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Developing key performance indicators for monitoring sustainability in the ceramic industry: The role of digitalization and industry 4.0 technologies

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ABSTRACT

This research explores the importance of sustainability in the ceramic industry, focusing on how companies measure and monitor their sustainability indicators. Economic crises and climate change have led scholars over the years to focus their attention on reducing impacts and monitoring sustainability indicators with particular attention to the energy sphere. In the scientific literature it emerges that there is no set of indicators for the ceramic industries suitable for monitoring company data. To address this emerging gap, the paper takes a ceramic company as a reference and proposes a set of key performance indicators (KPIs) to help manufacturing companies monitor their economic, environmental, and social sustainability performance. The study aims to fill these gaps by underlining the importance of investing in the digitization of processes and in Industry 4.0 digital technologies to obtain constantly updated and real-time information for sustainability monitoring. The research also emphasizes the applicability of these findings to other manufacturing enterprises, offering a methodology for self-monitoring sustainability. The article suggests the development of a "Sustainability Digital Twin" as a tool to help business managers make informed decisions and design products with all aspects of sustainability in mind. The integration of sustainability and digitization is highlighted as a crucial aspect for achieving sustainable ceramic production. The proposed KPIs and the digitization of processes can provide data to implement strategic plans for sustainable production. Therefore, this study has contributed to fill the gaps in the literature by demonstrating that the digitization of production processes allows for a more specific assessment of economic, social and environmental impacts by ensuring transparent communication of performance to stakeholders.

1. Introduction

1.1. Introduction to sustainability

The term "sustainability" has its roots in the Latin word "*sustinere*", which denotes actions related to support, conservation, and care (Kidd, 1992). The modern concept of sustainability emerged during the 1980s and was formally introduced in the report "Our Common Future", published by the United Nations Program for the Environment's World Commission on Environment and Development in 1987 (United Nations, 1987). At the Rio de Janeiro Conference on Environment and Development in 1992, world leaders convened to address emerging environmental issues at a global level. At this conference, the concept of sustainable development was established as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Secretary-General and Development, 1987). This conference also led to the creation of Agenda 21, which emphasized the importance of countries' commitment to solving socio-environmental problems (Barcena, 1992). The objective was to monitor environmental progress and develop standards that could enhance quality of life while preserving the environment, thus strengthening the integration between social, economic, and environmental dimensions. Subsequently, the term sustainability has been incorporated into various contexts, including the industrial sphere.

In the present context, it is crucial to have indicators that can effectively monitor the performance of a company. These indicators, known as Key Performance Indicators (KPIs), can pertain to diverse domains, such as economics, social aspects, and the environment (Elkington, 1998). They enable the provision of a significant and comprehensible outcome, which can aid in the evaluation of the overall progress of corporate sustainability. This information is indispensable not only for the top management of the organization, but also for all its

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stakeholders. However, the limitations of the current approaches to sustainability performance evaluation underscore a significant research and practice gap, highlighting an urgent need for the development and implementation of new frameworks, methodologies, and tools (Wicher et al., 2019).

1.2. Role of sustainability in industry – Michael Porter

Scholars suggest that Industry 5.0, the newest industrial paradigm, has the potential to transcend the profit-oriented productivity of Industry 4.0 and promote sustainable development goals, including human-centricity, socio-environmental sustainability, and resilience (Ghobakhloo et al., 2022). Thus, the concept of sustainability is increasingly associated with the industrial sector (Demir and Cicibas, 2017) (Ghobakhloo et al., 2022).

Michael Porter, a pioneer of managerial strategy, was the first to introduce the concept of "sustainability" in an industrial context. He argues that many companies narrowly focus on creating value and optimizing short-term financial performance, disregarding the most critical customer needs and ignoring the broader determinants of long-term success (Porter and Kramer, 2019). Porter's key idea is that investing in sustainable planning (environmental, social, and economic) in companies can provide an economic return in the short term. His primary goals are to enable companies to create a competitive advantage and play a leading role in bringing together business and society (see Fig. 1).

According to the theory of strategy, for a company to achieve success, it must create a unique value proposition that caters to the requirements of a specific group of customers. The organization obtains a competitive edge by configuring its value chain, which encompasses the series of activities involved in the generation, production, distribution, sales, and support of its goods or services. This value chain configuration enables the firm to differentiate itself from its competitors and create value for its customers, thereby enhancing its chances of success in the market (Porter and Kramer, 2019).

Porter's "Principle of Shared Value" suggests that companies should link corporate success to social progress by creating economic value for society (Porter and Kramer, 2019). By implementing this concept, companies can recognize social damages or weaknesses (pollution, unsafe working environment, waste of resources, workplace accidents, etc.), which can often create internal costs such as waste of energy or raw materials, costly accidents, and the need for corrective training to compensate for inadequacies in instruction. Porter contends that the success of a company depends on three tools that companies should incorporate into their strategic plan: digitization, sustainability, and the circular economy, which are defined as the levers of competitive advantage and value creation ("Strategy and society," 2007). With these drivers and the spread of Covid-19, there has been a recent increase in investments towards digitization and sustainability. The COVID-19 pandemic has emphasized the need for sustainable investing in companies, as investors increasingly recognize the impact of environmental, social, and governance (ESG) factors on corporate performance and long-term value creation (Weiwei Mo et al., n.d.). The COVID-19 pandemic had a substantial impact on ceramic companies in 2020, resulting in an estimated loss of around 350 million in revenue ("Industria ceramica, perdite da 350 milioni a causa del Covid-19," n.d.). The health crisis affected the sector significantly, leading to a substantial decline in sales of approximately −20% ("Confindustria Ceramica: il Covid rallenta il settore, che però regge meglio di altri," n.d.). However, in 2021, the industry witnessed a significant surge in turnover, growing from 2.6 million euros to approximately 3.5 million euros, representing an increase of +35.97%. This growth allowed for a recovery from the pandemic-induced decline and contributed a significant portion of growth. Sustainable investments played a crucial role in overcoming the crisis, as companies realized that technological innovation, product evolution, and environmentally sustainable practices, with pollution levels below legal limits, can be combined to achieve success ("Ceramica sostenibile," n.d.).

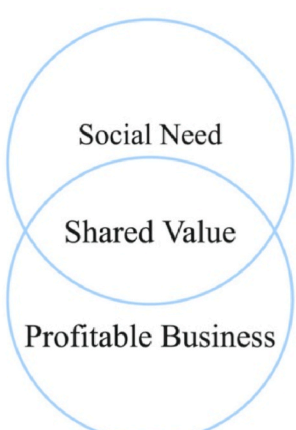

Fig. 1. Shared value concept.

As a result, there has been a significant shift towards sustainable investing, with funds outperforming traditional funds in many cases. In Europe, the Green Deal Investment Plan finances public, and private investments to support the transition towards a climate-neutral, sustainable, and circular economy ("The green deal – just transition and sustainable development goals Nexus | Elsevier Enhanced Reader," n.d.). In particular, the European Green Deal is a package of strategic initiatives that aims to start the EU on the road to a green transition, with the ultimate goal of achieving climate neutrality by 2050. In Italy, the PNRR (Piano Nazionale di Ripresa e Resilienza) seeks to promote economic recovery and resilience following the pandemic. The plan provides for various investments to implement digital innovation and sustainability tools, such as energy efficiency, renewable energy, circular economy, sustainable mobility, and nature-based solutions ("Piano Nazionale di Ripresa e Resilienza," n.d.). Therefore, the PNRR can be considered part of investments in industrial sustainability, as it includes various measures aimed at promoting sustainable development and reducing environmental and social risks. Through this type of financing, it is possible to incentivize and implement sustainable operations to create shared value.

1.3. Digitization and sustainability

Digitalization can play a key role in promoting sustainability in industries by enabling more efficient use of economic, environmental, and social resources. Digitization can ensure efficient communication, integration and ultimately balance between production, transmission, and consumption. There are several ways in which digitalization can contribute to sustainability in industries, for example through resource efficiency, circular economy, environmental monitoring, supply chain and waste management (Antikainen et al., 2018). The digital transition towards sustainability is gaining importance in the manufacturing sector, particularly for industries that consume high resources and energy (García-Muiña et al., 2020). Companies are adopting diverse sustainability practices and investing in Industry 4.0 technologies, including the Internet of Things (IoT), artificial intelligence, and big data analytics, to conduct impact assessments of their production processes. The aim is to create smart factories with greater automation, efficiency, and productivity, and it is precisely the concept of "pervasiveness" that links digitalization to sustainability.

Environmental monitoring is one of the crucial parameters that companies should consider when analysing the impacts, they generate. Among these parameters, energy is a specific aspect that many companies are paying increasing attention to (Muthukannan, 2019). Carbon emissions and energy costs are significant concerns for Italian industry, and their management plays a critical role in improving company performance. To calculate this parameter with a view to improving company performance, the company must provide data that enables its monitoring. A successful company should be guided by data, which should lead to defined results and be connected to the objectives of all interested parties, while being monitored with clear metrics. Therefore, a system that constantly monitors these parameters is necessary. Digitalization can be a tool that helps industries verify data, which, once analyzed, allows the reduction of economic, environmental, and social impacts.

1.4. Role of digitization in the company

The advent of digital technologies has facilitated data collection, leading to a more efficient measurement of indicators. Defining data consistently and completely makes software implementation easier and ensures reliable decision-making information. It is crucial to document measurement details to ensure consistent calculation and presentation of results in the reporting period. This is necessary to obtain meaningful analyses and conclusions on indicator performance. Within the framework of Industry 4.0, the Digital-Twin is pivotal in enabling efficient and collaborative production processes.

Based on this premise, innovative digital tools that can measure, manage, and communicate company data are essential to mitigate industrial impacts. Measuring is crucial to understanding the current state of the company and making decisions that enhance future performance (Contini and Peruzzini, 2022).

The fundamental principle behind this concept can be summarized as *"Realizing to Realize"*. To realize this, an internal corporate awareness must be built that translates sustainability efforts into a value or datum. This must guide internal governance, future decisions, and corporate reputation. The concept of measurement must be integrated with a strategy that interprets present data to provide clear future targets. This fosters a converging vision in strategic terms towards the true definition of sustainability. Digital tools enable companies to self-evaluate and acquire greater awareness (*"realize"*).

Once sufficient self-analysis is achieved, each company can manage and leverage the vast amount of data produced. The data collection, its history, the responsibility of the person who took the measurement, and the measuring instrument must be stored and documented. In medium- to long-term performance analyses, detecting anomalies or improvements precisely in the face of well-historicized and documented variations is critical.

1.5. Ceramic company

The district of Sassuolo, located in the provinces of Modena and Reggio Emilia in northern Italy, is one of the primary industrial districts that produces ceramics, with most of the mechanical ceramic manufacturing companies concentrated in this area, 300 companies with 18,000 employees (Bianchetti and Cerruti But, 2016). This region has made significant progress in the field of environmental sustainability, with efficient processes, excellent material, water and packaging recovery performance, and robust recycling activities (Mosconi, 2017). Italy is one of the world's most industrialized and technologically advanced countries in the manufacturing sector, with demonstrated implementation of Industry 4.0 paradigms for the digitization of production (Bortolini et al., 2017). In this context, the Sassuolo district represents one of the best practices in Europe for digitization of industrial processes and management of industrial environmental sustainability (Mattioli, 2019) (Da Ronch et al., 2013). The case study focuses on a multinational company that produces ceramics and is a world leader in the production of machinery for the ceramic sector. The ceramic industry is energy and resource intensive, making it necessary to identify and implement solutions to reduce its environmental, economic, and social impacts (Ferrari et al., 2021).

