NEW DEVELOPMENTS FOR CERAMIC PLANTS WITH LOW ENVIRONMENTAL IMPACT

Andrea Bresciani, Claudio Ricci

SACMI, Imola BO, Italy

1. ABSTRACT

Ceramic tile production is currently going through difficult times: on the one hand, the ever-growing demands for new products, formats, finishes, decorations, and even new uses (furniture, kitchen countertops, etc.). On the other hand, both end consumers and national and international governmental authorities demand increasingly stringent levels of environmental emissions and greater recycling capabilities from the ceramic industry.

The Kyoto Protocol (1997) and its successive follow-ups aim to counteract global warming by imposing a progressive reduction in CO_2 emissions from the use of fossil *(non-carbon-neutral)* energy sources.

In particular, since 2005, the EU has implemented its Emissions Trading System (ETS) as a mechanism to control and reduce industrial emissions. The EU's next target milestone is a 55% reduction (compared to 1990) by 2030.

Added to that comes the general public's increased sensitivity (especially among younger generations) towards environmental problems and the future of the planet.

A review thus becomes necessary of the entire ceramic tile production process, which inevitably consumes large amounts of energy given the high temperatures used, (known as a *hard-to-abate sector*) in order to further reduce CO_2 emissions and increase opportunities to reuse and recycle natural resources.

To do so, it is no longer enough simply to rationalise and optimise production plants: a radical change is needed, in particular in those systems capable of using energy (heat and power) from renewable sources and/or sources with a low environmental impact.

This paper presents a study carried out of an entire ceramic plant (producing porcelain stoneware of medium size and thickness), where the same quality and quantity of finished goods can be produced with significantly lower CO_2 emissions (over 50%) and greater internal recycling capabilities (more than 80%).

This result is achieved by drawing on synergies between the availability of "green" energy sources (such as electric power from renewable sources and hydrogen) and new technical solutions for machinery and installations, capable of taking advantage of new trends while safeguarding the quality of the end product and ensuring the overall efficiency of the system. In particular, the sections with the highest energy intensity (materials preparation, forming, drying and firing) will be assessed with innovative technical and installation solutions.

This synergy between innovation for machines and installations and the availability of renewable energies will allow the industrial sector to keep the ceramic process permanently sustainable with the same standard of finished product, even when faced with future targets that are likely to include stricter demands in terms of emissions and circularity.

2. INTRODUCTION

Ceramic tile production is one of the energy-consuming industries (called *hard-to-abate sectors),* such as cement, steel, or the chemical industry [1 it involves processes that transform raw materials using large amounts of electrical power and heat energy at high temperatures.

As in other industries (and unlike transport, construction and electricity generation), emissions from these sectors have followed the trend shown in the graph in Fig. 1. It is clear that, while Europe and the United States kept emissions constant until the 2000s, before beginning a progressive reduction (the result of early actions to contain global warming*),* the current values reported by China and India, on the other hand, almost triple those of the year 2000.

