary energy savings can be obtained analyzing the percentage of self-produced energy in the site.

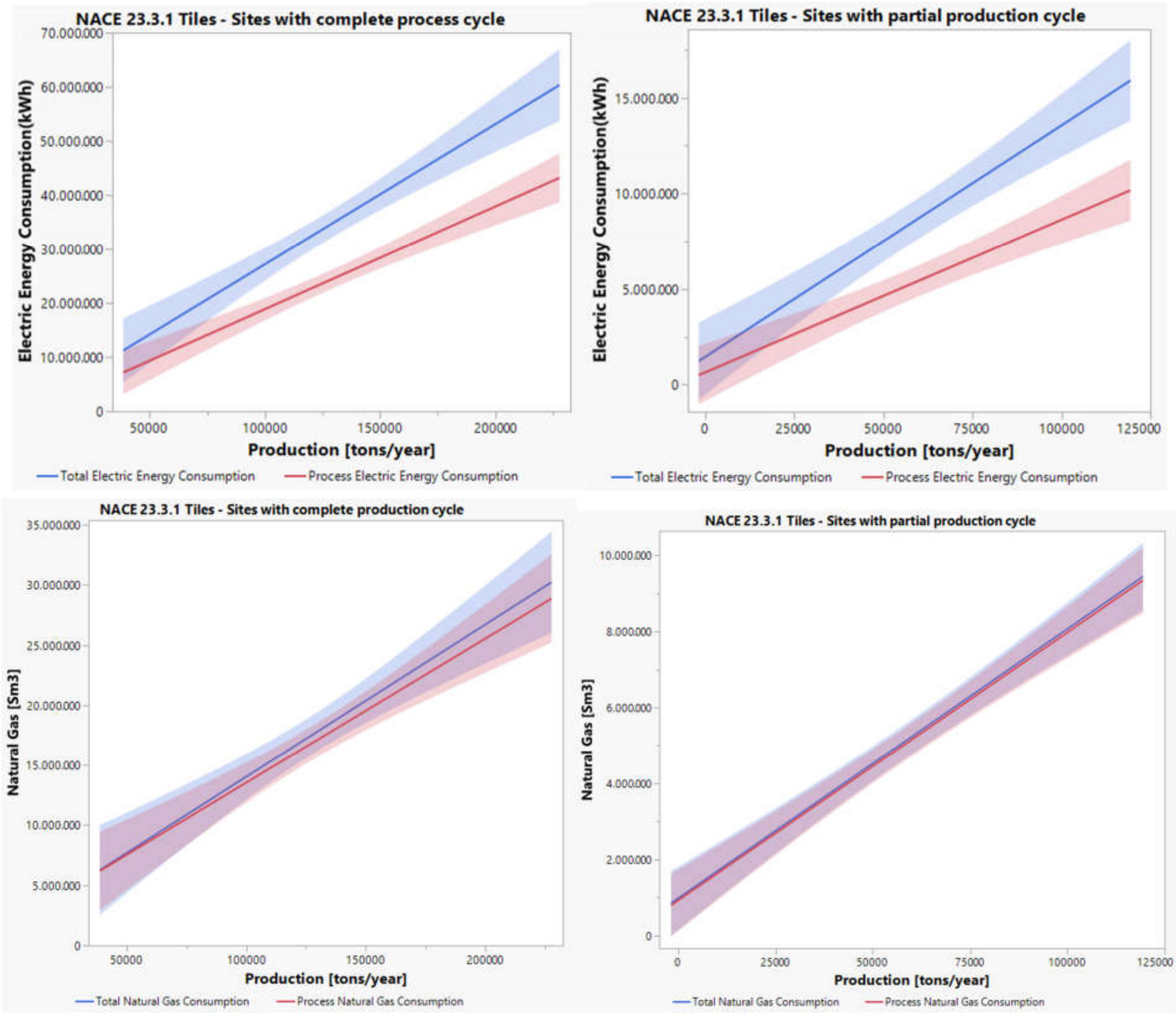

Figure 2 NACE 23.3.1: Energy consumption vs Production regression lines

Table 1 NACE 23.3.1 model parameters for total energy consumption (electric energy, thermal energy and global energy)