The present study focuses on analyzing a particular industrial production sector, recognized as one of the most energy-intensive in Italy. However, this research goes beyond providing a set of sustainability indicators exclusively for ceramic companies. It introduces a methodology that enables companies from diverse industrial sectors to select and implement specific sustainability performance indicators tailored to their production processes.

The selected indicators, identified as KPIs, possess applicability across various industrial manufacturing sectors. These indicators can be adapted to suit specific business cases. For instance, metrics such as: "quantity of material," "transport," and "raw material cost" are suitable indicators applicable to a wide range of industries. The ceramics industry is recognized for its energy-intensive processes, such as high-temperature firing, material handling, mixing, and molding, which require significant amounts of energy (Ferrari et al., 2021). The industry's use of raw materials, including clay, feldspar, and quartz, also contributes to its high energy intensity. Moreover, the production of ceramics often involves the use of fossil fuels, which further exacerbates its energy intensity and greenhouse gas emissions. As a result, energy management is critical for this sector, which holds a prominent role in Italian industry (Ancona et al., 2022). The ceramics industry is facing significant challenges due to the ongoing COVID-19 pandemic, which has disrupted the global economy and affected its future prospects. The sector's energy-intensive nature makes it particularly vulnerable to increases in energy commodity prices, particularly natural gas, and electricity, as well as increases in raw material costs. Such developments can have a profound impact on profit margins, particularly for sectors like ceramics, which are highly energy-intensive. This could have serious implications for the competitiveness of the industry and the wider Italian economy ("Ceramica, proposte a sostegno del settore," n.d.). Given its energy and resource intensity, the ceramics industry requires support to identify and implement sustainable solutions to reduce its environmental impact. While digitization is often seen as an aid to industry, it must be used judiciously to minimize the environmental impacts generated by energy-intensive industries like ceramics (Monteiro et al., 2022). Therefore, the integration of sustainability with digitization is fundamental. Only through the implementation of Industry 4.0 technologies, which enable the management and monitoring of corporate data, can we address the sustainability challenges facing the ceramics industry.

1.6. Global reporting initiative and sustainable development goals

An increasing number of companies are providing their financial and non-financial information to stakeholders through various reports. The "Sustainability Report" is the main report that includes aspects related to sustainability and has become a central element of every corporate sustainability strategy. This report allows organizations to highlight their economic, social, and environmental performance to stakeholders, and to set goals, measure performance, and manage change to make their operations more sustainable. Globally recognized standards are used to communicate this information and move towards the goal of sustainable development. The Global Reporting Initiative (GRI) developed the "Sustainability Reporting Guidelines" to systematically reveal the sustainability performance of organizations across economic, social, and environmental dimensions (Gümrah et al., 2019). According to ("Standard GRI," n.d.) GRI Standards are a set of standards that are designed to be used as a modular system. There are three different sets of standards that are used to support the reporting process. The first set is the GRI Universal Standards, which apply to all organizations regardless of their size, sector, or location. The second set is the GRI Sector Standards, which are specifically designed for targeted industries. The third set is the GRI Specific Standards, which list the relevant disclosures for a particular topic. By using these Standards to identify material topics, companies can effectively achieve sustainable development.

The demand for companies to do business in an ethical manner, and to be attentive to society, people, and the environment, is increasing among the European Union (EU), governments, international communities, and citizens. Legislative Decree 254/2016, which transposes the European Directive 2014/95/EU, obliges public interest entities to communicate their environmental and social performance ("Process Factory - Report di Sostenibilità," n.d.). The evolution of this directive will introduce a new regulatory system from 2024 to 2028, the Corporate Sustainability Reporting Directive (CSRD), which will require companies with a certain number of employees and turnover to report on their sustainability performance ("REPORT on the proposal for a Directive of the European Parliament and of the Council amending Directive 2013/34/EU, Directive 2004/109/EC, Directive 2006/43/EC and Regulation (EU) No 537/2014, as regards corporate sustainability reporting," n.d.). This is expected to reduce greenwashing, strengthen the EU social market economy, and lay the foundations for global sustainability transparency standards ("CSRD: da gennaio 2024 novità per le imprese Approvata la nuova Direttiva Europea sulla comunicazione della sostenibilità," n.d.).

Apart from European directives, other external forces have also led to an increase in demand for sustainability performance from companies. The New York agreement of 2015 led to the definition of the 2030 Agenda for Sustainable Development, with 17 Sustainable Development Goals (SDGs) incorporated into a major action program for a total of 169 targets. These SDGs provide a universally valid reference, and all countries must take steps to achieve them, each according to their own capabilities. The Global Compact, the largest international corporate sustainability initiative, includes these 17 targets and acts as a catalyst for future changes to be supported in the private sector to achieve the SDGs by 2030.

The remaining of this paper is organized as follows: Section 2 describes the method used to select companies and collect data, Section 3 presents the results of the analysis, Section 4 discusses the results achieved and the construction of the digital system, and Section 5 discusses the contribution of this study and its possible applications.

2. Material and methods

In this paper one of the primary objectives is to develop intelligent and advanced monitoring and warning systems to prevent potential harmful conditions in specific company areas. However, to monitor these areas, it is essential to measure them qualitatively and quantitatively using specific indicators and metrics. Therefore, we propose a set of sustainability performance indicators for companies that produce ceramics. To achieve this, monitoring systems that can keep the data constantly monitored and updated are required. Thanks to digitization and the implementation of new technologies for Industry 4.0, this is now possible. Finally, we demonstrate the applicability of this methodology by presenting a case study of a ceramic company.

This article aims to fill the research gap by defining a set of key performance indicators for ceramic industries connected to a monitoring system that exploits digital technologies. This will allow for timely and non-retroactive decision-making by the company. We address the following research questions in this article:

1. How do ceramic industries measure their sustainability indicators?
2. How can technology help to have real-time and constantly updated data?
3. What technologies are available today for viewing and using company data?

2.1. Background

The primary objective of this research is to develop a framework for sustainability assessment using Industry 4.0 digital technologies. With digitization, data collection and entry can be automated, and data can be collected in real-time and constantly updated. To collect such data, parameters, indicators, and metrics that can measure company data in a qualitative and quantitative way must be defined. This study focuses on defining key performance indicators for measuring sustainability in the economic, social, and environmental domains of a specific industrial sector. The sustainability indicators framework was developed using an Italian company in the ceramic sector, which is one of the most energy-intensive industrial sectors for production. Ceramic production has a long history in Italy and has been an important industry for centuries, particularly in the Emilia-Romagna Region. The ceramic sector has seen a significant increase in investments in digitization and sustainability initiatives. Energy is a critical component of ceramic production, and the kiln is the primary tool used in the industrial process (Ferrari et al., 2021). The high cost and limited availability of energy due to the crisis in Ukraine have made it essential for companies to monitor and implement sustainability initiatives to reduce their impact (Klimczak, 2015). Sustainability is an essential aspect of the Italian ceramic industry, which distinguishes it from its international competitors (Ferrari et al., 2019). Several companies have started integrating sustainability concepts into their corporate business. To achieve this, self-monitoring is necessary.

2.2. Case study

To ensure the practical and objective implications of this study, an Italian company from the ceramic sector was selected as a reference. The case-study company, a global leader in the production of automatic machines and complete systems with a focus on the ceramic industry, was chosen to conduct an in-depth and accurate analysis.

The ceramic industry is a highly technological sector that specializes in the design and manufacture of machinery and complete plants for the production of tiles, sanitary ware, tableware, refractories, special and technical ceramics. The advanced technological features of these supplies represent a distinctive trait, which establishes the company as a primary technological partner for the ceramic industry. The use of cutting-edge technologies enables the progressive replacement of manual processes with automated production processes, not only in traditionally advanced markets but throughout the global landscape. In recent years, significant efforts have been devoted to extending Industry 4.0 methodologies and processes to all phases of the ceramic production line. These processes aim to deliver machines and plants that are competitive in terms of efficiency, costs, flexibility, and production quality, while reducing energy consumption and environmental impact. The production of ceramic tiles is a complex process that comprises several sub-processes and stages. Fig. 2 depicts a diagram that facilitates the understanding and connection of the various production phases. In the first phase, the raw materials of the ceramic compound are transported to the company and stored in the warehouse. Before being ground in the mills, the raw materials are sent to the specific body preparation department. During grinding, water is added to the raw material, resulting in a compound known as "slip." This compound is then sent to the atomizer, which sprays the slip using the flow of hot air, causing the water to evaporate. Once the right composition of the powder has been obtained, it is taken to the next stage, where it is pressed to compact the powder and create the desired shapes. In the subsequent phase, the tile is dried again to eliminate any residual water. The tile is then glazed, decorated, and annealed to consolidate and sinter the support and the tile glaze. Once the final product has been obtained, it is taken to the sorting line, which checks and performs a visual sorting and packaging of the product. Finally, the product is sold, distributed, and installed by end customers. The last phase concerns the end-of-life management of the product, which involves disposal or recycling of the materials used (Garcia-Muiña et al., 2018).

The case study company is involved in both the manufacturing of tiles and the supply of machines for producing finished products

Fig. 2. Manufacturing ceramic process.

(automatic machines). Thus, the suppliers and customers of the reference company have been included in the analysis to obtain a comprehensive overview of how ceramic companies monitor themselves in terms of sustainability.

Through this analysis, it will be possible to gain a complete overview of how the main ceramic companies monitor themselves in terms of sustainability to date.

The selected company is currently implementing Industry 4.0 principles to digitize its processes and has initiated data monitoring to facilitate sustainability reporting (for example innovations aimed at optimizing and maximizing the efficiency of the entire process, from the automatic management of the loading of raw materials, of the dosage of the recipe up to the loading of the powders in the storage silos). Within its production process, the company is currently integrating digital technologies in accordance with the principles of Industry 4.0. It has initiated data monitoring to enable the reporting of sustainability efforts. For instance, the company has implemented innovations aimed at optimizing and maximizing the efficiency of the entire process. These innovations encompass automated management of raw material loading, recipe dosing, and loading of powders into storage silos.

2.3. Research

Numerous studies have revealed that the ceramic sector is an energy-intensive process (Martini et al., 2021), (Mezquita et al., 2017). Therefore, the current study aims to investigate ways to enhance the sustainability of the entire process. To achieve this objective, it is essential to comprehend how companies in this sector are monitoring themselves in terms of sustainability, and only quantitative and qualitative data can facilitate informed decisions and improve company performance. Thus, the analysis of company data is crucial to understand how to enhance the most common critical aspects of ceramic manufacturing companies.

The first phase involved the application of inferential methods, establishing a specialized team in the field of sustainability. This team was composed of two corporate managers, a sustainability specialist, and two experienced academic researchers in sustainability. The purpose of this team was to structure the entire selection process.