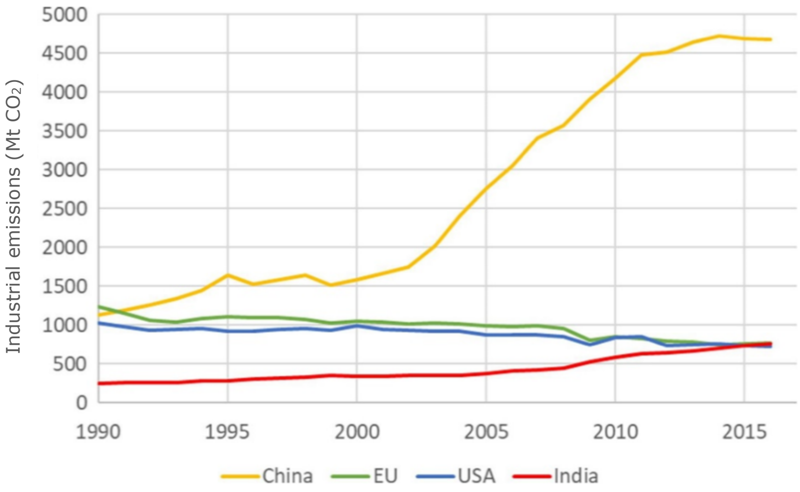


***Fig. 1**– Industrial emissions in the main regions from 1990 to 2016 [1]*

At present (2019), total world CO_2 emissions have reached 38 Gton and are expected to continue growing, driven by consumption in developing countries (particularly in Asia and Africa) – see Fig. 2.

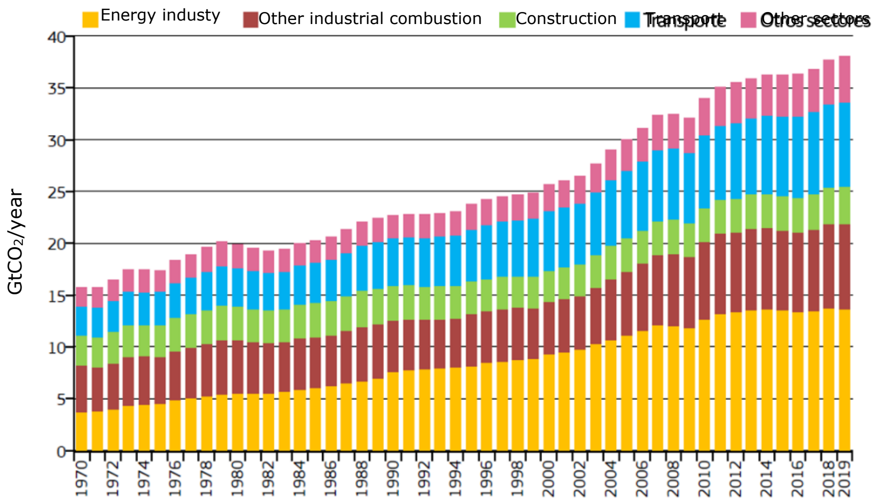
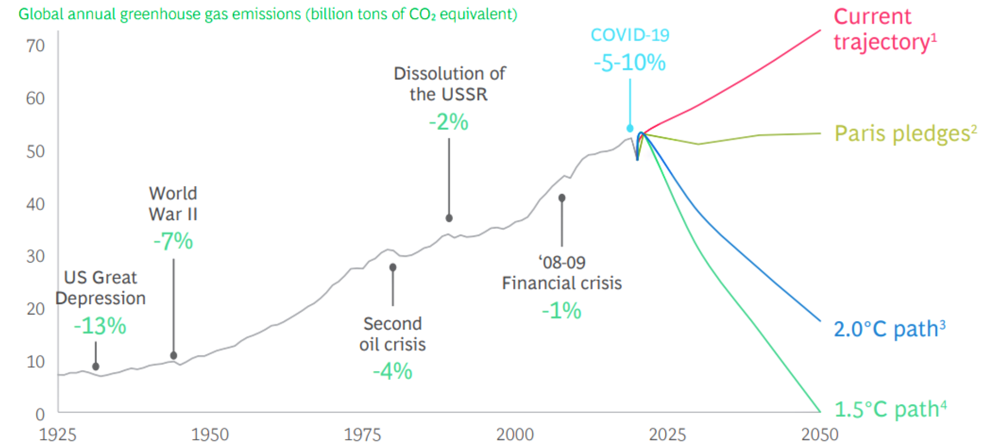


***Fig. 2** – Total annual global emissions of fossil CO_2 in Gt CO_2/year by sectors. Fossil CO_2 emissions include fossil fuel energy sources, industrial processes, and product use [2*

As shown in Fig.3, with the current emissions growth rate, CO_2 emissions will be in excess of 70 Gton by 2050, if no measures are taken to contain them, with the resulting increase in the Earth's average temperature estimated at around 4°C by 2100 (red curve), with terrible effects on the world ecosystem. If the Paris agreements (2015) are respected, emissions will remain at their present value (yellow curve).



