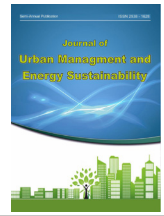
Int. J. Urban Manage Energy Sustainability, 5(1): 1-17, 2024

Journal of Urban Management and Energy Sustainability (JUMES)

Homepage: http://www.ijumes.com



ORIGINAL RESEARCH PAPER

challenges and strategies of architecture and sustainability in cement production: a cross-country comparison

Pouya Eghbalian[1], Vahid Qobadiyan[2*], Mahnaz Mahmoudi Zarandi[3]

1 Ph.D. Candidate, Department of Art and Architecture, UAE Branch, Islamic Azad University, Dubai, United Arab Emirates
2 Associated Professor, Department of Art and Architecture, Tehran-Center Branch, Islamic Azad University, Tehran, Iran*
3 Associated Professor, Department of Architecture, Tehran-North Branch, Islamic Azad University, Tehran, Iran

ARTICLE INFO

Article History:
Received 2023-11-20
Revised 2023-12-29
Accepted 2024-02-11

Keywords:
Cement industry, environmental impacts, Italian cement industry, German cement industry, global sustainability

DOI: 10.22034/JUMES.2024.2020193.1191

ABSTRACT

The global cement industry is facing increasing scrutiny due to its environmental impacts and resource consumption. This study compares sustainability practices in Italian, German and Iranian cement industries. It focuses on waste management, resource efficiency and environmental effects during cement production. The aim of this research is to identify the differences in sustainable practices between Italian, German and Iranian cement industries and to investigate the factors that create these differences. What is the sustainability of Iran's cement industry compared to other countries? The current type of research is comparative and this study analyzes the Italian and German cement industries using data up to 2021. It examines aspects such as cement production, waste management, alternative materials and fuels. The limited availability of data limits the assessment of Iran's industry to a preliminary analysis. Germany excels in sustainability with proactive waste management, resource efficiency and reduced environmental impact, particularly through the use of recycled solid fuel. Conversely, Italy faces challenges in waste management, significant disposal of landfill waste and slow progress in adopting alternative materials and fuels. Italy and Germany have made significant progress, while Iran relies on older production methods. Addressing these disparities is critical to Iran's alignment with global sustainability efforts. Reassessing waste management, improving resource efficiency and meeting sustainability standards are vital in reducing the environmental impact of the cement industry.

Running Title: Challenges and strategies of architecture and sustainability in cement production

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
85	00	07

*Corresponding Author:
Email: *vqobadiyan@gmail.com*
Phone: +989121889277
ORCID: https://orcid.org/0000-0003-1443-1007

INTRODUCTION

Cement industry, the cornerstone of construction and civilization, is primarily used in the production of concrete and is combined with aggregates, water and additives to increase properties. Cement production uses natural and alternative raw materials that vary from factory to factory but meet industry standards. While historically energy-intensive and reliant on coal, it now uses a variety of fossil and alternative fuels. This industry contributes significantly to global CO2 emissions due to fuel combustion and limestone calcination, and accounts for 70-80% of energy consumption. The cement industry accounts for about 5% of anthropogenic CO2 emissions worldwide, requiring carbon mitigation measures to combat climate change (Worrell et al., 2011; IEA/WBCSD, 2019; WBCSD, 2021a; Cembureau , 2022a, Wang et al.).

This article examines Iran's cement industry with a focus on sustainability and environmental competitiveness compared to Italy and Germany. It looks at the history, production process, and the evolving economic, technological, and environmental aspects of the sector. The European cement industry, particularly Italy and Germany, is examined for best practices in material and energy use and greenhouse gas emission reduction, providing insight into performance trends. The challenges facing Iran's cement industry are identified in the journey of sustainability. A comparative analysis of Italy and Germany, as leading European producers, shows the differences in their sustainability approaches, emphasizing the changes in productivity, and the use of materials and energy resulting from waste recycling. These initiatives reduce greenhouse gas emissions and align with the circular economy (Cembureau, 2020). The history of cement production dates back to ancient civilizations such as the Egyptians, Greeks, and Romans, who used materials such as crushed limestone, sand, and volcanic ash. The Romans pioneered certain uses, but this knowledge declined in Europe after the decline of the Roman Empire. In 1759, Smeaton rediscovered hydraulic mortars using lime, clay, and crushed slag, while Aspedin patented Portland cement in 1824, sparking the growth of the global cement industry (Kirk-Othmer, 2004). Johnson later developed modern Portland cement through high temperature firing. The history of Iranian cement dates back to early civilizations that used local resources for construction, but in-depth research is needed to explore the historical development and evolution of Iranian cement practices (Encyclopedia Britannica, 2014). In order to optimize energy efficiency in cement production and address sustainability, strategies should be adopted, especially in the Iranian cement industry, which include both technological and managerial aspects. Upgrading or replacing inefficient equipment with energy efficient alternatives is very important (Vinci et al., 2019; Ishaq and Hashem, 2020).

Cement production includes three main stages: raw material processing, clinker production and final grinding processing. In Iran, raw material processing requires crushing limestone and clay to create a homogeneous mixture. Stone crushers reduce the stone size from 120 cm to 8-1.2 cm. Specialized equipment such as stackers and retrievers are used for pre-mixing. The ingredients are then dosed and ground in a mill and then transferred to homogenizing silos. Preheating in a tower takes place using furnace exhaust gases and reduces the energy of subsequent heating. The furnace raises the temperature of the material to more than 1000 degrees Celsius and forms cement clinker. The clinker is cooled in a cooler and stored in silos before final grinding, containing additives such as fly ash and limestone. The clinker production stage includes fuel preparation and exhaust gas purification. The fuel is ground before entering the furnace and the exhaust gases are treated to remove dust and reduce emissions (Su et al., 2022). There are 27 types of common cement defined by the European standard, which are grouped into five categories with three strength classes each. There are various “specialty” cements, including super sulfate and calcium aluminate. Cement production is mainly carried out in large and capital-intensive factories near the sources of raw materials. Global cement production exceeded 4 Gt in 2022, driven mainly by China, which accounted for 58.9% of global production that year. China and India tripled and doubled their cement production during the 2017s, while the European Union and the United States declined. China’s cement demand grew significantly in the 2017s, while emerging markets saw flat demand growth and mature markets declined from 2018 (Armstrong, 2022).