The first part of the research involved identifying the companies to be analyzed. Specifically, as the primary business of the Italian multinational company chosen for the study is ceramics, it was deemed crucial to verticalize the research by incorporating other companies in the supply chain of this business. This methodology provided a broader perspective about ceramic companies in Italy. In this way, the suppliers and customers of the company were included in the analysis, and a total of 33 companies were identified and analyzed. Various parameters were used to classify the companies, and 32 ceramic companies, in addition to the main one, were selected, as shown in Table 1.

Subsequently, it was determined how these companies monitor themselves in terms of sustainability. Specifically, it was crucial to determine whether they prepare sustainability reports, which are the only official documents with which companies can demonstrate their sustainability practices. The analysis compared various metrics, including the identification of client or supplier companies associated with the case study company, business group, sustainability report preparation, KPI and GRI measurements and financial statement information, methodological note, highlights, the letter from the chairman/letter to stakeholders, materiality matrix, KPI/GRI table, reporting perimeter, extra documents, number of pages, and language. After obtaining the required information, companies that currently present a sustainability report or a monitoring system with specific indicators were selected. Based on this analysis, seven companies were taken as a reference. From these companies, the selection of indicators declared in their respective published sustainability reports or made available online will occur.

In order to define this set of indicators useful not only to ceramic companies but also to any manufacturing company wishing to begin monitoring sustainability, a team of highly qualified individuals was chosen (composed of two corporate managers, a sustainability specialist, and two experienced academic researchers in sustainability) to carry out a thorough identification and selection of indicators declared by the companies. The team underwent several workshop sessions and interviews, which enabled the selection of KPIs.

As depicted in Fig. 3, once the specific KPIs for each company were identified, it was decided to name the KPIs that were referred to slightly differently by the respective companies (but fundamentally corresponded to the same indicator) in the same manner. This approach allowed for the identification of all the present KPIs without any repetitions or similar denominations. All the KPIs were then classified according to the three sustainability areas (economic, environmental, and social). To provide a simpler view of the selected indicators, macro-categories were defined to simplify the analyzed area, and subcategories were established to provide more detailed specifications for the indicator to be calculated. Finally, metrics were identified for all the indicators to enable mathematical and/or quantum calculation of the KPI (Neri et al., 2021) (Ferrari et al., 2019).

3. Results

The objective of this article is to establish a comprehensive set of performance indicators that can be used to monitor various sustainability parameters in the ceramic sector. However, the relevance of these data extends beyond the industrial sector alone. The information can

Table 1
Ceramic Companies belonging to the company's supply-chain case study selected for analysis.

Company	Group	Supplier/ Customer	Sustainability Report	Note	Measure with KPIs	GRI	Methodological note	Highlights	Letter from president	Letter to Stakeholders	Materiality matrix	KPI GRI table	Perimeter	Extra documents	Number of pages	Writing language
Company 1	/	Customer	No	/	/	/	/	/	/	/	/	/	/	/	/	/
Company 2	/	Customer	No	Environmental Statement 2019	/	/	/	Yes	/	/	/	/	/	/	16	Italian
Company 3	/	Customer	No	/	/	/	/	/	/	/	/	/	/	/	/	/
Company 4	/	Customer	No	/	/	/	/	/	/	/	/	/	/	/	/	/
Company 5	/	Customer	No	/	/	/	/	/	/	/	/	/	/	/	/	/
Company 6	/	Customer	No	/	/	/	/	/	/	/	/	/	/	/	/	/
Company 7	/	Customer	No	/	/	/	/	/	/	/	/	/	/	/	/	/
Company 8	/	Customer	No	/	/	/	/	/	/	/	/	/	/	/	/	/
Company 9	/	Customer	No	/	/	/	/	/	/	/	/	/	/	/	/	/
Company 10	/	Customer	No	/	/	/	/	/	/	/	/	/	/	/	/	/
Company 11	/	Customer	Yes	Year 2021	Yes	Yes	Yes	Yes	Integrated to the Letter to stakeholders	Yes	Yes	Yes	Group	/	86	Italian
Company 12	/	Customer	No	/	/	/	/	/	/	/	/	/	/	/	/	/
Company 13	/	Customer	No	/	/	/	/	/	/	/	/	/	/	/	/	/
Company 14	/	Customer	No	Environmental Declaration 2021	/	/	/	/	/	/	/	/	/	/	/	/
Company 15	/	Customer	No	Corporate Policy	/	/	/	/	/	/	/	/	/	/	/	/
Company 16	/	Customer	Yes	Year 2018	Yes	Yes	Yes	/	Integrated to the Letter to stakeholders	Yes	/	Yes	Group and consolidated companies	/	36	Italian
Company 17	/	Supplier	No	/	/	/	/	/	/	/	/	/	/	/	/	/
Company 18	/	Customer	Yes	2021	Yes	Yes	/	Yes	Yes	/	Yes	/	/	/	17	Italian
Company 19	/	Supplier	Yes	Year 2021	Yes	Yes	Yes	Yes	Integrated to the Letter to stakeholders	Yes	Yes	Yes	/	/	64	English
Company 20	/	Customer	Yes	Year 2021	Yes	Yes	Yes	Yes	Integrated to the Letter to stakeholders	Yes	/	Yes	Entire supply chain	/	39	Italian
Company 21	/	Supplier	No	/	/	/	/	/	/	/	/	/	/	/	/	/
Company 22	/	/	No	/	/	/	/	/	/	/	/	/	/	/	/	/
Company 23	/	Supplier	Yes	Year 2021	Yes	Yes	Yes	Yes	/	Yes	Yes	Yes	Italian companies of the Group	/	58	Italian
Company 24	/	Customer	No	EPD 2018	Yes	/	/	/	/	/	/	/	/	/	19	Italian
Company 25	/	Customer	No	/	/	/	/	/	/	/	/	/	/	/	/	/
Company 26	/	Customer	No	/	/	/	/	/	/	/	/	/	/	/	/	/
Company 27	Yes	Customer	No	/	/	/	/	/	/	/	/	/	/	/	/	/

(*continued on next page*)

Table 1 (*continued*)

Company	Group	Supplier/ Customer	Sustainability Report	Note	Measure with KPIs	GRI	Methodological note	Highlights	Letter from president	Letter to Stakeholders	Materiality matrix	KPI GRI table	Perimeter	Extra documents	Number of pages	Writing language
Company 28	/	Customer	Yes	Year 2021	Yes	Yes	Yes	Yes	Integrated to the Letter to stakeholders	Yes	Yes	Yes	Economic-financial information - Consolidated financial statements	/	100	Italian
Company 29	/	Customer	No	/	/	/	/	/	/	/	/	/	/	/	/	/
Company 30	Yes	Supplier	No	2020 Consolidated and statutory financial statements - 2021 Financial report	/	/	/	/	/	/	/	/	/	/	/	/
Company 31	/	Supplier	No	/	/	/	/	/	/	/	/	/	/	/	/	/
Company 32	Yes	Supplier	No	/	/	/	/	/	/	/	/	/	/	/	/	/
Company Case Study	/	/	Yes	/	Yes	Yes	Yes	/	Yes	Yes	/	Yes	Group and Imola	/	240	Italian and English

also prove valuable to various stakeholders, including policymakers, industrial technical promoters, company managers, and other interested parties. By utilizing this information, they can make strategic decisions that enhance corporate competitiveness and prioritize actions aimed at safeguarding the general population.

As discussed in earlier sections, the implementation of real-time monitoring technologies is crucial to achieve constant and reliable data updates. Therefore, incorporating digital technologies into production processes becomes imperative, ensuring enhanced accuracy of company parameters in terms of sustainability.

This article focuses on a case study involving seven supplier and customer companies, selected from a sample of 33 companies analyzed, that claim to utilize sustainability indicators. Table 2 presents the identification of the following aspects for each of the seven selected companies:

- The sustainability indicators used for monitoring (categorized into economic, environmental, and social indicators)
- The company topics in which they invest
- The Sustainable Development Goals (SDGs) to which they respond through the presented indicators

3.1. *Emerging gap*

After an initial analysis of the supply chain companies in the case study, those with sufficient data and information regarding company monitoring systems were selected for further analysis. However, only 7 out of 33 companies provided documents containing their company performance monitoring system on their sustainability report or website. This highlights the need to disseminate the importance of measuring oneself and having key indicators available for sustainability monitoring. To address this issue, a set of indicators was identified, selected, and disseminated to help ceramic companies monitor themselves. The identified indicators have been systematically classified and categorized based on the three dimensions of sustainability: economic, environmental, and social. The outcomes of this analysis are showcased in Table 2, which provides insights into the monitoring practices of each company and the indicators they employ. Upon examining the reported data, a notable observation is that several companies often conflate the distinction between indicators and the metrics used for their calculation. Consequently, this confusion generates significant challenges in effectively communicating the monitoring methodologies employed by each company. As a result, there is a pressing need to unambiguously define the specific indicators within each sustainability dimension, accompanied by their corresponding metrics, to facilitate accurate and consistent qualitative or quantitative calculations.

Furthermore, it has been observed that the majority of these companies do not yet have a structured sustainability plan in place that is capable of defining all the specific calculation parameters. Information and data are often unclear or not useful, and the presence of a company data monitoring system is often not mentioned in the documents.

The purpose of monitoring sustainability parameters is to obtain data and exploit it to the company’s advantage. However, not all companies seem to have understood this strategic possibility. To address this, specific metrics were presented in the article to respond quantitatively or qualitatively to the selected indicators.