Sources: EDGAR 5.0; FAO; PRIMAP-hist v2.1; Global Carbon Project; IPCC; UNEP Emissions Gap Report; WRI; BCG analysis.
Note: These figures exclude land use, land-use change, and forestry.
[1] Assumes GHG emissions grow from 2018 at the same rate as the "current policies" scenario in UNEP 2019 Gap report to 2050 (1.1% CAGR).
[2] Assumes countries decarbonize at the same annual rate that was required to achieve their intended nationally determined contributions from 2020-2030.
[3] Assumes 25% reduction by 2030 and net zero by 2070.
[4] Assumes 45% reduction by 2030 and net zero by 2050.

Fig. 3 *– Historical evolution of global CO_2 emissions and possible future scenarios[3]*

In contrast, if more aggressive policies are implemented to reduce emissions and transform energy, industrial and transport processes, depending on the intensity of such a reduction, zero CO_2 emissions could be achieved by 2070 (blue curve) or by 2050 (green curve) - in either case, global warming would be contained with an increase in the Earth's average temperatures limited to 1.5 - 2°C.

Obviously, reversing the trend shown by the blue and green curves in Fig. 3 calls for a great deal of effort at all levels, with actions taken both at production plants and at the sources of energy made available by operators and distribution grids.

3. THE CERAMIC PRODUCTION PROCESS

In recent decades, the production process of ceramic tiles and slabs has been the subject of considerable innovation in order to achieve high quality standards, high production efficiency, waste reduction, and lower energy consumption.

By way of example, one only has to recall single-channel roller firing, hydraulic pressing, or heat recovery systems between the kiln and the dryer. In addition, the use of increasingly selected raw materials, backed by appropriate technological research, has led to products of increasing quality with less wastage. In short, over the last 10 years, digital decorating and surface finishing techniques (*lappato*, polishing) have significantly increased the aesthetic value, and therefore the added economic value, of ceramic products while restricting waste generation.

However, the fact remains that the production process is inherently energy-consuming and makes abundant use of natural raw materials (such as minerals and water).

Fig. 4 *– Mass and energy balance in the ceramic production process*

Fig.4 shows a typical mass and energy balance in the production of one square metre porcelain stoneware of medium size (60x60 cm) and thickness (10 mm). If those values (purely indicative) are multiplied by current production levels[4], the result is the large consumption and emission rates shown in Tab. 1.

Although the values in Tab. 1 are highly significant, they nevertheless represent a small fraction of industry's total emissions. In 2019, global CO_{2eq} emissions were about 53 Gton, of which 18% are attributable to industrial processes, i.e. 9.5 Gton [5The ceramic industry (worldwide) is responsible for about **1%** of all industrial CO_2 emissions.

In any event, emissions from the ceramic sector, whose production centres are normally concentrated in small geographical areas in the form of industrial clusters, represent a problem both for the environment in the surrounding areas and for neighbouring regions.

	Production	Natural gas	Electrical energy	Raw materials	Water	CO_2
	Mm^2	Gm^3	TWh	Mton	Mm^3	Mton
Italy	416	1.0	1.9	10.0	5.0	3.0
Spain	530	1.2	2.4	12.7	6.4	3.8
Europe	1,185	2.7	5.3	28.4	14.2	8.4
China	5,680	13.1	25.6	136.3	68.2	40.3
World	13,099	30.1	58.9	314.4	157.2	93.0

Tab. 1 *– World consumption and emissions in absolute terms [4]*

Added to that is increasing pressure from law makers (national and international) to limit CO_2 atmospheric emissions, increased energy costs in the form of carbon taxes or other systems (e.g. ETS in Europe), and very challenging medium-term reduction targets (e.g. see the EU's *"Fit for 55"* programme [6].