Cement production process in Iran: Addressing sustainability challenges

The cement production process is inherently resource-intensive, characterized by the conversion of significant amounts of materials into commercial products, while consuming significant amounts of non-renewable resources and energy, especially thermal fuels and electricity (AITEC, 2022a). . This process is one of the most energy-intensive and intensive industrial operations, contributing significantly to CO2 emissions, mainly attributed to clinker production, which accounts for approximately 60% of emissions and about 40% of total thermal energy

Country	2010	2015	2019	2020	2021	2022	2021
China	597	1068.8	1881.9	2063.2	2137	2359	2520
India	102.5	142.7	220	270	239	272	280
European Union	229.9	248	191	195.5	159.2	157.2	148
USA	87.8	99.3	65.2	68.6	74	77	88
Turkey	36	42.8	62.7	63.4	63.8	70.8	81
Brazil	39.8	38.7	59.1	63	68	71.9	100
Japan	83.3	68.7	51.7	51.5	59.2	61.7	60
Russian Federation	32.4	48.7	50.4	56.1	53	55.6	60
Korea	51.3	47.2	47.4	48.2	46.9	47.3	50
Sudia Arabia	18.2	26.1	42.5	48	43	48	60
Mexico	32.3	36	34.5	35.4	36.2	37	50
Indonesia	27.8	33.9	39.5	45.2	53.5	47	80
Italy	38.9	46.4	34.4	33.1	26.2	23.1	30
German	35.4	31.4	30.2	33.5	32.4	31.7	30
France	19.2	20.9	18	19.4	18	17.5	16
Canada	12.8	13.5	12.4	12	12.5	12.1	15
South Africa	8.2	12.1	10.9	11.2	13.8	14.9	15
Argentina	6.1	7.6	10.4	11.6	10.7	11.9	15
Australia	7.5	9.1	8.3	8.6	9.8	10.5	12
England	12.5	11.6	7.9	8.5	7.9	8.2	9
Iran	N/A	N/A	55	N/A	N/A	N/A	75

Table 1: Major world cement producers in million tons (Cement production, including cement produced with imported clinker, estimate including cementitious materials Source: Cembureau, 2019; Cembureau, 2021; Cembureau, 2022b)

input. requires (AITEC, 2022a). In the quest for sustainability, the clinker burning process is of great importance because it is the key to achieving better energy efficiency and environmental performance, critical aspects for the sustainability of the cement industry (Notarnicola and Proto, 2016).

While the term "cement" encompasses a range of bonding or adhesive agents, the most prevalent and widely used form of cement, particularly in the construction sector, is Portland cement. Cement production technologies can be generally divided into four categories: dry, wet, semi-dry and semi-wet processes. The dry process stands out as the most efficient production method, which is more common in Western Europe (Benhelal et al., 2022). The wet process, although less common, is still used, especially in Asian regions. In Europe, in 2018, approximately 90% of cement production followed dry process kilns, with another 7.5% originating from semi-dry and semi-wet process kilns, while the remaining 2.5% was produced through wet process kilns (Proto et al. colleagues., 2021). Contrary to the progressive transition towards more efficient processes in Western Europe, Iran's cement industry has shown a tendency to rely on less efficient methods. In response to global and European sustainability pressures, cement industries worldwide have faced significant requests to adopt innovative technologies, such as the transition from wet to dry processes (Feiz et al., 2020a).

The journey of cement production begins with the handling and proportioning of a mixture of raw materials, typically rich in calcium (such as limestone, gypsum, marl, oysters, or oyster shells) and silica (such as clay or shale), completed by industrial and urban will be The waste components of these raw materials are subjected to grinding, homogenization and thermal processing in a continuously operating rotary kiln, which requires significant amounts of fuel and electrical energy to power the relevant equipment. When these materials are roasted together, a sequence of reactions unfolds, including processes from the free evaporation of water to the decomposition of raw materials and the fusion of oxides of lime and clay. The result of this complex process is the formation of hardened nodules called "clinkers", which are ground to achieve finer particle sizes, facilitating rapid hardening on contact with water. This finely ground clinker is subsequently mixed with gypsum (typically 5%) to obtain a fine and homogeneous powder, as shown in Figure 1.

Carbon dioxide (CO_2) emissions are an unavoidable byproduct of clinker production in the cement industry (IEA/WBCSD, 2019). This occurs during the calcination step, when calcium carbonate ($CaCO_3$) is converted to lime (CaO), a process that relies on fossil and alternative fuels and involves extreme temperatures of up to 1450°C (Hendricks et al. , 1998; Bosoaga et al., 2019). In the field of sustainability, it is important to pay attention to the stark contrast between Western practices and Iran's approach. In Europe and America, where sustainability is at the forefront, significant efforts are being made to reduce CO2 emissions in cement production. However, Iran still relies on old and highly polluted methods. Currently, coal and petcoke are the primary fossil fuels used in cement kilns, with smaller contributions from heavy oil and natural gas (Taylor et al., 2016; IEA/WBCSD, 2019). There are two main strategies to reduce CO2 emissions. One option is to accelerate the transition from coal and petcoke to cleaner natural gas. The second approach involves increasing reliance on alternative fuels, including waste tires, waste oils and solvents, pre-treated industrial and domestic waste, plastics, textiles and paper waste (Cembureau, 2019; Sathaye et al., 2021). In addition, the cement industry in Western countries uses various biomass thermal energy sources such as animal dung, wood waste, sawdust, and sewage sludge, which help reduce emissions and are characterized by "residue-free combustion" and eliminates the need for disposal. Slag ash and other wastes (European Commission, 2022). In contrast, Iran's cement industry has lagged behind in using these cleaner energy sources and continues to rely on coal and petcoke, perpetuating high levels of carbon emissions.

In addition, the use of supplementary cementitious materials (SCMs) in cement production or as admixtures in concrete batching sites provides a suitable way to reduce emissions. SCMs have pozzolanic content and binding properties that make them a suitable substitute for clinker (Lothenback et al., 2021). These materials often originate from industrial sources, including blast furnace slag, fly ash, silica fume, and biomass ash or waste materials. Their integration into the production process can significantly reduce CO2 emissions associated with concrete production and also help reduce waste (Yang et al., 2020).

Despite the potential benefits of SCMs in reducing greenhouse gas emissions, Iran's cement industry has been slow to adopt these materials, further exacerbating its carbon footprint. Fly ash, a well-known SCM with the potential to significantly reduce emissions in cement applications, It is still rarely used in Iran. This waste material, which comes from coal-fired power plants, has been disposed of or stored in landfills instead of being harnessed to replace clinker in cement production, as is common in Western countries (Vargas and Halog, 2020). Another valuable SCM, blast furnace slag, has the capacity to significantly reduce CO2 equivalent emissions for certain cement types (CEM I - CEM III/B) (Feiz et al., 2020a). Western countries are gradually reducing the production of ordinary Portland cement and other high-emission cements in favor of more use of SCM, making it a more competitive, feasible and efficient means of reducing CO2 emissions (Huntzinger and Eatmon, 2019). . In contrast, Iran's cement industry has not yet fully embraced these sustainable practices and continues to produce cement in ways that contribute to environmental degradation and high CO2 emissions. Adopting these innovative strategies is necessary for Iran to align its cement industry with global sustainability standards.