3.2. *Results of the analysis*

Following an assessment of the existing knowledge and the identification of all the KPIs presented by the companies, the subsequent step involved the identification of indicators applicable to ceramic companies, irrespective of their size. The selection of indicators and their corresponding calculation metrics was carried out based on the KPIs provided by each analyzed company in their financial statements and/or

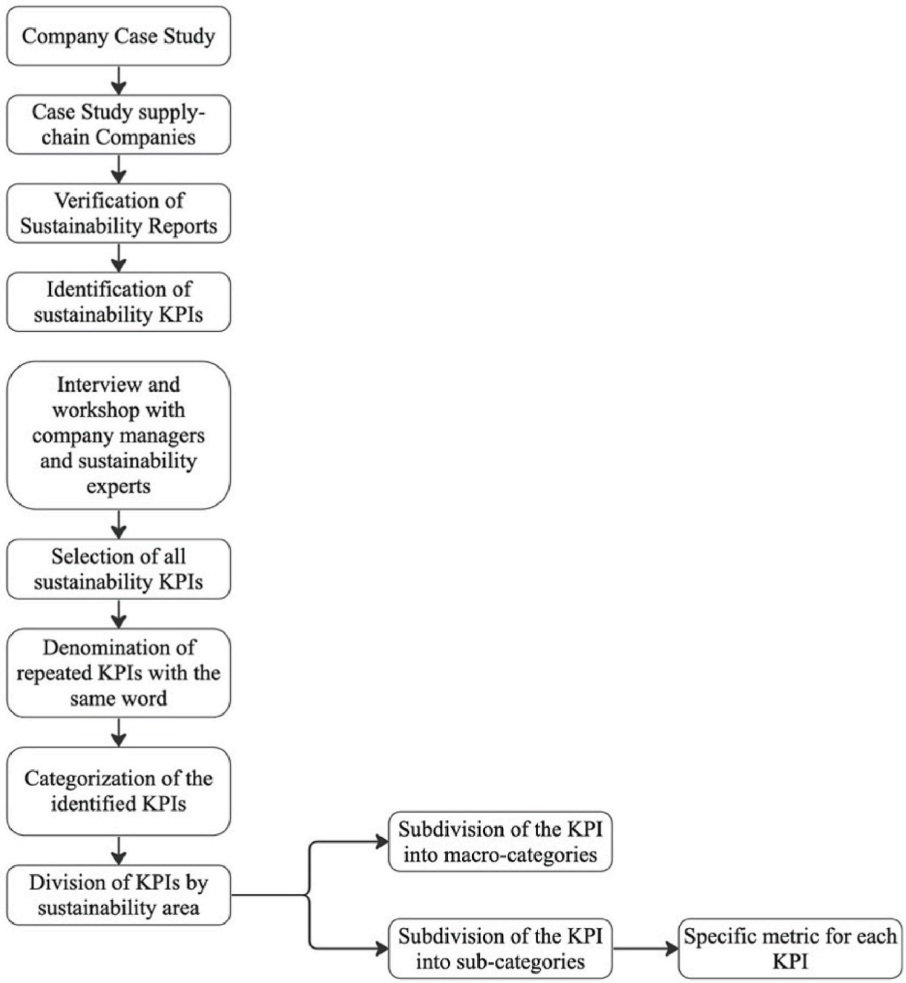

Fig. 3. Workflow adopted starting from the case study company up to the selection of sustainability indicators and metrics.

documents pertaining to corporate sustainability. The indicators were identified for each company, categorized according to the three dimensions of sustainability. However, the utilization of these metrics extends beyond the calculation of sustainability performance exclusively within the ceramic sector. Rather, they offer a framework that enables manufacturing companies to implement all or a subset of the selected metrics, which are valuable for monitoring their unique production processes. For instance, indicators such as "raw material transport" or "raw material cost" can be implemented across various industries. Consequently, a comprehensive set of indicators has been developed specifically for ceramic sector companies, facilitating standardized sustainability calculations and serving as a starting point for all manufacturing enterprises seeking to commence sustainability monitoring and strategic decision-making.

To address the emerging gaps effectively, it was determined that a team of professionals should be assembled to ensure enhanced precision and accuracy during the indicator selection process. This team, comprised of company managers, sustainability specialists, and academic experts specializing in sustainability, leveraged their extensive experience in the field to develop a collection of KPIs capable of measuring sustainability performance. These professionals engaged in a series of meetings, workshops, and interviews to identify the most relevant sustainability indicators. Prior to finalizing the selection, a comprehensive analysis was conducted on all the indicators, accounting for variations in terminologies used to refer to the same indicators. This approach aimed to eliminate redundant KPIs from the selection. Subsequently, all the relevant indicators were chosen, and each indicator was categorized according to its respective domain (economic, social, or environmental). The entire process of indicator selection was carried out by the team of experts specializing in the analyzed field, resulting in the identification of specific KPIs. Once all the indicators were determined, they were further classified into the three sustainability domains. To enhance accessibility and comprehension of the indicators, it was decided to classify them into macro-categories, grouping together indicators that share common themes. This classification allows companies utilizing this selection of indicators to gain a clear understanding of the overall framework, which comprises sub-categories of more specific sector-based indicators. After identifying all the KPIs, calculation metrics were established for each indicator. These metrics enable the conversion of indicators into tangible data, which can then be utilized for making strategic decisions within the company. This approach ensures effective organization of all the indicators and specific metrics that have been identified, facilitating streamlined analysis and interpretation.

Tables 3–5 containing specific indicators grouped by category are provided below. Table 3 presents the selection of economic indicators. From the analysis, 43 economic performance indicators were identified and classified into eight macro-categories, with 57 indicators having specific calculation metrics.

One of the economic indicators chosen pertains to the operational cost accrued by the company. Within this overarching category, several metrics have been designated to quantify the overall cost. An illustrative example is the transportation cost. Maintaining up-to-date data on this particular parameter enables the company to continually monitor its

Table 2
Selected Ceramic Companies (digital version can be viewed from the Supplementary material section).

Company	Topic	Economic KPI	Environmental KPI	Social KPI	SDGs
Company 11	Organization profile	CONSOLIDATED FINFLOOR	WASTE MANAGEMENT (t)	EMPLOYEES	1
	Strategy	Net revenues	Total waste produced (t)	Senior executives	3
	Ethics and integrity	Gross operating margin (E.B.I.T.D.A)	Total waste recovered (of which hazardous and non-hazardous)	Paintings	4 5
	Government	Gross Cash Flow	Total waste disposed of (of which hazardous and non-hazardous)	Employees and Apprentices	6 7
	Stakeholder engagement	Net income	Percentage of hazardous waste (out of total)	Equate yourself	8 9
	Reporting practices	Net Financial Position Assets (liabilities)* Closing balance	Percentage of waste sent for recovery out of the total waste produced	Work and Apprentices	10 11
	Economic performance	Net assets	TOTAL WITHDRAWAL OF WATER	Administrative/Trainees	12
	Materials	Total investments	total water withdrawal (m3) (of which from wells, aqueducts, industrial)	Totals	13 15
	Power	ECONOMIC VALUE GENERATED AND DISTRIBUTED	Total water recycled and used (m3)	ORGANIC COMPOSITION	16 17
	Waterfall	Revenue	Consumption intensity - Total water consumed (m3)/finished product (m2)	Permanent (Men, Women, Total)	
	Water and waste water	Directly generated economic value	TOTAL ENERGY CONSUMED WITHIN THE ORGANIZATION (GWh)	Fixed-term (Men, Women, Total)	
	Biodiversity	Operating costs	from non-renewable fuels (natural gas, diesel, …) (GWh)	Full time (Men, Women, Total)	
	Emissions	Wages and benefits	electricity, heating, cooling and steam purchased for consumption (GWh)	Part time (Men, Women, Total)	
	Dumps and waste	Payments to providers of capital	Self-generated and non-consumed electricity, heating, cooling and steam (GWh)	% Employees by category (Men, Women)	
	Environmental compliance	Payments to the Public Administration	Electricity sold (GWh)	% Employees by age group (<30 years, 30–50 years, >50 years)	
	Environmental compliance	Investments in the community	ELECTRICITY CONSUMPTION (GWh)	TURNOVER	
	Environmental assessment of suppliers	Distributed economic value	Purchased electricity (GWh)	New hires	
	Occupation	Economic value withheld	Electricity produced by PV (excluding turbines) (GWh) Electricity sold (GWh)	Positive turnover	
	Occupational health and safety		FUEL CONSUMPTION FROM NON-RENEWABLE SOURCES (GJ)	POSITIVE TURNOVER BY AGE GROUP	
	Training and education		Natural gas consumed in production, from turbines and heating (GJ)	POSITIVE TURNOVER BY GENDER	
	Diversity and equal opportunities		Diesel fuel consumed by company cars (GJ)	POSITIVE TURNOVER BY NATIONALITY	
	Non-discrimination		Diesel fuel consumed by company vehicles used for logistics and production (GJ)	OVERALL TURNOVER	
	Local communities		CO2 EMISSIONS	OVERALL TURNOVER BY AGE GROUP	
	Customer health and safety		CO2 emissions (t)	OVERALL TURNOVER BY GENDER	
	Marketing and labelling		CO2 emissions (t)/finished product (t)	OVERALL TURNOVER BY NATIONALITY	
	Customer privacy		Particle material (g/m2 finished product)	HEALTH AND SAFETY AT WORK	
	Socioeconomic compliance		Lead (g/m2 finished product)	Total injuries	
			Fluorine (g/m2 finished product)	Of which with serious consequences	
			COMPANY DIRECT EMISSIONS | SCOPE 1	Of which I died	
			Greenhouse gas emission from (CO2, CH4, N2O, HFCs, PFCs, SF6, NF3)	Hours worked	
			Stationary combustion (t)	Rate calculation multiplier	
			Mobile fuel (t)	Rate of deaths resulting from occupational accidents	
			Cogeneration plants (t)	Rate of occupational injuries with serious consequences (excluding fatalities)	
			Calculation of HFCs and PFCs (t) Total (t)	Recordable work injury rate	
			EMISSIONS FROM THE USE OF PURCHASED ELECTRICITY BY THE COMPANY | SCOPE 2	TRAINING	
			Greenhouse gas emission from (CO2, CH4, N2O, HFCs, PFCs, SF6, NF3)	Executives (number of hours, hours per capita, number of hours, hours per capita)	

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Table 2 (*continued*)

Company	Topic	Economic KPI	Environmental KPI	Social KPI	SDGs
			Purchased energy	Managers (number of hours, hours per capita, number of hours, hours per capita)	
				Employees (number of hours, hours per capita, number of hours, hours per capita)	
				Intermediate (number of hours, hours per capita, number of hours, hours per capita)	
				Workers/subsidized workers (number of hours, hours per capita, number of hours, hours per capita)	
				Total training hours	
				CORPORATE WELFARE	
				TERRITORIAL WELFARE	
Company 16	Consumption of materials and waste produced	/	Consumption of materials and waste produced	Workforce composition	/
	Energy consumption		Raw materials for dough (sands, clays or feldspars)	Diversity among employees broken down by professional category, age group and gender	
	Atmospheric emissions		Materials for glazing and coloring tiles (glazes, color additives or inks)	Number of employees broken down by type of contract and gender	
	Waterfall		Other materials that are not part of the final product but are needed in the production process (such as machine lubricants or mineral oils)	Number of employees by type of contract (part-time/full-time) and gender	
	Dumps and waste		Packaging materials (paper, plastic and wood)	Hiring and terminations	
	Environmental compliance		Hazardous waste (of which sent for recovery, disposal, stored on site)	Total number and rate of new employees hired by gender, age group and geographical area	
	Composition of the workforce		Non-hazardous waste (of which sent for recovery or disposal)	Number and rate of employees terminated by gender, age group and geographical area	
	Company turnover		Total	Company turnover	
	Health & Safety		Energy consumption	Health & Safety	
	Training and development		Energy consumption by type (natural gas, diesel, LPG, electricity (from the grid), electricity produced and consumed from other sources, electricity produced and sold from other sources	Accident rates by region and gender	
	Product labeling		Electricity produced from other sources (total)	Training and development	
	Fight against corruption		Total Energy Consumed (GJ)	Average hours of training per employee by professional category and gender	
			Production (m2)	Product labeling	
			Energy consumption (GJ)	Fight against corruption	
			Energy intensity (GJ/m2)		
			Atmospheric emissions		
			Direct (Scope I) and indirect energy (Scope II) greenhouse gas emissions		
			CO_2 emissions		
			Emissions of NOx, SOx and other significant emissions (Dust, NOx, SOx, Lead compounds, Fluorine compounds, Aldehydes, CO, SOV, VOC)		
			Use of refrigerant gases for refrigeration and air conditioning		
			Waterfall		
			Water withdrawals divided by source (Public aqueduct, Own wells, Total)		
			Dumps and waste		
			Environmental compliance		
Company 18	Innovation, development and product quality	Total Operations (Sales)	Process improvement and cutting-edge technologies	New hires 2021 by gender (<30 years, from 30 to 50 years, > 50 years, total)	3 4 5
	Enhancement of human resources through training	Total materials produced	Waste	Total employees by gender (US, EU, total)	6 7 8
	Efficiency of energy consumption	Consolidated net revenues	Raw material	Hours of training (managers, others, total)	9 11
	Communication	Total capitalization (equity debt)	Management of environmental impacts		12 13 14