NACE	Energy	Equation	R^2	P_{value}	EPI model reliability
23.3.1.CC	**EE [kWh]**	1.224.509+ 259**p [tons]*	0,799	<0,0001	HIGH
23.3.1.PC		1.462.964 + 121**p[tons]*	0,924	<0,0001	HIGH
23.3.1.CC	**Eth[Sm³]**	1.378.264 + 127**p[tons]*	0,704	<0,0001	HIGH
23.3.1.PC		980.448 + 71**p[tons]*	0,924	<0,0001	HIGH
23.3.1.CC	**Eg[toe]**	1.529+ 0,164**p[tons]*	0,795	<0,0001	HIGH
23.3.1.PC		1.102+ 0,082**p[tons]*	0,922	<0,0001	HIGH

Table 2 NACE 23.3.1 model parameters for process energy consumption (electric energy, thermal energy and global energy)

NACE	Energy	Equation	R^2	P_{value}	EPI model reliability
23.3.1.CC	EE [kWh]	-179.390+ 190* *p [tons]*	0,823	<0,0001	HIGH
23.3.1.PC		653.302+80* *p [tons]*	0,83	<0,0001	HIGH
23.3.1.CC	Eth[Sm^3]	1.564.146 + 120* *p [tons]*	0,743	<0,0001	HIGH
23.3.1.PC		924.162+71* *p [tons]*	0,926	<0,0001	HIGH

Table 3 NACE 23.3.1 Average percentage difference between EPIs model and real data

EPI	Cycle	Average Δ[%] EPI Model vs Real
EPI_{el}	Complete	14%
	Partial	20%
EPI_{th}	Complete	16%
	Partial	13%

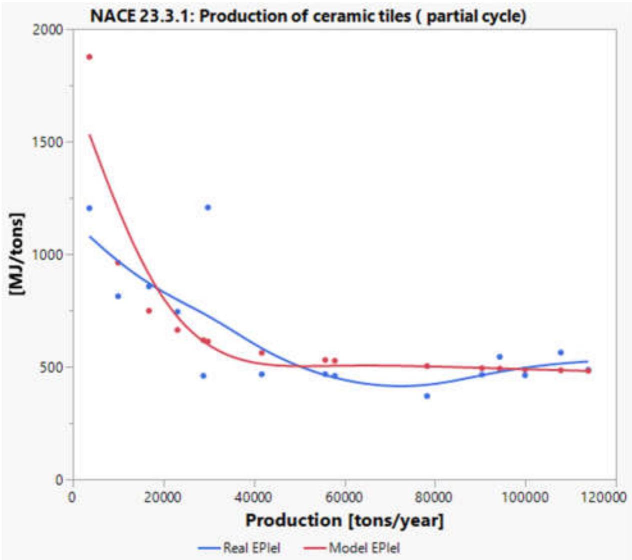

Figure 3 NACE 23.3.1: Real vs Model EPI_{el}

Table 4 NACE 23.3.1 Average EPIs

NACE 23.3.1 : Production of ceramic tiles					
Sites with complete process cycle			Sites with partial process cycle		
Production range		EPI_{el}	Production range		EPI_{el}
Min	Max		Min	Max	
[tons/year]	[tons/year]	kWh/tons	[tons/year]	[tons/year]	[kWh/tons]
45.000	≤105.000	322±46,8	3.500	≤42.000	244,6±79,7
>105.000	220.000	261±34,8	>42.000	115.000	132,2±15,3

Production range		**EPI_{th}**	**Production range**		**EPI_{th}**
Min	**Max**		**Min**	**Max**	
[tons/year]	**[tons/year]**	**MJ/tons**	**[tons/year]**	**[tons/year]**	**[MJ/tons]**
45.000	220.000	5.301±969	10.000	115.000	3.004±313
Production range		**EPI_g**	**Production range**		**EPI_g**
Min	**Max**		**Min**	**Max**	
[tons/year]	**[tons/year]**	**toe/tons**	**[tons/year]**	**[tons/year]**	**[toe/tons]**
45.000	≤145.000	0,18±0,033	3.500	≤42.000	0,153±0,047
>145.000	220.000	0,16±0,014	>42.000	115.000	0,0947±0,007