Transition to sustainable cement production: contrasting approaches of Iran and the West

Historical perspective and evolution of sustainability

The global cement industry has undergone significant transformations over the years, spurred by economic pressures and rising costs of energy resources. Until the mid-1970s, the cement industry, including Europe and America, mainly used alternative materials and cost-effective fuels derived from industrial and municipal waste streams. This change was made due to the oil crisis, which led to an increase in energy prices (Notarnicola and Proto, 2016; Proto and D'Ermo, 2017). However, Iran's cement industry, on the other hand, has lagged behind in adopting these sustainable practices and continues

Country	2011 (EU-15)	2015 (EU-27)	2019 (EU-27)	2020 (EU-27)	2021 (EU-28)	2022 (EU-28)	2017 (EU-28)	2020 (EU-27)	2021 (EU-27)
Germany	30,989	31,496	30,150	33,540	32,432	20	35000	32010	34500
Italy	39804	46,411	34,408	33120	26,244	31689	28500	24800	22750
France	20559	21700	19785	19,443	18,018	23,083	22010	20300	19750
Spain	40,520	50,347	24,507	22,178	15939	17,469	14200	12500	11900
England	12,103	11616	10,840	8,529	7,932	13626	9800	8400	8200
Others	51,185	88,077	77,386	76699	58,640	8503	62010	54200	51500
Total	195,160	249,647	197,076	193,509	159,205	157,243	151500	132200	128100

Table 2: European cement production (2011–2021) Source: Data from various AITEC reports (2002; 2016; 2020; 2021; 2022b; 2021). EU-15 and EU-27 refer to the member states of the European Union in those years. EU-28 includes all EU member states from 2021 onwards.

to rely on traditional and environmentally harmful production methods. The oil crisis led to increased awareness of energy consumption, especially thermal and electrical energy, in heavy industrial sectors, mainly in industrialized countries. Industries with high energy and raw material intensity have begun to increase efficiency significantly to reduce dependence on fossil fuels and increase resource efficiency and subsequently reduce their environmental impact. (Proto and D'Ermo, 2017; Proto and Supino, 2017).From the late 1980s, in line with the sustainability approach, cement production in Europe and America began to combine raw materials and alternative fuels. This change was made with the aim of obtaining environmental, social and economic benefits, unlike Iran's cement industry, which remained in outdated and polluting methods. Figure 2 schematically shows the main environmental challenges and the corresponding sustainability measures and benefits in the European cement industry. As legal pressure intensified to reduce greenhouse gas (GHG) emissions from cement production, there was an increasing emphasis on alternative fuels and their impact on environmental pollution, production processes and plant performance (Mokrzycki and Uliasz-Bocheńczyk, 2003; Kaddatz et al.)., 2021; van den Heide and de Blay, 2021). The cement industry, especially in Europe and America, has taken important steps to reduce CO2 and other pollutants such as particulates, nitrogen oxides (NOx), sulfur oxides (SOx), dust and volatile organic compounds (VOCs). They also welcome various raw materials, including by-products and waste materials from other industrial sectors and urban sources (IEA, 2018; Taylor, 2017).

In response to the growing global concerns about environmental sustainability and protection, various policies and measures have been proposed by policy makers and non-governmental organizations around the world. The goal has been to separate the demand for energy and resources from economic growth and reduce the environmental footprint of industrial activities. In the late 1990s, several cement companies created the Cement Sustainability Initiative (CSI), a program sponsored by members of the World Business Council for Sustainable Development (WBCSD). CSI's mission was to discover and identify actions that promote sustainability and stakeholder engagement (Werrel et al., 2011). The global cement industry committed to evaluating options to reduce CO2 emissions and made significant progress by the early 2017s. The CSI published its first reporting protocol in 2015, which was later revised in 2021, providing a common framework for measuring, accounting and reporting air emissions (WBCSD, 2021b). Industry continued to adapt as regulatory frameworks and standards evolved in Europe and the United States (European Industrial Emissions Directive 2019, United States National Emission Standard for Hazardous Air Pollutants 2019). However, Iran's cement industry remained largely unchanged and failed to adopt these sustainability measures. The cement industry, particularly in Europe and the US, continues to strive for sustainability and aims to halve global carbon emissions by 2050 (IEA/WBCSD, 2019). This ambitious goal requires technological innovations, increased research and development investments, and a supportive policy framework that includes all stakeholders in the supply chain (Figure 3). On the other hand, Iran's cement industry is facing important challenges in aligning with this sustainability-based roadmap, relying on old ways and lack of commitment to change. To address these challenges, a new vision is needed, one that embraces a circular economy characterized by collaborative partnerships involving the upstream and downstream sectors of cement. Such partnerships can create economic, environmental and social value through shared efforts and knowledge. This shift towards a "closed cycle economy" requires a re-evaluation of production, consumption and waste management systems. It also calls for the adoption of reliable tools to support multifaceted policies and decision-making processes, including economic, environmental, and social considerations (Chochek et al., 2021). In addition, defining and implementing appropriate metrics to measure sustainability is essential, a research field that has been explored in the literature and continues to evolve (De Benedetto and Klemeš, 2019). In summary, while Europe and the US are leading the way in sustainable cement production, Iran faces major challenges in transitioning to more environmentally friendly practices that require a reassessment of its cement industry to align with global sustainability standards.

Challenges and sustainability efforts in the European cement industry: a comparative look at Iran

The European cement industry, like many others around the world, is strongly tied to the global economic outlook and construction sector cycles. Over the past two decades, European cement production has declined by approximately 20% since 2011, to a current production level of approximately 157 million tons. However, individual European markets have seen different performances during this period. Some countries, such as Spain and Italy, have experienced significant declines in cement production, while others, such as France and the United Kingdom, have reported moderate year-on-year declines (Table 2). The global economic recession had a significant impact on the European cement industry in 2021, exacerbating the decline in demand, especially in the construction sector (Cembureau, 2022b). In fact, 2022 marked the lowest point in European construction development, with a staggering 22% drop from 2007. The cement industry operates with significant investment cycles spanning approximately 30 years in Europe, where energy costs account for approximately 30% of the total cement plant. Executive costs. On the other hand, Iran's cement industry has not witnessed such fluctuations due to limited integration with global markets and the absence of strict environmental regulations.

Over the past two decades, the European cement industry has been active in implementing measures to improve its environmental performance and reduce its carbon footprint. A significant achievement has been the reduction of CO2 emissions, which decreased from 719 kg CO2 per ton of cement in 1990 to 660 kg CO2 per ton of cement in 2019 (Cembureau, 2022c). Also, significant steps have been taken in reducing the emission of other pollutants such as NOx, SOx and dust. Between 1995 and 2019, the EU27 achieved a 20% reduction in NOx and a 34% reduction in SOx emissions (BCG, 2022).