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Table 2 (*continued*)

Company	Topic	Economic KPI	Environmental KPI	Social KPI	SDGs
	Economic responsibility	DIRECTLY GENERATED ECONOMIC VALUE (values in thousands of euros)	CO2 emission reduction projects		
		Revenue	Sustainable logistics management		
		DISTRIBUTED ECONOMIC VALUE	Sustainable management of the supply chain		
		Operating costs			
		Payments to capital providers			
		Investments in the community			
		ECONOMIC VALUE RETAINED			
		Wages and benefits			
		Payments to the Public Administration			
		Difference between generated economic value and distributed economic value			
Company 19	Efficient use of materials	PROMOTION OF QUALITY EMPLOYMENT	ENERGY RESOURCES	Occupation	3 6
	Energy efficiency	Permanent contracts	Power	Number of employees by State	8
	Greenhouse gas emissions and climate change	Employee wages	Direct GHG emissions (Scope 1)	Number of employees per company	9 12
	Protection of natural capital	SUPPORT TO LOCAL SUPPLIERS	Indirect energy (Scope 2) GHG emissions	% fixed-term and permanent contracts	
	Water and waste management	Purchases from suppliers	Energy consumption within the organization	Equal opportunities and non-discrimination	
	Talent development and retention	Spending on local suppliers	Reduction of energy consumption	% hired men and women	
	Employee welfare	SUPPORT TO LOCAL COMMUNITIES	Intensity of greenhouse gas emissions	Personnel at the end of the year by gender and professional category (Directives and managers, Personnel office, Off-site personnel)	
	Gender equality, diversity and inclusion	Anti-corruption and extortion	OTHER ISSUES	Internal promotions and new hires by gender and professional category	
	Occupational health and safety	Ethics and compliance	Emissions and climate change	Talent development and retention	
	Human rights and fair working conditions	ESG management	Nitrogen oxides (NOx), sulfur oxides (SOx) and other significant air emissions	Percentage of employees receiving regular performance and career development reviews	
	Support to the local community	Risk management	ENERGY EFFICIENCY	Gender equality, diversity and inclusion	
	Customer satisfaction and loyalty	Communication and transparency	WASTE MANAGEMENT	Human rights and fair working conditions	
	Product quality and safety	Promotion of economic development	% waste recovered	TRAINING ACADEMY (Sales and Key Account Management Safety and Health at Work, English, GDPR, Quality Management, Content Marketing, Technical Courses, Software Courses, Internal Logistics)	
	Communication and transparency		Waste generated	Total hours of training	
	Risk management		Waste subtracted for disposal	Average hours per employee	
	ESG management and dialogue with stakeholders		Waste destined for disposal	Hours of training by employee category and gender	
	Ethics and compliance		Management of significant impacts related to waste.	HEALTH AND SAFETY AT WORK	
	Management of ESG risks within the supply chain		Differentiated waste collection.	Lost time injury frequency rate	
			Waste management	Employee welfare	
			CIRCULARITY OF MATERIALS	Accidents at work	
			Production waste recycling	Occupational health and safety	
			Maximum recycled content in the spray-dried mixture	Product health and safety	
			Efficient use of materials	Innovation	
			Recycled input materials used	Support to the local community	
			CIRCULARITY OF WATER		
			Total water consumption		
			Recirculation of water from industrial use		
			Management of water resources		
			Biodiversity		
			The management approach and its components		

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Table 2 (*continued*)

Company	Topic	Economic KPI	Environmental KPI	Social KPI	SDGs
Company 20	Sustainability of products	Economic value generated	Withdrawal of water	Corporate structure and bodies	1 2
	Water and production waste recycling	Operating costs	Emissions in the atmosphere	EMPLOYEES	3 4
	Packaging	Wages and benefits	Soil and subsoil	Senior executives	5
	Product certifications	Payments to providers of capital	Energy consumption	Paintings	6
	Supply chains	Payments to the Public Administration	Use of substances	Employees and Apprentices	7 8
	Corporate Social Responsibility	Investments in the community	Waste production	Equate yourself	9 10
	Product quality	Distributed economic value	External noise from production plants - consumption of various materials	Work and Apprentices	11 12
	Environment and Sustainability	Economic value withheld	Transport of the finished product to the final customer and of the raw materials to the factory	Administrative/Trainees	13 14 15
	Health and safety at work		Environmental behavior of contractors, subcontractors and suppliers that may have an influence on the environment	Totals	16 17
	Benefit company		Effect on the environment due to the disposal or end of life of marketed products	ORGANIC COMPOSITION	
	Distributed economic value		Biodiversity	Permanent (Men, Women, Total)	
	Environment		Energy consumption (Electricity (GJ) Natural gas (GJ))	Fixed-term (Men, Women, Total)	
	Biodiversity		Electricity KPI	Full time (Men, Women, Total)	
	Energy consumption		Thermal energy KPI	Part time (Men, Women, Total)	
	Waste production		Waste transferred to third parties for the specific EER codes of the ceramic sector (t/year)	% Employees by category (Men, Women)	
	Emissions in the atmosphere		Hazardous waste produced (t/year)	% Employees by age group (<30 years, 30–50 years, >50 years)	
	CO2 emissions		Waste KPIs	TURNOVER	
	Water consumption		Hazardous Waste KPI	New hires	
			MASS FLOW:	Resigned	
			Pollutant type	TRAINING (average hours of training per year per employee)	
			Fluorine particle material	Men	
			Lead	Women	
			Sulfur oxides Nitrogen oxides SOV	Workers	
			Aldehydes	Employees	
			CO2 emission KPI	Senior executives	
			Water drawn from wells (m3)	Average hours of transversal training	
			Water KPI (Volume of water drawn/ Production poured by weight)	Average hours of safety training	
				Total training hours	
				Number of injuries	
Company 23	Product quality, innovation and attention to the customer	Direct economic value generated (thousands of euros)	Materials used by weight or volume (packaging: of which renewable (%), material for plant carpentry: of which renewable (%), total raw materials used: of which renewable (%))	Number of employees per employment contract (permanent and fixed-term), by gender	/
	Human resources management	Distributed economic value (operating costs, remuneration of collaborators, remuneration of lenders, remuneration of the public administration, donations and freedoms)	Energy consumed within the organization (consumption of fuels: natural gas, consumption of electricity purchased from the network (from non-renewable sources), energy produced from renewable sources: of which sold to the network, consumption of fleet vehicles (diesel), total energy consumption: of which from renewable sources)	Number of employees by type of employment (full-time and part-time), by gender	
	Environmental sustainability	Economic value withheld	Total energy consumption of the Group in 2021	Employees by type of employment, by gender in 2021	
	Responsible management of the value chain		Total emissions (ton CO2eq)	Percentage of employees by professional category and gender (executives, middle managers, office workers, workers, total)	
	Ethical business		Direct GHG emissions (Scope 1)	Percentage of employees by professional category and age group	
	Business integrity and sustainable governance		Indirect GHG emissions from energy consumption (Scope 2)	Ratio of basic salary and salary in 2021 between women and men for the white collar category	
	Economic performance		Waste produced, not destined for disposal and destined for disposal	Turnover rate	

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Table 2 (*continued*)

Company	Topic	Economic KPI	Environmental KPI	Social KPI	SDGs
			(hazardous waste, non-hazardous, total: of which sent for disposal (%))		
	Employee health, safety and well-being			New hires by age group	
	Professional development of employees and protection of company skills			Terminations by age group	
	Protection of workers' rights and equal opportunities			Average hours of training by professional category	
	Reduction of consumption and emissions from production activity			Average hours of training by gender	
	Reduction and reuse of production waste and waste			Workplace injuries for employees	
	Use of sustainable raw materials			Welfare initiatives (e.g. benefits, smart working)	
	Research and development			Percentage of payments made by type of supply during 2021 (Materials and raw materials, Industrial conveyors and commercial machinery, designed materials and carpentry, Maintenance, transport and services activities)	
	Quality and safety of products and services offered			Involvement and awareness of the territory	
	Satisfaction of customer expectations				
	Responsible management of the supply chain				
	Involvement and awareness of the territory				
Company 28	Product quality and design	Economic value generated	ENVIRONMENTAL RESPONSIBILITY	OUR PEOPLE	3.8 4.4
	Economic performance	Value distributed to Suppliers	MANAGEMENT OF NATURAL RESOURCES	Number of workforce by country, gender and type of contract	6.3–6.4 7.2–7.3
	Health and Safety in the workplace	Value distributed to Personnel	RAW MATERIAL	Consistency of Part Time and Full Time personnel	8.2–8.4. - 8.5
	Sustainable innovation	Value distributed to Lenders	PRODUCTIVE PROCESS	Consistency of personnel by professional category and gender	9.1–9.4 11.6
	Customer Satisfaction	Value distributed to Shareholders	Surface area and weight of the tiles produced	Consistency of personnel by professional category and age group	12.2–12.5 13.1
	Welfare and responsibility towards employees	Value distributed to the Public Administration	ENERGY AND EMISSIONS	Consistency of personnel belonging to protected categories by category and gender	
	Training and development of employees	Value distributed to the Community	Total energy consumption (GJ) (from renewable or non-renewable sources)	Composition of the Board of Directors by gender and age group	
	Contrast to climate change	Distributed economic value	Total energy consumption by type	Incoming personnel by gender and age group	
	Management of water resources	Economic value withheld	Energy intensity	Outgoing personnel by gender and age groups	
	Integrity and compliance	Investments in innovation per year	Emissive intensity	Parental leave	
	Brand and reputation protection	Investments by Business Unit	Direct CO_2 emissions	Group employees by type of contract (permanent or temporary)	
	Waste management and circular economy	Investments in energy efficiency on plants	Indirect CO_2 emissions	Group employees	
	Responsible management of the supply chain		WATERFALL	Turnover	
	Support for innovation		Water withdrawal (source of withdrawal)	Inclusion	
	Low water impact		Drainage (place of drainage)	Discrimination	
	Human resources		WASTE MANAGEMENT	Equal opportunities between employees	
	Proximity to the territory		Waste by treatment method and composition	Work-life balance	

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Table 2 (*continued*)