All of the above entail the need for the ceramic - especially tile - production industry to review its production processes in order to significantly reduce consumption levels and associated CO_2 emissions and to cut down wastage of raw materials and water.

4. NEW PROPOSALS AT PLANT LEVEL FOR DECARBONISATION

Typical life cycle assessment (LCA) techniques were used to examine an entire ceramic plant in its standard configuration for production of about 10,000 m^2/day of porcelain stoneware tiles, of medium size (60x60 cm) and thickness (10 mm). Total CO_{2eq} emissions (for current plants in a European context) stand at around 7.1 kg/m^2 and are subdivided into the various sections in the plant, as shown in Fig. 5.

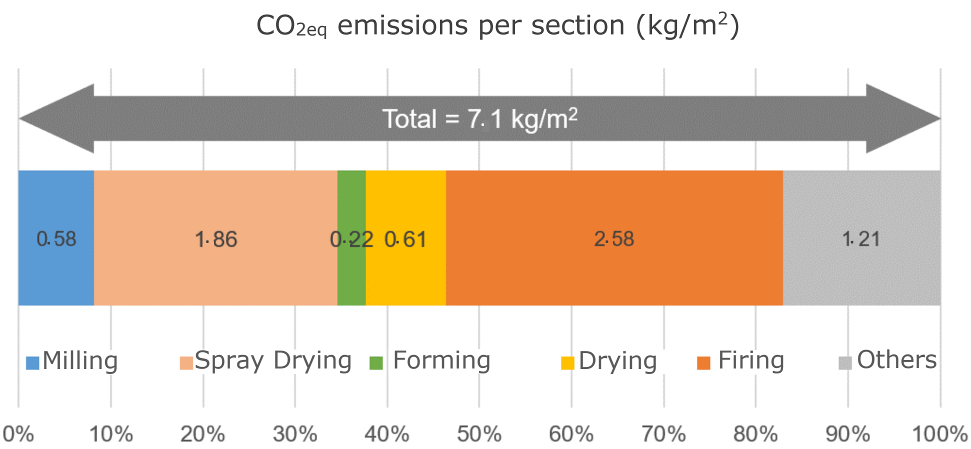


Fig. 5 *– Current CO_2 emissions subdivided into sections at a ceramic plant*

As can be seen in Fig. 5 the sections with the greatest impact are (in descending order): firing, spray drying, drying, milling, and forming. Together, they account for about 85% of the plant's total emissions.

For the above sections, an innovative plant proposal has been drawn up, which is going to be implemented over the coming years (estimated for **2025),** and which also takes into account improved power supply conditions by operators in the sector (with a growing proportion of renewable sources). The LCA assessment was repeated with the new plant configuration in order to compare estimated emissions with the standard (current) situation. The values calculated for each section are shown in Tab. 2, where they are compared to current figures and with the % of reduction shown.

CO_2 emissions (kg/m^2)		
Sections	**Current**	**2025**
Preparation	2.44	1.29
		-47%
Forming	0.22	0.022
		-90%
Drying	0.61	0.13
		-79%
Firing	2.58	1.73
		-33%
Other sections	1.21	0.60
Total	**7.06**	**3.77**
		-46%

Tab.2 *CO_2 emissions per section – current and estimated with the innovative system (2025)*

For the **milling** section, the use of modular continuous milling is envisaged, which allows for a significant reduction in the electrical power used to mill ceramic bodies, as well as for better quality and process control. Compared to traditional milling, modular milling enables electricity savings of 44% (from 50 kWh/ton to 28 kWh/ton). In addition, it is proposed to use thermal recovery to heat the milling water and thus reduce total energy consumption, with a saving of about 62 MJ/ton (and therefore lower emissions). For **spray drying**, solutions that entail using hydrogen in part replacement of natural gas (up to 50% by volume) are being studied. This will lead to a significant reduction in CO_2 emissions, if, logically, an adequate supply of **hydrogen** is available at an acceptable cost at the ceramic plant. Thus, emissions reductions in the preparation section (milling + spray drying) are estimated at -47%.