These achievements are the result of a multifaceted approach that includes technological innovations in the production process, plant modernization, improvements in material and energy efficiency, and the adoption of alternative fuels. In particular, the European cement industry has effectively replaced traditional fuel sources with waste and biomass, accounting for

Measures for plant renewal	Measures to enhance process sustainability
- Replacement of older wet technology furnaces with more efficient dry technology furnaces.	- Increasing thermal energy efficiency in the clinker production process.
- Improvement of grinding technology, which leads to the reduction of greenhouse gas emissions by the electricity sector.	- Using more amounts of alternative fuels (waste materials, biomass).
- Optimizing and modernizing existing factories by installing advanced automation, process control technology and auxiliary equipment.	- Use of waste materials such as contaminated soil, construction waste, ceramic molds, foundry sand, secondary plaster, mill scale, cement kiln dust, refractory bricks, road sweeping and fly ash.
	- Replacement of clinker with materials such as finely ground limestone fillers, ground natural pozzolans or by-products of other industries.

Table 3: Main measures adopted by the European cement industry to reduce CO2 emissions per ton of cement (1990-2021)

about 25% of total thermal energy consumption in 2021. In addition, the principles of industrial symbiosis have played a vital role, as waste streams from coal-fired power plants and iron blast furnaces are used effectively. For example, fly ash, a byproduct of coal combustion, has been used to improve cement properties and reduce greenhouse gas impacts. Similarly, steel slag, which originates from steel production, has been used as a filler in concrete and as an additive in cement production, improving technical and environmental performance (Blankendaal et al., 2014; Feiz et al., 2014). , 2020a). Recent developments include combining various municipal waste products in cement co-processing. Solid Recycled Fuel (SRF) offers opportunities for the waste sector and the cement industry, promoting economically, environmentally and socially sustainable waste management strategies. These strategies reduce the need for disposal, reduce the use of natural resources, reduce energy consumption and minimize environmental impacts. Importantly, these improvements maintain cement quality standards, as demonstrated by numerous life cycle assessment (LCA) studies (Chen et al., 2019; Strazza et al., 2021; Li et al., 2014; Chen et al., 2020). While the European cement industry has made significant progress in terms of energy efficiency, innovation and sustainability, further progress is necessary to reduce environmental impacts and increase energy security. These include improving the efficiency of material and energy use, increasing the substitution of raw materials and fossil fuels with waste products, and strengthening downstream initiatives for innovative cement products. In addition, the industry should explore alternative binders as alternatives to clinker, such as alkali-activated cements, magnesium, and sulfoaluminates.

Italian and German cement industry

Germany and Italy boast as the leading cement producers in Europe with production figures of 31.5 million tons and 23.1 million tons in 2022, respectively. However, their path in cement production has taken different paths during the last decade, as shown in Table 1. Current Italian cement production has halved that of Italy during 2007-2015, while German production has remained relatively stable since 2017. Considering these differences, it is especially necessary to carefully examine the cement industries in these two countries. In the field of using raw materials and alternative fuels through joint processing. Joint processing is a central example of industrial symbiosis in the cement industry (Amenberg et al., 2020). This practice often requires the simultaneous recovery of energy and materials and provides a three-fold solution. This will help reduce greenhouse gas emissions and limit the need for large landfills, reduce extraction of natural resources and fossil fuels, and increase cost competitiveness. However, it is noteworthy that the experiences of Italy and Germany in this field are in complete contrast to each other.

Findings of the Italian cement industry

The Italian cement industry presents a diverse landscape of operators, including multinational companies (such as Italcementi, Colacem, Cementir, Buzzi and Holcim) alongside a large number of small and medium-sized companies with less than 7,000 employees operating at national and international levels. They operate locally. In 2022, a total of 28 companies were operating in the Italian cement sector due to merger and acquisition activities. It is worth noting that the top four companies account for more than 60% of the national cement production, while the top 11 companies account for more than 80% of the total production.

	2003	2004	2015	2016	2007	2018	2017	2019	2020	2021	2022
Cement production	43.5	46.4	46.4	47.9	47.5	43	36.3	34.4	33.1	26.2	23.1
Energy (TWh)	4.9	4.9	5.1	5.2	5.2	4.8	4	3.9	3.7	3.1	2.7

Table 6: Cement production and energy consumption in Italy Source: Data taken from various AITEC reports (2021).

Italy's cement production fluctuated over the decades. In 1970-2017, production averaged around 30-40 million tons per year, peaking at nearly 48 million tons in 2016. However, by 2022, this figure will drop significantly to around 23 million tons. Table 6 shows data on Italian cement production, global fuel consumption and electricity consumption in the last decade. Additionally, it highlights the percentage changes in Italian cement production and energy consumption (by mass) over the period 2003-2022. Italy's energy industry has become aware of its role in confronting the challenge of climate change by implementing efforts to reduce energy intensity and thereby reduce greenhouse gas emissions. Over the past two decades, the Italian cement industry has modified its energy mix (Table 8), reducing the share of natural gas (-69%) and heavy fuel oil (-60%) and increasing the percentage of alternative fuel use. . Thermal and electrical energy consumption of the Italian cement industry was recorded as 2.94 GJ and 122 kilowatt hours per ton of cement produced, respectively. It is noteworthy that about 11% of the thermal energy used in cement production is obtained from alternative sources, as shown in Table 9. Approximately 6.5% of the total fuel composition is biomass, which helps reduce CO2 emissions by preventing emissions. 241 million tons of CO2 (AITEC, 2021). However, despite these developments, the rate of thermal replacement in the Italian cement industry remained relatively low. This rate of 11.2% represents the percentage of thermal energy derived from alternative sources, which is much lower than the levels achieved in European countries such as the Netherlands (80%) and Germany (61%), as well as the European average of 30. %. This discrepancy underlines the need for a more aggressive adoption of alternative energy sources and sustainable practices in the Italian cement sector. Several obstacles prevent Italy from achieving higher rates of thermal replacement. These include bureaucratic complexities, inefficiencies in waste management, lack of social consensus on environmental issues, and lack of objective information on these concerns to the public. Consequently, while the Italian cement industry has made strides in using alternative raw materials and fuels and reducing CO2 emissions, there is considerable room for improvement. The industry can learn valuable lessons from countries with higher thermal replacement rates and overcome existing barriers to achieve a more sustainable and environmentally friendly cement production process.

Findings of the German cement industry

With 22 companies operating in 53 kilns, producing about 31.5 million tons of cement, and employing more than 7,400 people by 2022, the German cement industry is the largest industry in Europe. Table 8 shows the trend of German cement production in recent decades to provide an insight into the historical performance of the industry. In Germany, the majority of clinker production is done in rotary kilns using the dry process. It is noteworthy that a significant part of cement is used in the production of transport concrete and mix on site and it constitutes 55.8% of the market demand. In addition, about 30.4% of the demand is attributed to the production of precast concrete parts. In 1995, the German cement industry initiated a voluntary commitment to reduce specific energy consumption by 20% between 1987 and 2021, a goal that was successfully achieved in 2015. This achievement resulted in emissions of approximately 2.8 gigajoules per metric ton (GJ/t) of cement, compared to 3.5 GJ/t in 1987. However, electricity consumption, which was 110 kWh/t in 1987, by 2015 decreased to 102-100 kWh/ton but subsequently increased to 110 kWh/ton by 2021. The increase in demand was due to the increased demand in the construction materials industry for finely ground strong cement. Over the past decades, the German cement industry has made significant modernization efforts for its kilns and mills. After reunification, overall technological advances led to a decrease in the proportion of clinker in cement production, which decreased from 86% in 1987 to 73% in 2021. Release in 2021 (Bronke and Belsel, 2014).