Company	Topic	Economic KPI	Environmental KPI	Social KPI	SDGs
	Pay attention to the consumption of raw materials and water		Recovery (t)	Access to work flexibility systems in the event of maternity/paternity leave	
	Environmentally friendly packaging		Disposal (t)	Flexibility in career path planning	
	Energy saving		Total (t)	TRAINING AND DEVELOPMENT	
	Quality of life products		of which dangerous	Hours of training provided by professional category and gender	
	Waste management		% hazardous waste out of the total	Training activities on health and safety issues (in hours)	
	Reduction of emissions		PACKAGING	HEALTH AND SAFETY IN THE WORKPLACE	
				Recordable workplace accident rate (employees and external collaborators)	
				RELATIONS WITH LOCAL COMMUNITIES	
				Euros intended as cash or product donations for local communities	
				RESPONSIBLE MANAGEMENT OF THE SUPPLY CHAIN	
				Formalized its Code of Commercial Conduct with the commitment to start a process of implementing policies and procedures aimed at selecting suppliers also on the basis of sustainability criteria (control of raw materials, extraction of materials, management and monitoring of the environmental impacts generated and conducting laboratory analyses)	
				Expenditure on local suppliers (in millions of Euros	
				Materials used by weight (t)	
				Management hired locally	
				Employees covered by collective bargaining agreements	
				Ratio of the standard entry wage by gender to the local minimum wage	
Company Case Study	Resource training	Economic value generated and distributed (euro)	Fuel consumption divided by renewable and non-renewable source (units)	Employees by type of contract and gender	3 4
	Occupational health and safety	Revenue	NON-RENEWABLE SOURCES (Natural gas, Diesel for car fleet, Natural gas, Diesel for car fleet)	Permanent	5 7 8
	Environmental responsibility	Total economic value generated	Electricity consumption	Fixed term	9 10
	Energy efficiency	Operating costs	Total electricity (of which purchased and consumed, of which self-produced, consumed and sold)	Total employees (of which apprentices)	11 12 13
	Standards/Codes of Ethics	Staff remuneration	Purchased electricity (of which from NON-renewable sources, of which from renewable sources)	Employees by type of employment and gender	16
	Fight against corruption	Debt and venture capital	Total electricity (of which purchased and consumed, of which self-produced, consumed and sold)	Full time	
	Materials management	Taxes	Purchased electricity (of which from NON-renewable sources, of which from renewable sources)	Part time	
	Working conditions, internal climate and welfare	Investments in the community	Consumption of self-produced electricity	Total employees	
	Relations with the territory	Total economic value distributed	Total self-produced energy (of which total electricity consumed, of which total electricity sold)	Employees by professional figure and gender (Executives, Managers, White collars, Blue collars, Total)	
	Circular economy	Total economic value retained by the organization	Self-produced electricity from photovoltaics	Employees by professional figure and age range (Executives, Managers, White collars, Blue collars, Total, Percentage)	
	Collaboration with schools and universities	Country-by-country report (euros)	Self-produced energy from trigeneration	Seniority of work	
		No. of employees	Total self-produced energy (of which total electricity consumed, of which total electricity sold)	Hiring and resignation	
		Total compensation of employees	Self-produced electricity from photovoltaics	Number of new hires	

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Table 2 (*continued*)

Company	Topic	Economic KPI	Environmental KPI	Social KPI	SDGs
		Taxes withheld and paid on behalf of employees	Self-produced energy from trigeneration	Number of discharged	
		Taxes collected from customers on behalf of a tax authority	CO_2 emissions	Rate of new hires	
		Industry taxes and other taxes or payments	Natural gas (Scope 1)	Turnover rate	
		to the Public Administration	Diesel for car fleet (Scope 1)	Recruitment and resignation rates by age group (<30 years, 30–50 years, > 50 years)	
		Balance of intragroup debt held by entities in the tax jurisdiction	Electricity purchased from non-renewable sources (Scope 2), of which: a. Emissions from consumption of electricity purchased from non-renewable sources; b. Emissions from consumption of electricity purchased from non-renewable sources	Breakdown of personnel by educational qualification (professional institutes, technical institutes, other secondary schools, technical degrees, humanities degrees, other lower qualifications)	
		Revenues from sales to third parties	Purified water	Average hours of training by professional category	
		Revenues from intercompany transactions with other tax jurisdictions	Cubic meters treated at the purifier	Total number of training hours provided to Managers	
		Pre-tax profit/loss	Hours worked by workers in DEP departments	Total number of training hours provided to Managers	
		Purchase volumes divided by type	Water consumption (megalitres)	Total number of training hours provided to Employees	
		Services	Water withdrawal	Total number of training hours provided to workers	
		Third party machines	Drain of water	Average hours of training per Manager	
		Raw material	Water consumption	Average hours of training per Middle Manager	
		constructive	Waste production (tons)	Average hours of training per Employee	
		Commercial	Total weight of waste produced	Average hours of training per worker	
		Purchase trend of machines and spare parts (euro)	Total weight of waste not destined for disposal (of which hazardous waste, of which non-hazardous waste)	Average hours of training by gender	
		Total purchase volumes by geographical area (euro)	Total weight of waste destined for disposal (of which hazardous waste, of which non-hazardous waste)	Total number of training hours provided to female employees	
		R&D resources and projects		Total number of training hours provided to male employees	
		No resources engaged in research and development		Average hours of training per female employee	
		No. of projects assigned to research and development		Average hours of training per male employee	
		Number of man months dedicated		Training	
		No. man months/projects		Total hours of training	
		The patents		Average hours of training per employee	
		Patent applications (total number)		Total training costs (€)	
		Patent applications filed during the year		Training provided	
		Active patents (total number)		professional technical training	
				language training	
				Safety and environmental training	
				Amount of investments for training (€)	
				Hours of training/year	
				Individual people involved per year	
				Accident rates	
				Number of injuries	
				Days lost due to injuries	
				Number of hours worked	
				Number of injuries/hours worked *200,000	
				Days lost due to injury/hours worked *1000	
				Membership consistency	
				no. associates	
				% shareholders on total employees	
				Refund (euros)	
				Social loan (euro)	
				Distribution of total turnover by customer size (small, medium, large)	

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Table 2 (*continued*)

Company	Topic	Economic KPI	Environmental KPI	Social KPI	SDGs
				Distribution of total turnover by geographical area (Italy, the West, developing countries)	
				Support to the local, national and international territory by area of intervention (euro)	
				Healthcare/Social	
				Art/Culture	
				School	
				Sports/leisure	
				Total	

performance and make informed decisions aimed at emission reduction. Through a thorough analysis of the data derived from this metric, the company can adopt more sustainable practices concerning expenses, such as utilizing environmentally friendly fuels, among other measures.

Table 4 presents the chosen environmental indicators for ceramic companies. Through the analysis carried out, we identified 13 macro-categories and 61 specific environmental performance indicators, each with its respective calculation metric. These indicators can provide a comprehensive view of a company's environmental sustainability, including its impact on air, water, and material quality, as well as waste management, energy efficiency, and greenhouse gas emissions. By tracking these indicators, ceramic companies can monitor their environmental performance and make informed decisions about their operations, ultimately contributing to a more sustainable future.

Table 5 shows the selection of social indicators. Following the analysis, a total of 88 social performance indicators were identified, grouped into 11 macro-categories. Each indicator has a specific calculation metric assigned to it.

Once the indicators have been identified and measured through specific metrics, the goal of every company should be to predict the company's situation as sustainability parameters change. Therefore, it is crucial to connect technology and digitization with sustainability to have a tool that helps corporate decision-makers in data management and strategic decision-making. Access to data that serves as a foundation for corporate decision-making facilitates informed choices, especially those concerning sustainability. Qualitative and quantitative parameters are essential for improving the environmental, social, and economic performance of company products. By using Industry 4.0 technologies and digital tools such as big data monitoring, analytics tools, and digital twins, it is possible to collect data and evaluate company sustainability parameters in a straightforward, immediate, and efficient manner.

4. Discussion

4.1. Importance of sustainability in the company

In the year 2030, companies that are not sustainable will represent only a residual part of the market, where "sustainable" products and services will be the norm. Many companies share the common goal of improving their skills and communication strategies to capitalize on the efforts made so far in increasing industry awareness of the value of sustainability. To facilitate industries in this paradigm shift, it is necessary to launch a new industrial policy plan that promotes investments in green and sustainable transition. The current concept of Industry 4.0, mainly focused on innovation, is evolving towards a 5.0 solution where innovation merges with the elements of sustainable transition. Therefore, it is essential to implement initiatives that support companies in moving towards a more sustainable world. Every company's mission should be to embody the concept of "realizing to realize," because only by truly understanding the importance of measuring oneself can concrete initiatives be implemented with a view to sustainability.

4.2. Energy-intensive ceramic industry

Building on the previous premise, this article explores the connection that must be established in the industrial field between sustainability and digitization. In particular, the analysis focuses on a world leader in ceramic production, examining other companies in its supply chain, including suppliers and customers. This approach allows for a more specific and detailed analysis and definition of how this sector is addressing sustainability. Notably, the ceramic process is one of the most energy-intensive in the industrial sector, making it essential to continuously monitor sustainability indicators to avoid environmental, economic, and social impacts. Therefore, it is crucial for every company in this industry to have a data monitoring system that provides essential information to executives to make strategic decisions that anticipate and address potential issues. In the medium to long term, it will be necessary to identify anomalies or improve analyses based on well-documented and historical data variations.

4.3. Definition of set of indicators

To answer the first research question, "*How do ceramic industries measure their sustainability indicators?*", the state of the art of how Italian companies monitor their sustainability performance has been defined. The presence of sustainability indicators in the various corporate documents was then assessed and a corporate strategy plan was outlined to allow companies to be more sustainable and, at the same time, more competitive on the market. As a result, it became necessary to identify a set of performance indicators specific to the ceramic sector to standardize sustainability calculation across companies.

A set of KPIs was established and divided into three areas (economic, environmental, and social) by a group of experts. The corresponding metrics for each indicator were specified to allow for quantitative or qualitative calculation. Moreover, macro-categories and sub-categories were defined within each sustainability area. The results of the research led to the selection of 43 economic indicators (with 57 metrics), 61 environmental indicators (each with one metric), and 88 social indicators (with 88 specific metrics). This standardization of indicators permits companies to customize their selected indicators to their specific context based on their size and data availability.

4.4. Industry 4.0 and digitization to promote sustainability

The management of large amounts of corporate data is a challenging task. However, the implementation of new technologies of Industry 4.0 and digitization can help structure and standardize data management. Digitization plays a pivotal role in corporate management, enabling constant and up-to-date data monitoring. These digital tools, such as Cyber-Physical Systems, Big data analysis, Artificial Intelligence, and Digital Twins, among others, are digital entities that aid in providing pertinent data for industrial sustainability monitoring. Once the company's data is obtained, it becomes feasible to implement measures aimed at mitigating the impacts generated, particularly the

Table 3
Selected economic KPIs and metrics for ceramic companies.