Forming is a fundamental stage in the ceramic process but it requires very little energy (the forces involved are very high but with little physical displacement). Continuous compaction, developed by SACMI [7], enables a considerable reduction in the electrical power used to compact the ceramic powder (from 16 kWh/ton to 3.2 kWh/ton), which is an 80% saving compared to a hydraulic press of equivalent capacity, while still maintaining excellent quality in the end product and high productivity. Compared to today's traditional line, the solution with continuous compaction (in combination with "greener" electricity, foreseeable in 2025) will lead to a reduction in emissions of -90%.

The **drying** stage requires large amounts of thermal energy (at low temperature) to remove excess water from the ceramic body in a controlled fashion. Traditional dryers, which use natural gas burners, have high energy consumption (about 340 MJ/ton) and, therefore, high emissions. The project envisages installing an innovative "zero fuel" dryer with full thermal energy recovery from the hot air recovered from the firing kiln (in the same line). That way, fossil fuels are no longer used, which implies huge energy savings (and very low emissions). Electricity consumption (for motors, fans, ...) remains at around 19 kWh/ton, so the overall reduction in CO_2 emissions will be -79%.

Firing is the most significant stage in the process in terms of thermal energy consumption and emissions. In order to significantly reduce emissions, a new single-channel kiln will be used with complete digital control of the air-fuel ratio in the different firing zones, thus optimising combustion in all operating situations. In addition, innovative burners capable of working with hydrogen-methane mixtures and/or high-temperature electric heating systems will be implemented. These new burners (patent pending) can operate hydrogen-methane mixtures with a hydrogen content of up to 50% (by volume), thus achieving a reduction in CO_2 emissions of up to -23%. The combination of a digitally controlled kiln and new burners will allow (by 2025) a reduction in CO_2 emissions of -33%. Once again, in order to take full advantage of these new technologies, hydrogen and electricity from renewable sources need to be available on site at acceptable costs.

If we take both current total CO_2 emissions and those estimated with the new configuration (as of 2025) and compare them with the historical values of 1990 (the baseline set in the Kyoto Protocols on which to calculate the % reduction), the result is the graph shown in Fig.6**.** It also depicts (horizontal lines) the reduction thresholds imposed by European regulations. The values refer to producing 1m^2 porcelain stoneware tile, 60x60 cm format, thickness 10 mm, with a mass of 23 kg.

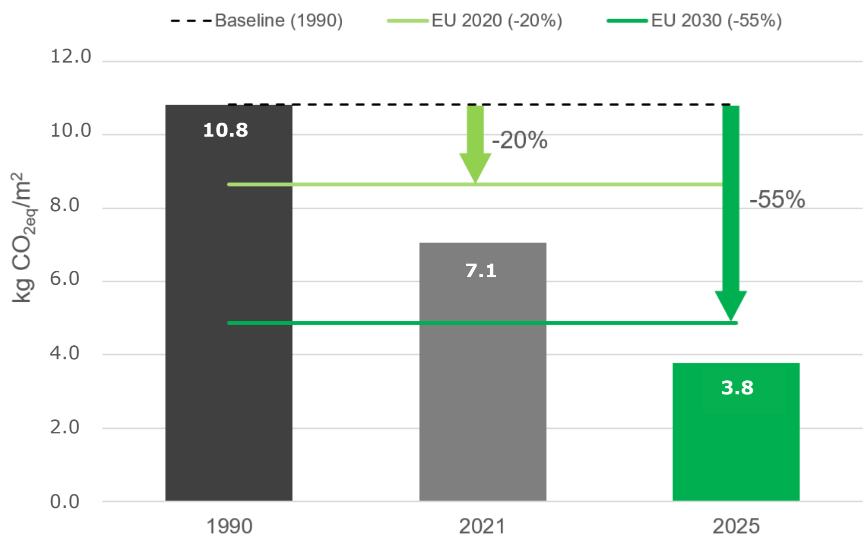


Fig. 6 *– Total CO_2 emissions, based on production plant evolution*

After 30 years of improvements and optimisations of their facilities, plants currently in service emit 7.1 kg/m^2 CO_{2eq}. This reduction (-35% compared to 1990) is greater than the EU's requirement for 2020 (-20%), currently in force.