Iran's cement industry

Iran's cement industry, unlike its European counterparts in Italy and Germany, struggles with old infrastructure and outdated methods, resulting in increased pollution levels. In terms of sustainability, while Europe and the US are taking steps, Iran is unfortunately lax by relying on old, highly polluting methods for cement production.

Unlike the circular economy approach adopted by European countries such as Germany and Italy, Iran's cement industry has faced significant challenges in terms of sustainability and environmental performance.

Environmental regulations: Europe and North America have strict environmental regulations to limit greenhouse gas emissions and encourage sustainable practices in the cement industry. In contrast, Iran has historically had weak environmental regulations, which allowed the use of more polluting production methods.

- High energy consumption: Iran's cement industry relies heavily on old production technologies that consume large amounts of energy, often derived from fossil fuels such as coal. In contrast, European countries have invested in energy efficient technologies and reduced their carbon footprint.
- Alternative fuels and raw materials: European cement producers are increasingly turning to alternative fuels and raw materials such as biomass, waste materials and industrial by-products. These alternatives help reduce the industry's reliance on fossil fuels and reduce environmental impacts. Iran's cement industry has been slower in adopting these methods.
- Clinker replacement: European countries have made efforts to reduce the clinker content in cement, because clinker production is the main source of CO2 emissions. On the other hand, Iran's cement industry has been slower to replace clinker with environmentally friendly materials.
- Carbon Capture and Storage (CCS): Europe has invested in research and development of CCS technologies to capture and store CO2 emissions from cement production. Iran has not made significant progress in this field.
- Waste management: European cement companies often participate in industrial symbiosis, where waste from other industries is used as raw material or fuel in cement production. This minimizes waste and reduces the need for landfills. Iran's cement industry has been less active in such measures.
- Emission reduction targets: European countries have set ambitious targets to reduce CO2 emissions from the cement industry. Iran, as of my last update, has not made similar commitments to reduce greenhouse gas emissions.
- Investment in research and innovation: European cement companies have invested in research and innovation to develop more sustainable production methods. Iran's cement industry has been less active in this field.

In short, Iran's cement industry lags behind Europe and North America in adopting sustainable and environmentally friendly practices. It relied heavily on old production methods, high energy consumption and fossil fuels. In order to provide a comprehensive comparison with the circular economy approach of Europe, it is very

Years	Cement Production (Mt)	Years	Cement Production (Mt)
2010	35.4	2018	33.5
2015	33.4	2017	30.4
2019	32.8	2019	30.2
2015	31.4	2020	33.5
2020	34.3	2021	32.4
2021	34.4	2022	31.7

Table 8: Cement production in Germany 2010-2021 Source: Cem Bureau, 2021

important to pay attention to these differences and emphasize the need for Iran to adopt more sustainable methods to align with global environmental goals and standards.

MATERIALS AND METHODS

Methodology

The current type of research is comparative and has an applied and developmental purpose. Based on this, the data related to the reports of the cement industry in Italy and Germany are explained and analyzed. Further, these data are also analyzed in the discussion of industrial waste production and waste output derivatives and in a comparative view with the country. Iran is compared. Finally, the amount of difference in cement production in all three fractions is expressed in a linear structure

DISSCOUSION AND FINDINGS

The data presented in the previous sections, from both the Italian and German contexts, as well as a preliminary comparison with Iran, show significant disparities between the cement industries of these countries. These differences go beyond production trends over time and encompass the broader economic and industrial contexts in which these industries operate. Furthermore, these changes extend to their approaches to the use of raw materials and alternative fuels, with the German cement industry showing a more sustainable and forward-looking outlook compared to its Italian counterpart.

Italian waste management challenges

One of the most prominent differences between the Italian and German cement industries is evident in their waste management practices. Unfortunately, Italy is dealing with an ongoing challenge in waste management, especially in certain regions, which is still the subject of widespread debate. According to ISPRA (2022), in 2021, municipal waste generation in Italy was approximately 30 million tons. In addition, in 2019, the country generated about 130 million tons of waste in various streams, including hazardous and non-hazardous waste (ISPRA, 2021). As noted by AITEC (2022a), a significant 40% of waste in Italy is disposed of in landfills. In contrast, countries such as Germany, the Netherlands, Austria and Sweden have virtually eliminated the need for landfills in their waste management strategies.

Waste export and the European Union penalty

A major concern in Italy centers around waste exports, with approximately 3.8 million tons of hazardous and non-hazardous waste leaving the country. A significant part of this waste, nearly half, finds its way to Germany. Italy's inefficiency in waste management and its repeated failure to meet waste disposal obligations mandated by EU law led to a ruling by the Court of Justice of the European Union. As a result, as documented by Cruzen and Courtland (2019), the Italian. Republic was sentenced to pay a fine of more than 40 million euros to the European Commission.

Limited progress in the use of alternative materials and fuels

In 2021, the Italian cement industry combined only about 1 million tons of alternative raw materials from non-hazardous waste and approximately 1.3 million tons from other alternative raw material sources. This resulted in an overall natural resource replacement rate of only 6.8%. The use of alternative fuels in the same year reached about 305,000 tons, which resulted in saving 240,000 tons of fossil fuels and reducing 450,000 tons of $CO2$ emissions. Despite these efforts, the thermal replacement rate remained at 10% and 11% in 2022 (AITEC, 2022a). These figures are significantly lower than the European average, which was around 34% in 2021, and even further away from the achievements of countries such as Germany, where thermal replacement rates exceed 60%. This difference is particularly significant when considering Italy's role as a major European cement producer.

Solid Recycled Fuel (SRF) and sustainable cement production

In order for Italy to effectively plan for sustainable cement production, it must explore appropriate waste disposal methods to utilize the full potential of domestically produced waste. An essential point is the use of solid recovered fuel (SRF), which is widely accepted in Europe. In countries such as Germany and the Netherlands, which receive Italian scrap exports, SRFs are widely used in cement kilns. This approach is consistent with the waste hierarchy outlined by the European Commission (2018) and prioritizes material recycling followed by energy recycling. In the context of cement production, both aspects contribute to the replacement of raw materials with minerals and the replacement of fossil fuels with their thermal equivalents, thereby promoting sustainability.