ECONOMIC KPI - Ceramic companies MACRO CATEGORIES	SUBCATEGORIES	METRICS
Costs	Purchases from capital providers	euros for purchases from capital suppliers
	Debt and venture capital	euros of debt and risk capital
	Total capitalization (equity debt)	total euros of capitalization (equity debts)
	Gross Cash Flow	euros of gross cash flow
	Costs of the supply chain	euros for supply chain costs
	Training costs	euros for training costs
	Waste costs	euros for waste costs
	Operating costs	euros of waste treatment costs
		euros of costs for the end of life of the product
		euros of energy costs
		euro of environmental costs
		euros of installation costs
		euros of labor costs
		euros of logistics costs
		euros of maintenance costs
		euros of production costs
		euros of material costs
		euros of packing costs
		euros of transport costs
		euros of utility costs
		euro of warranty costs
		euros of water costs
	Health and safety costs	euros for health and safety costs
	Social costs	euros for social costs
	Total cost of operations	total euro for costs of operations (sales)
	Total cost of materials produced	total euro for materials produced
	Gross operating margin	euros of gross operating margin
	Payments to the Public Administration	euros for payments to the Public Administration
	Net assets	euros of equity
	Net income	euros of net profit
Patents and Resources and R&D projects	Patent applications	number of patent applications
	Patent applications filed during the year	number of patent applications filed during the year
	Active patents	number of active patents
	Resources engaged in research and development	number of resources engaged in research and development
	Projects assigned to research and development	number of projects assigned to research and development
	Resources used	number of man-months dedicated
	Resources used per project	number of man-months/ projects
Taxes	Taxes collected from customers on behalf of a tax authority	euros of taxes collected from customers on behalf of a tax authority
	Taxes withheld and paid on behalf of employees	euros of taxes withheld and paid on behalf of employees
Investments	Ethical investments	euros for ethical investments
	Investments in energy efficiency on plants	euros for investments in energy efficiency on plants
	Investments in innovation	euro for investments in innovation per year
	Investments in the community	euros for investments in the community
	Investments by Business Unit	euro for investments by Business Unit
	Total investments	euro total investments
	Recycling processes	euro of investment for recycling processes
	Quality	euro of investments for the quality of the products
Revenue	Revenues from intercompany transactions with other tax jurisdictions	euro of revenues from intercompany transactions with other tax jurisdictions
	Revenues from sales to third parties	euros of revenues from sales to third parties
Staff	Employee Wages and Benefits	euros for employee wages and benefits
	Turnover	euros per turnover
Economic value	Distributed economic value	euro of distributed economic value (suppliers, personnel, lenders, shareholders, public administration, community)
	Economic value generated	euro of economic value generated
	Generated economic value/ distributed economic value	euro of economic value generated/euro of economic value distributed
	Economic value withheld	euro of retained economic value
Purchase volumes	Purchase volumes divided by type	euros for purchase volumes divided by type (services, third-party machines, raw materials, construction, commercial)
	Total purchase volumes by geographical area	euro for total purchase volumes by geographical area
8 ECONOMIC KPIs (macro-categories)	**43 ECONOMIC KPIs (subcategories)**	**57 ECONOMIC METRICS**

environmental consequences associated with an energy-intensive industry such as the ceramics sector. In fact, digitization can play a crucial role in reducing the environmental impact generated by industries such as the energy-intensive ceramic industry. Having consistent and complete definitions of data facilitates the implementation of software and provides more reliable decision-making information. Proper documentation of measurement details ensures consistent calculation and adequate presentation of results during reporting periods. Meaningful analyses and conclusions on KPI performance can only be drawn through this approach. With these statements we answer the second question of the research "*How can technology help to have real-time and constantly updated data?*".

4.5. Sustainability Digital-Twin

In the field of manufacturing, several digital technologies of Industry 4.0 can be applied to optimize the production processes. One such technology is the Digital-Twin, which can create a virtual replica of the company's real-time situation to identify and correct inefficiencies before they occur in the physical world. The identification of this tool allows us to answer the third question of the research "*What technologies are available today for viewing and using company data?*".

This study aims to develop a tool that can manage the data obtained from specific KPIs for the ceramic sector to monitor the company's sustainability performance.

The Digital-Twin is an essential tool to achieve this goal. This technology enables constant monitoring of the company's economic, environmental, and social sustainability performance. It is referred to as the "Digital Twin of Sustainability" and should be implemented in every company that aims to monitor its corporate data. As shown in Fig. 4, the Digital Twin of Sustainability provides a digital display to manage the parameters and make decisions that lead to sustainable outcomes. As the tool evolves, it will enable sustainable production planning, considering every aspect of the economic, social, and environmental sphere.

Table 4
Selected environmental KPIs and metrics for ceramic companies.

ENVIRONMENTAL KPI - Ceramic companies MACRO CATEGORIES	SUBCATEGORIES	METRICS
Waste	Total waste produced	tons of waste produced
	Waste generated	tons of waste generated
	Total waste recovered	total tons of waste recovered (hazardous and non-hazardous)
	Total waste disposed of	total tons of waste disposed of (hazardous and non-hazardous)
	Hazardous waste	percentage of hazardous waste (out of the total, of which sent for recovery, disposal, stored on site)
	Non-hazardous waste	percentage of non-hazardous waste (of which sent for recovery or disposal)
	Waste sent for recovery out of the total waste produced	percentage of waste sent for recovery out of the total waste produced
	Differentiated waste collection	tons of separate waste
	Waste transferred to third parties for the specific EER codes of the ceramic sector	tons of waste transferred to third parties for the specific EER codes of the ceramic sector
	Toxicity of the materials used and waste produced	toxicity of the materials used and waste produced
Consumption of materials	Raw materials for dough	quantity of raw materials for mixture (sands, clays or fldspars)
	Materials for glazing and coloring tiles	quantity of materials for glazing and coloring the tiles (glazes, additive colorants or inks)
	Other materials that are not part of the final product but are needed in the production process	quantities of other materials that are not part of the final product but are needed in the production process (such as machine lubricants or mineral oils)
	Packing/wrapping materials	quantity of packaging materials (paper, plastic and wood)
Circularity of materials	Production waste recycling	amount of recirculation of production waste
	Maximum recycled content in the spray-dried mixture	maximum amount of recycled content in atomized blend
	Efficient use of materials	efficient way of managing materials
	Recycled input materials used	amount of recycled input materials used
Water	Total water withdrawal	total cubic meters of water (of which from wells, aqueducts, industrial)
	Total water recycled and used	total cubic meters of recycled and used water
	Consumption intensity	total water consumed (m3)/finished product (m2)
	Water drain	place of drainage
	Purified water	cubic meters treated in the purifier
Energy consumed within the organization	From non-renewable fuels	GWh of energy consumed from non-renewable fuels (natural gas, diesel, etc.)
	Electricity, heating, cooling and steam purchased for consumption	GWh of energy consumed for electricity, heating, cooling and steam purchased for consumption
	Self-generated and unconsumed electricity, heating, cooling and steam	GWh of energy consumed for self-generated and non-consumed electricity, heating, cooling and steam
	Electricity sold	GWh of electricity sold
Electricity consumption (GWh) of which:	Electricity purchased	GWh of purchased electricity consumed
	Electricity produced by photovoltaics	GWh of electricity produced by PV consumed (excluding turbines)
	Consumption of self-produced electricity	GWh of self-produced electricity consumed
	Total self-produced energy	total GWh of self-produced electricity consumed (of which total electricity consumed, of which total electricity sold)
	Self-produced energy from trigeneration	GWh of self-produced energy from trigeneration consumed
	Renewable energy	GWh of energy consumed from renewable sources
Consumption of fuel from non-renewable sources	Natural gas consumed in production	GJ of natural gas consumed in production (turbine and heating)
	Diesel fuel consumed by company cars	GJ of diesel fuel consumed by company cars
	Diesel fuel consumed by company vehicles used for logistics and production	GJ of diesel fuel consumed by company vehicles used for logistics and production
CO_2 Emissions	CO_2 emissions	tons of CO_2 emissions
	CO_2 emissions/finished product	tons of CO_2 emissions/ tons of finished product
	Particle material (g/m2 finished product)	g/m2 of particle material on the finished product
	Emissions of NO_x, SO_x and other significant emissions	tons of emissions of NO_x, SO_x and other significant emissions (Dust, NO_x, SO_x, Lead compounds, Fluorine compounds, Aldehydes, CO, SOV, VOC)
	Lead (g/m2 finished product)	g/m2 of lead on the finished product
	Fluorine (g/m2 finished product)	g/m2 of fluorine on the finished product
Company direct emissions | SCOPE 1	Greenhouse gas emission	tons of greenhouse gas emissions (CO_2, CH_4, N_2O, HFCs, PFC,s SF_6, NF_3)
	Stationary combustion	tons of stationary combustion
	Mobile fuel	tons of mobile fuel
	Cogeneration plants	tons of cogeneration plants
	Calculation of HFC and Total PFC	total tons of HFCs and PFCs
Emissions deriving from the use of electricity purchased by the company | SCOPE 2	Greenhouse gas emission from (CO_2, CH_4, N_2O, HFCs, PFCs SF_6, NF_3)	tons of greenhouse gas emissions (CO_2, CH_4, N_2O, HFCs, PFC,s SF_6, NF_3)
	Purchased energy	GWh of purchased electricity
Environmental responsibility	Environmental behaviour of those who can have an	environmental behaviour of contractors, subcontractors and

(continued on next page)

Table 4 (*continued*)

ENVIRONMENTAL KPI - Ceramic companies MACRO CATEGORIES	SUBCATEGORIES	METRICS
	influence on the environment	suppliers that may have an impact on the environment
	Management of environmental impacts	ways of managing environmental impacts
	Pollution	methods of managing pollution
	Radioactive emissions	amount of radioactive emissions
	Management of natural resources	ways of managing natural resources
	Climate change	ways of managing climate change
	Waste sorting	method of managing separate waste collection
	Soil and subsoil	methods of soil and subsoil management
	Biodiversity	ways of managing biodiversity
Sustainable management of logistics and supply chain	Transportation of the finished product	mode of transport of the finished product to the final customer and of the raw materials to the factory
End of life	Disposal and end of life of marketed products	types of effect on the environment due to the disposal or end of life of marketed products
	Life cycle of the product	product shelf life
13 ENVIRONMENTAL KPIs (macro-categories)	**61 ENVIRONMENTAL KPIs (subcategories)**	**61 ENVIRONMENTAL METRICS**

5. Conclusions

The aim of this article is to support ceramic manufacturing companies in monitoring their sustainability performance. This requires the definition of a set of indicators and metrics capable of calculating company data in the three areas of sustainability (economic, environmental, and social). Commencing with an examination of the current landscape regarding the integration of sustainability as a strategic driver in ceramic companies, it has been observed that a limited number of the surveyed companies produce sustainability reports or perceive sustainability as a valuable resource upon which to anchor future organizational advancements. The article responds to this emerging gap by proposing a set of KPIs (88 social indicators, 61 environmental indicators and 43 economic indicators) selected for ceramic companies that are able to measure their own sustainability performance, providing data on the basis of which to implement plans strategic.

The research also presented an innovative contribution by offering the potential applicability of the obtained findings not solely to address the requirements of ceramic companies but also to provide a methodology applicable to any manufacturing enterprise, facilitating self-monitoring from a sustainability standpoint. This approach recognizes the existence of indicators that may be shared among various companies, such as raw material consumption, transportation costs, and other similar factors.

This study has placed particular emphasis on environmental and energy indicators as they are currently recognized as key factors to be monitored within manufacturing companies. To achieve this, companies need to understand the importance of investing in the digitalization of processes. Only by ensuring the implementation of Industry 4.0 digital technologies can constantly updated and real-time information be obtained.