The new plant proposal foresees (by 2025) total emissions of 3.8 kg/m^2 of CO_{2eq} (-65% compared to 1990), thus meeting EU requirements for 2030 [6 (EU requirement: a reduction of -55% compared to 1990).

The graph in Fig.6 shows how harnessing the synergies between the availability of "green" energy sources and new solutions for machines and installations capable of making optimal use of new energy vectors (hydrogen and electricity from renewable sources, etc.) allows for substantial reductions in emissions (almost half compared to the present day), while still maintaining the quality of the end product and the overall efficiency of the installation.

5. INCREASED CIRCULARITY IN THE CERAMIC SYSTEM

In order to increase environmental sustainability in the ceramic process in regard to the use of natural resources, the future plant must necessarily and inevitably improve waste management by increasing its recovery intensity, and therefore enhance **circularity**.

Fig. 7 shows some of the main points in the plant where waste is generated during production. The waste basically comprises:

- **solid waste,** which, with proper treatment techniques, can generally all be recycled within the process and returned to the previous stage.
- **liquid waste**, in particular washing and process waters, which need to be recovered, treated and reused, to ensure responsible management of such an important resource.
- **powders,** that need to be filtered to maintain a healthy working environment, to preserve machine operability, and to guarantee end product quality. Powder recovery also allows for savings in raw materials.

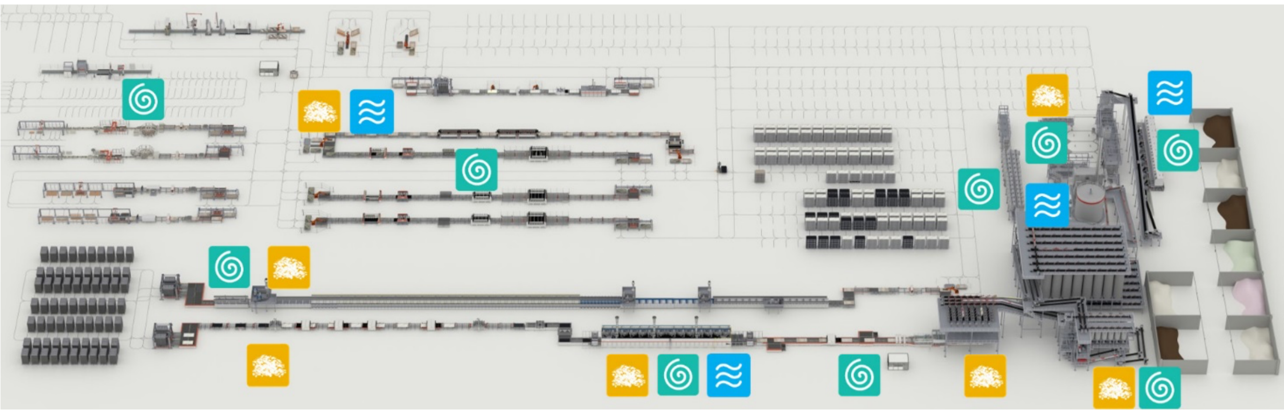


Fig. 7 *– Waste-generating points in the plant*

In today's ceramic plants, a large proportion (about 65%) of these materials are recovered and returned to the production cycle.

The plant of the future will implement automation in its recovery systems, pneumatic (powder) transport and dissolving systems, for subsequent pumping of the liquid phase (for raw waste), to prevent the spills that occur nowadays, thus making make it feasible to increase recovery intensity from 65% to over 80% (by 2025). Similarly, washing water (from the preparation and glazing sections) will also be recovered more efficiently and transferred to the wet milling section.