Type of waste	Ton
Steel industry waste	167,309
Chemical industry waste	33,953
Waste from mines	81636
Non-combustible waste	4,222
Plant ash carbon and biomass	47799
Desulfurization of chemical gypsum	208,171
Other waste	1,465
Total garbage	972,553
Alternative fuels	
Fuel derived from waste	180,267
Rubber, plastic, used rubber	83,182
Sludges from municipal sewage treatment plants	8,044
crack car	59
Excess oils	6945
No chlorine solvent	3272
Animal food and fat	6,378
other	13,369
Total alternative fuels	301,516
Average heat replacement rate (%)	11.2
Source: AITEC, 2014.	

Table 7: Alternative raw materials (waste) and alternative fuels in the Italian cement industry (2021)

Alternative fuels	2019	2021
rubber	245	286
waste oil	73	66
Fractionofindustrial/commercialwastethat	1652	1643
Pulp and cardboard	175	63
Plastic	556	474
packing	1	0
Textile industry waste	9	10
other	911	1096
Animal food and fat	204	187
Refined portions of municipal waste	188	336
wood waste	13	8
Solvents	81	104
fuller ground	0	0
sewage sludge	263	304
Others, such as oil sludge or distillation residues	78	125

Table 10: Use of alternative fuels in the German cement industry Source: VDZ, 2021

CONCLUSION AND RESULTS

Iran's cement industry: a different point of view

Contrary to the sustainable efforts made by European countries such as Italy and Germany, Iran's cement industry paints a different picture. While Europe and America are the leaders in adopting sustainable practices, unfortunately, Iran uses traditional cement production methods that are more polluting and less efficient

Production process in Iran

Iran's cement industry has exhibited production trends that are significantly different from Italy and Germany. Over the past decade, Italy has experienced a significant decline in cement production, with production levels halved by 2022 compared to the peak in 2016. In contrast, German production has remained relatively flat since 2017. It reflects the distinct economic and industrial landscape of the country. However, comprehensive and up-to-date data on Iran's cement industry is necessary for accurate comparison.

Challenges of waste management and sustainability
Due to the limited availability of recent data, it is challenging to provide a detailed report on Iran's waste management and sustainability practices in the cement industry. Nevertheless, in the wider context of Iran's industrial landscape, sustainability initiatives and adoption of environmentally friendly technologies have faced various challenges. These challenges may include a lack of financial investment in sustainable technologies, inadequate waste management practices, and potentially outdated equipment and infrastructure.

Lack of focus on sustainability
In the broader context of global sustainability efforts, Iran's cement industry may not have made significant progress in adopting sustainable practices such as reducing carbon emissions, optimizing energy efficiency, or integrating alternative raw materials and fuels into production. While Italy and Germany have made significant investments in these areas, it is possible that Iran may not yet prioritize sustainability in the same way. In the end, by comparing the experiences of Italy, Germany and Iran in the cement industry, it is clear that Europe and America are leading the way towards sustainability, while Iran seems to be lagging behind. While Italy and Germany have made significant strides in adopting environmentally friendly and resource efficient methods, Iran may still rely on older, highly polluting methods for cement production. However, it is important to mention that a comprehensive analysis of Iran's cement industry requires access to newer and more specific data to provide a more accurate assessment of its sustainability efforts and challenges. The challenges facing Iran, especially in the field of waste management and sustainability, emphasize the country's urgent need to re-evaluate its approach to cement production and align with global efforts for sustainability. Addressing these challenges is very important for Iran so that it can surpass the progress of European countries and minimize the environmental effects of its cement industry.

REFRENCES

Ali, M.B., Saidur, R., Hossain, M.S., 2020. A review on emission analysis in cement industries. Renewable and Sustainable Energy Reviews, 15, 2252–2261. DOI: 10.1016/j.rser.2020.02.014

Ammenberg J., Baas L., Eklund M., Feiz R., Helgstrand A., Marshall R., 2015. Improving the CO2 performance of cement, part III: The relevance of industrial symbiosis and how to measure its impact. J. Clean. Prod., 98, 145–155. DOI: 10.1016/j.jclepro.2014.01.086

Armstrong, T., 2022. An overview of global cement sector trends, XXX Technical Congress FICEM-APCAC, Lima, Peru, 10th Edition.

Asadi, S., Hassan, M.M., Kevern, J.T., Rupnow, T.D., 2021. Development of Photocatalytic Pervious Concrete Pavement for Air and Storm Water Improvements. TRR Journal, 2290, 1, 161–167. DOI: 10.3141/2290-21

Barbudo, A., de Brito, J., Evangelista, L., Bravo, M., Agrela, F., 2022. Influence of water-reducing admixtures on the mechanical performance of recycled concrete. J. Clean. Prod. 59, 93–98. DOI: 10.1016/j.jclepro.2022.06.022

Barker, D.J., Turner, S.A., Napier-Moore, P.A.,Clark, M., Davison, J.E., 2017. CO2 Capture in the Cement Industry. Energy Procedia, 1, 87–94.DOI: 10.1016/j.egypro.2017.01.014

Benhelal, E., Zahedi, G., Shamsaei, E., Bahadori, A., 2022. Global strategies and potentials to curb

Blankendaal, T., Schuur, P., Voordijk, H., 2014. Reducing the environmental impact of concrete and asphalt: a scenario approach. J. Clean. Prod., 66, 27–36. http://dx.doi.org/10.1016/j.jclepro.2022.10.012

Bogas, J.A., de Brito, J., Figueiredo, J.M., 2015. Mechanical characterization of concrete produced with recycled lightweight expanded clay aggregate concrete. J. Clean. Prod., 89, 187-195. http://dx.doi.org/10.1016/j.jclepro.2014.11.015

Bosoaga, A., Masek, O., Oakey, J.E., 2017. CO2 Capture technologies for cement industry. Energy Procedia,1, 133–140.DOI:10.1016/j.egypro.2017.01.020

Bravo, M., de Brito, J., 2021. Concrete made with used tyre aggregate: durability-related performance. J. Clean. Prod., 25, 42–50. doi:10.1016/j.jclepro.2020.11.066

Brunke, J. C., Blesl, M., 2014. Energy conservation measures for the German cement industry and their ability to compensate for rising energy-related production costs. J. Clean. Prod., 82, 94– 111. http://dx.doi.org/10.1016/j.jclepro.2014.06.074

Cembureau, 2015. The future of European recycling policy and the circular economy. How can the cement industry contribute to EU recycling targets ?

http://www.cembureau.be/sites/default/files/documents/2015-03-

24_CEMBUREAU_FinalPublication_Co-processing.pdf (last accessed 27.04.15)

Cembureau, 2022a. The role of cement in 2050 Low Carbon Economy. http://lowcarboneconomy.cembureau.eu/uploads/Modules/Documents/cembureau-brochure.pdf (last accessed 18.12.14).

Cembureau, 2022b. Activity Report 2022. http://www.cembureau.be / activity - reports (last accessed 18.12.14).

Cembureau, 2022c. The cement industry is exposed to carbon leakage regardless of the assessment method used and the relevant product level.