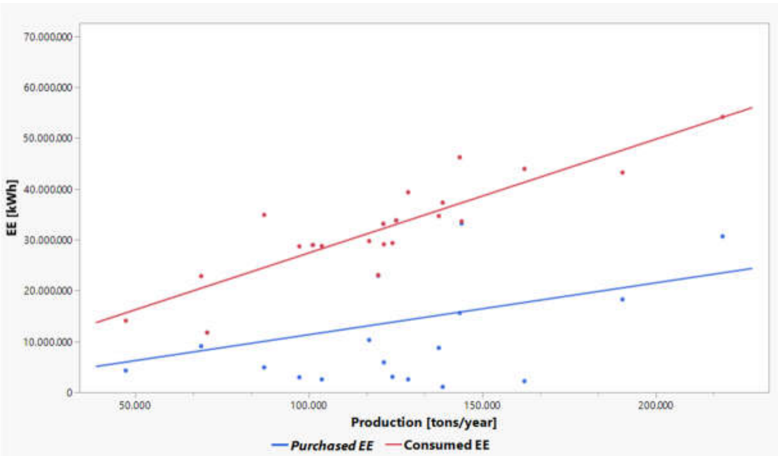

Figure 4 NACE 23.3.1 Complete Cycle: consumed and purchased Electrical Energy vs Production

In Figure 4 consumed and purcheased electrical energy for complete cycle production sites is shown. Almost 50% of electrical energy is self-produced on these sites as a demonstration of the fact that the strategy implemented by the sector in the last years mainly concerned the reduction of primary energy consumption by applying cogeneration/combined heat and power plants. A comprehensive analysis of the benefits of using combined heat and power (CHP) systems in the ceramic manufacturing sector has been presented by authors in [14].

5.3 Ceramic bricks

The dataset used for the analysis consists of 53 energy audits belonging to 44 companies. For the calculation of the EPIs, only 46 energy audits were considered. Of the 53 sent, one had non-congruent units and the others were considered outliers with respect to energy consumption.
The obtained regression lines for electrical energy and natural gas are presented in Figure 4.

Both total energy consumption and process energy consumption are represented for each energy vector.

The electrical energy consumption is attributable, on the average, for about 84,5% to the production process while auxiliary (compressed air system, pumping etc) and general services (lighting, air conditioning etc) account for 9,4% and 6,1% respectively.

The natural gas used for the process represents 86% of the total gas used on the sites analyzed.

The EPIs model parameters evaluated are reported in Table 5 and Table 6. Regression lines obtained present a high reliability as indicated by the high R^2 and low p-value and the average percentage difference between real and modeled EPIs is lower than 24% (Table 7).

For a direct comparison with the reference values reported in Section 3 average EPIs have been also calculated and included in Table 8. Average values are within the reference range however, with this analysis it was possible to define specific values as a function of the production range.