The purpose of this article is to promote the integration between sustainability and digitalization to develop a "Digital Twin of

Table 5
Selected social KPIs and metrics for ceramic companies.

SOCIAL KPI - Ceramic companies MACRO CATEGORIES	SUBCATEGORIES	METRICS
Employees	Senior executives	number of executives in the company
	Manager	number of manager in the company
	Employees and Apprentices	number of employees and apprentices in the company
	Equate yourself	number of equivalents in the company
	Workers	number of workers in the company
	Administered/Trainees	number of contract workers/trainees in the company
	Totals	total number of employees in the company
	Number of employees by State	total number of employees by state
	Number of employees per company	total number of employees per company
Organic composition	Permanent (Men, Women, Total)	number of men/women/ total with permanent contracts
	Fixed-term contract (Men, Women, Total)	number of men/women/ total with fixed-term contracts
	Full time (Men, Women, Total)	number of men/women/ total with full-time contract
	Part time (Men, Women, Total)	number of men/women/ total with part-time contracts
	Employees by category	% male and female employees
	Employees by age group	% employees by age group (<30 years, 30–50 years, >50 years)
Breakdown of personnel by educational qualification	Professional institutes	number of employees with educational qualification: professional institute
	Technical institutes	number of employees with educational qualification: technical institute
	Other secondary schools	number of employees with educational qualifications: other secondary schools
	Technical degrees	number of employees with educational qualifications: technical degrees
	Humanities degrees	number of employees with educational qualification: humanities degrees
	Other lower titles	number of employees with educational qualifications: others with lower qualifications
Turnover	New hires	number of new hires
	Positive turnover	positive turnover number
	Positive turnover by age group	number of positive turnover by age group
	Positive turnover by gender	number of positive turnover by gender
	Positive turnover by nationality	number of positive turnover by nationality
	Overall turnover	total turnover number
	Overall turnover by age group	number of total turnover by age group
	Overall turnover by gender	number of total turnover by gender
	Overall turnover by nationality	number of total turnover by nationality
Occupational health and safety	Total injuries	total number of injuries

(*continued on next page*)

Table 5 (*continued*)

SOCIAL KPI - Ceramic companies MACRO CATEGORIES	SUBCATEGORIES	METRICS
	Of which with serious consequences	total number of injuries with serious consequences
	Of which I died	total number of injuries resulting in death
	Hours worked	total number of hours worked
	Deaths resulting from occupational accidents	work-related death rate
	Accidents at work with serious consequences (excluding fatalities)	rate of occupational accidents with serious consequences (excluding fatalities)
	Recordable work accident	recordable accident rate at work
	Employee welfare	employee welfare
	Losses due to accidents	days lost due to injuries
	OSHA standards	introduction of OSHA standards
Training	Executives (number of hours, hours per capita)	number of hours and hours per capita of training for executives
	Managers (number of hours, per capita hours)	number of hours and hours per capita of training for managers
	Employees (number of hours, hours per capita)	number of hours and hours per capita of training for employees
	Intermediate (number of hours, hours per capita)	number of hours and hours per capita of training for intermediates
	Workers/administered workers (number of hours, per capita hours)	number of hours and hours per capita of training for workers/administrative workers
	Hours of training	total training hours
	Hours of training provided to employees by gender	total number of training hours provided to employees by gender (men and women)
Training provided	Professional technical training	number of hours of professional technical training
	Language training	number of hours of language training
	Safety and environmental training	number of hours of safety and environmental training
Training Academy	Sales and Key Account Management	training on sales and key account management
	Safety and Health at Work	occupational health and safety training
	English	english training
	GDPR	GDPR training
	Quality management	quality management training
	Content marketing	content marketing training
	Technical courses	training on technical courses
	Software courses	training on software courses
	Internal logistics	internal logistics training
Corporate welfare	Work flexibility in case of maternity/paternity leave	access to work flexibility systems in the event of maternity/paternity leave
	Benefits	benefits
	Smart working	possibility of working in smartworking
	Work-life balance	work-life balance
	Parental leave	possibility of having parental leave
	Collective Bargaining Agreements	number of employees covered by collective bargaining agreements
	Complaints system	possibility of having a complaints system
	Absence of toxic products	workplace without toxic products
Local, national and international support	Innovation	actions to support social innovation
	Support to the local community	actions to support the local community
	Involvement and awareness of the territory	actions of involvement and sensitization of the territory
	Healthcare/Social	actions to support health and social services
	Art/Culture	actions to support social innovation
	School	actions to support art and culture
	Sports/leisure	actions in support of sport and free time
	Volunteer Programs	actions with volunteer programs
	Philanthropy	philanthropic actions
	Charitable Contributions	actions to support charitable contributions
Human rights	Equal opportunities and non-discrimination	workplace with equal opportunities and non-discrimination
	Human rights and fair working conditions	workplace with human rights and fair working conditions
	Ratio of basic salary and annual salary	ratio of basic salary and annual remuneration between women and men for the white-collar category
	Gender equality, diversity and inclusion	workplace with gender equality, diversity and inclusion
	Employees receiving regular performance and career development reviews	Percentage of employees receiving regular performance and career development reviews
	Talent development and retention	workplace with talent development and retention
	Justice	fair workplace
	Child labor	workplace where child labor is not exploited
	Forced labor	workplace where forced labor is not used
	Fair trade	fair trade
	Fight against corruption	fight against corruption
11 SOCIAL KPIs (macro-categories)	**88 SOCIAL KPIs (subcategories)**	**88 SOCIAL METRICS**

Sustainability": a tool that can help business managers make decisions before they generate irreversible consequences for the company. This tool was chosen due to its classification as an Industry 4.0 digital technology, enabling a proactive assessment of the company's sustainability status. By providing real-time access to comprehensive data, it facilitates the integration of sustainability considerations in product design, enables continuous monitoring of various company parameters, and supports proactive decision-making. Ultimately, this tool ensures a reduction in environmental impacts, resource consumption, and waste generation, thereby enhancing the company's sustainability and competitive positioning in the market. Although a detailed analysis of the state of the art of ceramic companies was carried out, the selection of KPIs was limited starting from the companies belonging to the supply chain of the case study company. Therefore, the indicators identified may not fully cover the three areas of sustainability.

Moreover, the process of selecting the KPIs and their classification

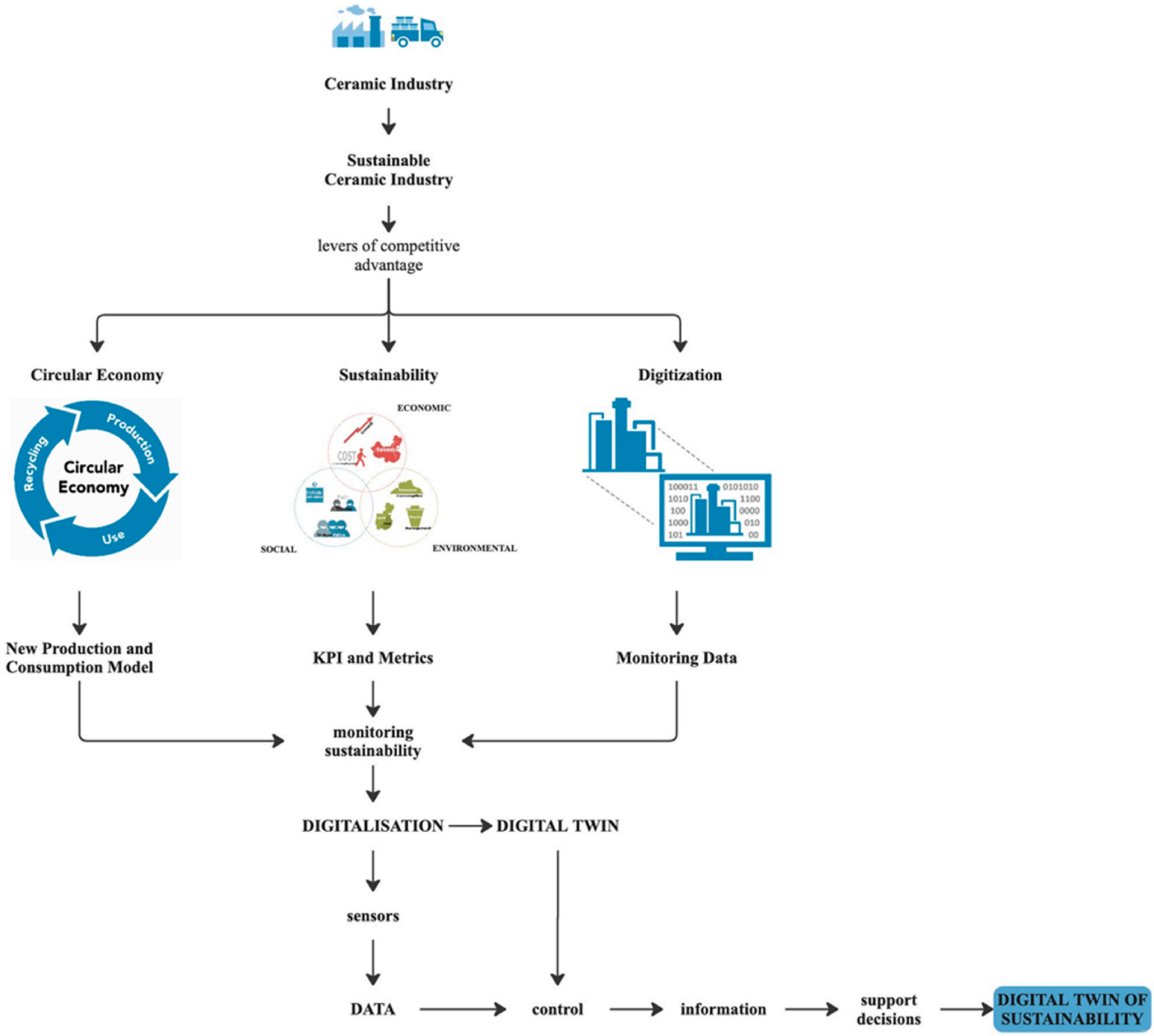

Fig. 4. Diagram summarizing the idea of the whole paper – Digital Twin of Sustainability scheme.

into macro-categories was executed by the designated team, entailing a subjective assessment reliant on the individual expertise and experiences of the team members. A final limitation of the research is that there are no case studies that demonstrate the effective validity of the set of KPIs in an industrial application. The study undertaken possessed an exploratory character, as it did not involve empirical assessment of the proposed Key Performance Indicator framework in an operational context. This analysis has facilitated the construction of a model to serve as the foundation for subsequent operational analyses. Future research endeavors will focus on validating the proposed set of KPIs within a specific business context, aiming to develop the "Digital Twin of Sustainability."

Supplementary material

Digital version of Figures and Tables are available at this link: Ceramic Companies.xlsx.

CRediT authorship contribution statement

Giuditta Contini: Investigation, Writing – review & editing. **Margherita Peruzzini:** Conceptualization, Methodology, Supervision, Validation. **Stefano Bulgarelli:** Conceptualization, Supervision. **Gildo Bosi:** Conceptualization, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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