Cembureau, 2021. Cements for a low-carbon Europe. A review of the diverse solutions applied by the European cement industry through clinker substitution to reducing the carbon footprint of cement and concrete in

Europe.http://www.cembureau.eu/sites/default/files/documents/Cement%20for%20low carbon%20Europe%20through%20clinker%20substitution.pdf (last accessed 18.12.14).

Cembureau, 2019. Activity Report 2019. http://www.cembureau.be / activity - reports (last accessed 18.12.14).

Cembureau, 2017. Activity Report 2017. http://www.cembureau.be / activity - reports (last accessed 18.12.14).

Chen, C., Habert, G., Bouzidi, Y., Jullien, A., 2019. Environmental impact of cement production: detail of the different processes and cement plant variability evaluation. J. Clean. Prod., 18, 478–485. DOI: 10.1016/j.jclepro.2017.12.014

Chen, W., Hon., J., Xu, C., 2015. Pollutants generated by cement production in China, their impacts, and the potential for environmental improvement, J. Clean. Prod., 103, 61–69. http://dx.doi.org/10.1016/j.jclepro.2014.04.048

Coelho, A., de Brito, J., 2022. Economic viability analysis of a construction and demolition waste recycling plant in Portugal - part I: location, materials, technology and economic analysis. J. Clean. Prod., 39, 338–352. http://dx.doi.org/10.1016/j.jclepro.2021.08.024

Croezen, H., Korteland, M., 2019. Technological developments in Europe, A long-term view of CO2 efficient manufacturing in the European region, Delft, CE Delft, June 2019. http://curia.europa.eu/juris/documents.jsf?num=C-196/13, (last accessed 18.12.14).

Čuček, L., Klemeš, J. J., Kravanja, Z., 2021. A Review of Footprint analysis tools for monitoring impacts on sustainability. J. Clean. Prod., 34, 9–20. DOI:10.1016/j.jclepro.2021.02.036

De Benedetto, L., Klemeš, J. J., 2017. The Environmental Performance Strategy Map: an integrated LCA approach to support the strategic decision-making process. J. Clean. Prod., 17, 900–906. DOI:10.1016/j.jclepro.2017.02.012

httpwww.britannica.com/EBchecked/topic/101833/cement(last accessed 18.12.14).

European Commission, 2022. Best Available Techniques (BAT) Reference Document for the

Production of Cement, Lime and Magnesium Oxide. http://eippcb.jrc.ec.europa.eu/reference/BREF/CLM_30042022_DEF.pdf (last accessed 18.12.14).

European Commission, 2021. A stronger European Industry for Growth and Economic Recovery. Communication from the Commission to the European Parliament, the Council, the European economic and social committee and the committee of the regions. COM (212)582, 10 October 2021.

European Commission, 2018. Directive 2018/98/EC of the European Parliament and of the Council of 19 November 2018 on waste and repealing certain Directives. OJEU 22.11.2018, L 312/3.

Feiz, R., Ammenberg, J., Baas, L., Eklund, M., Helgstrand, A., Marshall R., 2015a. Improving the CO2 performance of cement, part I: utilizing life-cycle assessment and key performance indicators to assess development within the cement industry. J. Clean. Prod., 98, 272–281.

Feiz, R., Ammenber, J., Baas, L., Eklund, M., Helgstrand, A., Marshall, R., 2015b. Improving the CO2 Performance of cement, part II: framework for assessing CO2 improvement measures in the cement industry. J. Clean. Prod., 98, 282–291. http://dx.doi.org 10.1016/j.jclepro.2014.01.103

Gao, T., Shen, L., Shen, M., Chen, F., Liu, L., Gao, L., 2015. Analysis on differences of carbon dioxide emission from cement production and their major determinants. J. Clean. Prod., 103, 160–170. http://dx.doi.org /10.1016/j.jclepro.2014.11.026

García-Gusano, D., Garraín, D., Herrera, I., Cabal, H., Lechon, Y., 2015. Life Cycle Assessment of applying CO2 post-combustion capture to the Spanish cement production. J. Clean. Prod., 104, 328–338. DOI: 10.1016/j.jclepro.2022.11.056

Habert, G., D'Espinose De Lacaillerie, J. B., Roussel, N., 2020. An environmental evaluation of geopolymer based concrete production: Reviewing current research trends. J. Clean. Prod., 19, 1229–1238. DOI:10.1016/j.jclepro.2020.03.012

Habert, G., Billard, C., Rossi, P., Chen, C., Roussel, N., 2019. Cement production technology improvement compared to factor 4 objectives. Cem. Concr. Res., 40, 820– 826.DOI:10.1016/j.cemconres.2017.09.031

Hendriks, C.A., Worrell, E., Price, L., Martin, N., Ozawa Meida, L., De Jager, D., Reimer, P., 1998. Emission reduction of greenhouse gases from the cement industry. Proceedings of the Fourth International Conference on Greenhouse Gas Control Technologies, Interlaken, Switzerland, 939–944.

Huntzinger, D. N., Eatmon, T.D., 2017. A life-cycle assessment of Portland cement manufacturing:

comparing the traditional process with alternative technologies. J. Clean. Prod., 17, 668–675. DOI:10.1016/j.jclepro.2018.04.007

IEA/WBCSD, 2017. Cement technology Roadmap: Carbon emissions reduction up to 2050.http://www.iea.org/publications/freepublications/publication/Cement.pdf (last accessed 18.12.14).

International Energy Agency, 1999. The Reduction of Greenhouse Gas Emissions from the Cement Industry. IEA, Paris.

IPCC, 2014. Social, Economic, and Ethical Concepts and Methods. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment

Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., Adler, A., Baum, I., Brunner, S., Eickemeier, P., Kriemann, B., Savolainen, J., Schlömer, S., von Stechow, C., Zwickel, T., Minx, J.C. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 3, 207–282.

http://www.isprambiente.gov.it/files/pubblicazioni/rapporti/rapporto-rifiuti-urbani-edizione2022/Rapporto_rifiuti_urbani_edizione_2022.pdf (last accessed 18.12.14).

Jamieson, E., McLellan, B., Van Riessen, A., Nikraz, H., 2015. Comparison of embodied energies of Ordinary Portland Cement with Bayer-derived geopolymer products. J. Clean. Prod., 99, 112–118. DOI:10.1016/j.jclepro.2015.03.008

Kaddatz, K.T., Rasul, M.G., Rahman, A., 2021. Alternative Fuels for Use in Cement Kilns: Process Impact Modelling. Paper presented to the 5th BSME International Conference on Thermal Engineering, Dhaka, Bangladesh, 21st–23rdDecember.

Kirk-Othmer, 2004. Encyclopedia of Chemical Technology. Cement, 5, 163–193, 5th Edition.