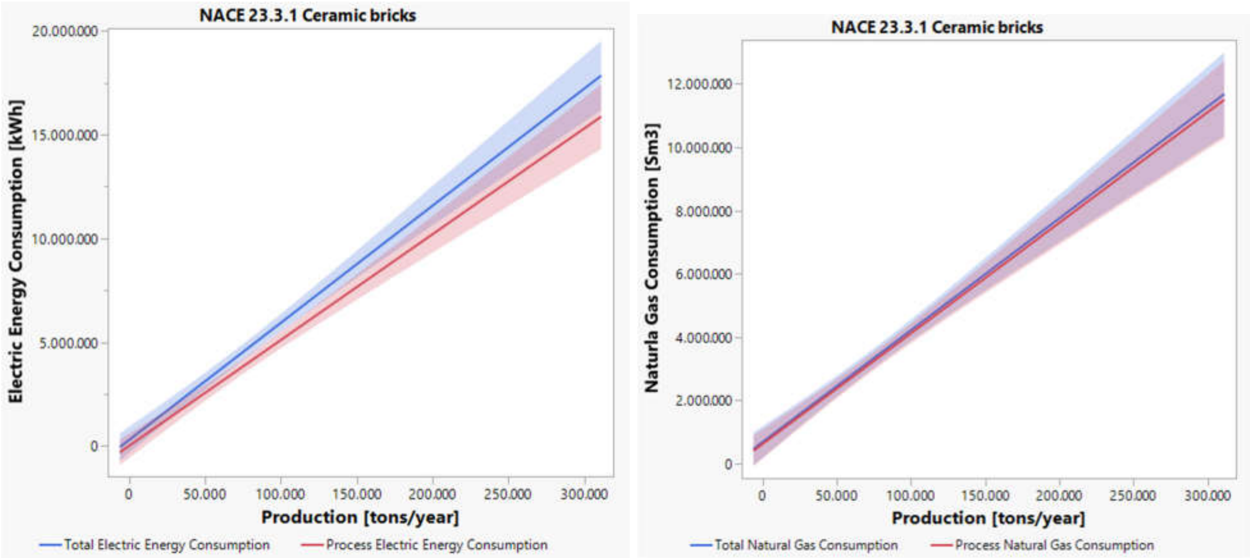

Figure 4 NACE 23.3.2: Energy consumption vs Production regression lines

Table 5 NACE 23.3.2 model parameters for total energy consumption (electric energy, thermal energy and global energy)

NACE	Energy	Equation	R^2	P_{value}	EPImodel reliability
23.3.2	**EE [kWh]**	293.645 + 56,4* *p [tons]*	0,87	<0,0001	HIGH
23.3.2	**Eth[Sm^3]**	676.247 + 35,38* *p [tons]*	0,9	<0,0001	HIGH
23.3.2	**Eg[toe]**	110 + 0,048* *p [tons]*	0,839	<0,0001	HIGH

Table 6 NACE 23..3.2 model parameters for process energy consumption (electric energy, thermal energy and global energy)

NACE	Energy	Equation	R^2	P_{value}	EPI model reliability
23.3.2	**EE [kWh]**	8.834+51* *p [tons]*	0,86	<0,0001	HIGH
23.3.2	**Eth[Sm^3]**	616.722 + 34,9* *p [tons]*	0,83	<0,0001	HIGH

Table 7 NACE 23.3.1 Average percentage difference between EPI model and real data

EPI	Average Δ[%] EPI Model vs Real
EPI_{el}	24%
EPI_{th}	23%

Table 6 NACE 23.3.2 Average EPIs

NACE 23.3.2: Production of ceramic bricks		
Production range		EPI_{el}
Min	**Max**	
[tons/year]	**[tons/year]**	**[kWh/tons]**
8.000	≤25.000	107±20
>25.000	300.000	61±18
Production range		EPI_{th}
Min	**Max**	
[tons/year]	**[tons/year]**	**[MJ/tons]**
8.000	≤45.000	2.328±540
>45.000	300.000	1.679±409
Production range		EPI_{g}
Min	**Max**	
[tons/year]	**[tons/year]**	**[toe/tons]**
8.000	≤45.000	0,067±0,02
>45.000	300.000	0,047±0,015

Conclusions

The analysis carried out represents the most important update of the EPI values in the Italian ceramic sector after the publication of the BREf in 2007. The data evaluated relate to energy audits drawn up by certified professionals (Energy Auditor and ESCos) and are the results of the application of reliable energy consumption monitoring plans. The analysis is therefore based on monitored and certified actual data.

Energy sources used in the ceramic processes analysed are mainly natural gas and electricity, with roughly 75% and 79% of the energy consumption credited to gas respectively for ceramic tiles and bricks manufacturing.

The values of the EPIs obtained and the analysed energy audits do not show us great differences in terms of average global energy consumption in the sectors compared to those reported in the literature previously. The production processes have not obtained significant improvements compared to the past, also because very probably a considerable technological maturity has already been reached in the ceramic sector and it is difficult to achieve further improvement in the process energy consumption.

Nevertheless, it is important to point out the attention of the sector towards the reduction of the purchased energy in their production sites in favor of self-production, through cogeneration, of electricity and thermal energy. Therefore, in terms of primary energy consumed, there has been a progressive improvement in the sector, which covers its energy consumption with increasing percentages of self-production of energy in situ

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