As for recovery of evaporated water (from the spray dryer and dryer), the intention is to reach 25% by 2025 (compared to 0% today), which calls for substantial changes to machinery and plant, with increased complexity and installation costs. This measure could be economically sustainable today in countries with a scarcity of water (e.g. Middle East, North Africa). Undoubtedly, this issue will become more pressing in Europe in the coming years.

Tab. 3 shows current and estimated recovery intensities (by 2025) for the different types of waste.

	Current	**2025**
Solid waste recovery	65%	81%
Liquid waste recovery	68%	80%
Evaporated water recovery	0%	25%

Tab. 2 *– Current and estimated recovery intensity with the innovative plant (2025)*

6. CONCLUSIONS

In response to increasing world attention to climate change and green economies, reducing environmental impacts, especially CO_2 emissions, is now an essential objective for the ceramic industry.

At European level, current regulations already impose restrictions on the share of carbon dioxide emitted, and even more stringent limits are planned in the short and medium term.

To meet these demands, SACMI is firmly committed to researching state-of-the-art plant system solutions that help to make the ceramic production process increasingly efficient and sustainable.

The work presented here shows how it is possible to intervene effectively in energy consumption at the main transformation stages (firing, body preparation, drying and forming), some of which are particularly high energy consumers, to achieve reductions in CO_2 equivalent emissions of about 65% compared to the standard values reported by traditional production technologies taken as reference (1990).

This means that the ceramics industry can reasonably meet the -55% target set by the European Union for 2030 with its "*Fit for 55*" programme.

At the same time, and from the point of view of circularity, it is estimated that the ceramics production sector, which already recycles a large part of its own by-products, will be able to further increase the intensity of its waste recovery in the near future.

However, it should be stressed that the environmental and energy challenges that the ceramic industry will face necessarily call for synergistic action between the availability of "green" energy sources and the development of innovative solutions for machines and plants capable of exploiting these new trends.

In this context, the innovative technologies proposed have been designed to protect and maintain the high quality of today's ceramic products, a decisive factor in retaining leadership over alternative materials.

REFERENCES

[1] PALTSEV S., MORRIS J., KHESHGI H., HERZOG H., "Hard-to-Abate Sectors: The role of industrial carbon capture and storage (CCS) in emission mitigation", Applied Energy, 300 (2021) doi:10.1016/j.apenergy.2021.117322

[2] CRIPPA, M., GUIZZARDI, D., MUNTEAN, M., SCHAAF, E., SOLAZZO, E., MONFORTI-FERRARIO, F., OLIVIER, J.G.J., VIGNATI, E.: "Fossil CO2 emissions of all world countries - 2020 Report", EUR 30358 EN, Publications Office of the European Union, Luxembourg, 2020, doi:10.2760/143674, JRC121460

[3] FAESTE L., CHEN B., HE D., LIU B., SHI S.: "Building a Greener Future", Boston Consulting Group, March 2021, https://web-assets.bcg.com/ff/a6/c514e7314190b5cb27b1383fae1b/bcg-x-cdrf-how-china-can-reach-its-dual-climate-goals-mar-2021-en.pdf

[4] "World production and consumption of ceramic tiles", 7th edition, ACIMAC, 2019

[5] "The time for climate action is now", Boston Consulting Group, April 2021, https://media-publications.bcg.com/BCG-Executive-Perspectives-Time-for-Climate-Action.pdf

[6] "Fit for 55 - The EU's plan for a green transition", Council of the European Union, 2021, https://www.consilium.europa.eu/en/policies/eu-plan-for-a-green-transition/

[7] BRESCIANI A., RICCI C.: "Innovative process for ceramic tile manufacturing by double pressing with continuous precompaction", Qualicer 2004, Vol. 1, P.GI, p. 49-60