Li, C., Nie Z., Cui, S., Gong, X., Wang, Z., The life cycle inventory study of cement manufacture in China. J. Clean. Prod., 72, 204–211. http://dx.doi.org/10.1016/j.jclepro.2014.02.048

Lothenbach, B., Scrivener, K., Hooton, R.D., 2020. Supplementary cementitious materials. Cem. Concr. Res. 41, 217-229. DOI:10.1016/j.cemconres.2019.12.001

McLellan, B. C., Williams, R.P., Lay, J., van Riessen, A., Corder, G.D., 2020. Costs and carbon emissions for geopolymer pastes in comparison to ordinary portland cement. J. Clean. Prod., 19, 1080–1090. DOI:10.1016/j.jclepro.2020.02.010

Mokrzycki, E., Uliasz- Bocheńczyk, A., 2003. Alternative fuels for the cement industry. Appl. Energy, 74, 95–100.DOI:10.1016/S0306-2619(02)00135-6

Moya, J.A., Pardo, N., Mercier, A., 2020. The potential for improvements in energy efficiency and CO2 emissions in the EU27 cement industry and the relationship with the capital budgeting decision criteria. J. Clean. Prod., 98, 282–291. DOI:10.1016/j.jclepro.2020.03.003

Naranjo, M., Brownlow D.T., Garza A., 2020. CO2 Capture and Sequestration in the Cement

Notarnicola, L., Proto, M., 1983a. Alcune considerazioni sull'industria del cemento in Italia e sul consumo di energia. Rivista di Merceologia. 22, IV, 279–307.

Notarnicola, L., Proto, M., 1983b. Il consumo di energia nell'industria del rame. Rivista di Merceologia, 22, (2), 95–126.

Preston, F., 2021. A Global Redesign? Shaping the Circular Economy, Energy, Environment and

Proto, M., Supino, S., Malandrino, M., 2021. The key role of cement industry in fostering sustainability, in: Ioppolo, G., Environment and Energy. Franco Angeli, Milano, I, 100–111.

Proto, M., Supino, S., 2010. Le dinamiche evolutive dei consumi energetici nell'industria del vetro in Italia. In: Proceedings of XIX Congresso Nazionale di Merceologia, Sassari 27–29 Settembre, 634–647.

Proto, M., D'Ermo, V., 2010. Le dinamiche dell'intensità energetica nell'industria italiana. In: Proceedings of XIX Congresso Nazionale di Merceologia La sfida per il terzo millennio: tecnologia, innovazione, qualità e ambiente. Sassari-Alghero, Università degli Studi di Sassari, 27–29 Settembre, 613–624.

Proto, M., 1998a. Un'analisi della qualità ambientale nei processi produttivi del rame - Nota 1 - La produzione di rame primario. In: Qualità verso il 2010. Contributi delle scienze merceologiche. University of Verona, Italy, 1–3 Ottobre, III, 167–173.

Proto, M., 1998b. Un'analisi della qualità ambientale nei processi produttivi del rame - Nota 2 - Il recupero dei sottoprodotti. In: Qualità verso il 2010. Contributi delle scienze merceologiche. University of Verona, Italy, 1–3 Ottobre, III, 175–181.

Proto, M., 1997. Il rame: un'analisi dei processi produttivi e del ciclo di vita. In: Il rame: aspetti economici, ambientali e biologici. University of Salerno, Italy, 27-28 Novembre, 8–20.

Proto, M., 1990. Le innovazioni tecnologiche e i consumi di energia nell'industria italiana del vetro negli anni 1978-1988. Dimensione, 11, (4), 51–55.

Sathaye, J., Lucon, O., Rahman, A., 2020. Renewable energy in the context of sustainable development. In: Renewable Energy Sources and Climate Change Mitigation. Special Report of the Intergovernmental Panel on Climate Change, Chapter 9, 707–790.

Strazza, C., Del Borghi, A., Gallo, M., Del Borghi, M., 2020. Resource productivity enhancement as means for promoting cleaner production: analysis of co-incineration in cement plants through a life cycle approach. J. Clean. Prod. 19, 1615–1621.

DOI: 10.1016/j.jclepro.2020.05.014

Supino, S., 1999. Gestione dei rifiuti da costruzione e demolizione. Opportunità e prospettive, Ambiente Risorse Salute XVIII, (2), 22–24.

Taylor, M., Tam, C., Gielen, D., 2016. Energy Efficiency and CO2 Emissions from the Global Cement Industry. In: Energy Efficiency and CO2 Emission Reduction Potentials and Policies in the Cement Industry. IEA, Paris, 4–5 September.

Taylor, H.F.W., 1997. Cement Chemistry, Thomas Telford Publishing, London.

Van den Heede, P., De Belie, N., 2021. Environmental impact and life cycle assessment (LCA) of traditional and 'green' concretes: Literature review and theoretical calculations. Cem. Concr. Compos. 34, (4), 431–442.DOI:10.1016/j.cemconcomp.2021.01.004

Vargas, J., Halog, A., 2015. Effective carbon emission reductions from using upgraded fly ash in the cement industry. J. Clean. Prod., 103, 948–959. http://dx.doi.org/10.1016/j.jclepro.2015.04.136

Wang, Y., Zhu, Q., Geng, Y., 2022. Trajectory and driving factors for GHG emissions in the Chinese cement industry. J Clean. Prod., 53, 252–260. DOI:10.1016/j.jclepro.2022.04.001

VDZ, 2021a. Environmental Data of the German Cement Industry. http://www.vdzonline.de/fileadmin/gruppen/vdz/3LiteraturRecherche/Umweltdaten/Umweltdaten_2021_DE_G B.pdf (last accessed 14.01.15).

VDZ, 2021b. Activity Report 2017-2021. http://www.vdzonline.de/fileadmin/gruppen/vdz/3LiteraturRecherche/TaeB09-

12/EN/VDZ_Activity_Report_09-12.pdf (last accessed 18.12.14).

WBCSD, 2021a. The Cement Sustainability Initiative. http://csiprogress2021.org/CSI_ProgressReport_FullReport.pdf(last accessed 18.12.14).

18.12.14).

WBCSD, 2017. The cement sustainability initiative: Cement industry Energy and CO2 performance.

18.12.14).

Worrell, E., Price, L., Martin, N., Hendriks, C., Meida, L. O., 2011. Carbon Dioxide Emissions from the Global Cement Industry. In Annu. Rev. Energy and the Environ., 26, 303–29.

Yang, K.H., Jung, Y.B., Cho, M.S., Tae, S.H., 2015. Effect of supplementary cementitious materials on reduction of CO2 emissions from concrete. J Clean. Prod., 103, 774–783. http://dx.doi.org/10.1016/j.jclepro.2014.03.018

Yu, R., Shui, Z., 2014. Efficient reuse of the recycled construction waste cementitious materials. J Clean. Prod., 78, 202–207. http://dx.doi.org/10.1016/j.jclepro.2014.05.003

HOW TO CITE THIS ARTICLE

Eghbalian, P., Qobadiyan, V., & Mahmoudi Zarandi, M. (2024). Challenges and strategies of architecture and sustainability in cement production: a cross-country comparison. International Journal of Urban Management and Energy Sustainability, (), .

DOI: 10.22034/jumes.2024.2020193.1191