DECARBONISATION CHALLENGES FOR THE SPANISH CERAMIC SECTOR

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1. ABSTRACT

The ceramic sector accounts for 60% of natural gas consumption in the Valencia Region. The prospect of using hydrogen, biomethane and electricity - all of renewable origin – in the industry's heat-intensive stages will bear significantly on manufacturing costs, as well as on capital investment in supply grids or networks to replace or supplement current gas pipelines and electricity grids.

2. BACKGROUND

The ceramic sector's industrial processes are thermal energy-intensive and the influence energy bears on manufacturing costs is decisive, so it is of great importance to understand which factors can increase those costs. Furthermore, by burning fossil fuels (natural gas), the industry is a major emitter of greenhouse gases.

Attaining climate neutrality in the ceramic sector by decarbonising its thermal processes entails, among other measures, reviewing its industrial techniques by eliminating or replacing fossil fuels and adapting its industrial thermal equipment to new technologies with which to generate heat.

In this regard, the European Union is setting new criteria for a 55% reduction in emissions compared to 1990 levels by 2030, with the aim of reaching climate neutrality by 2050. Spain has presented a new draft for the PNIEC[i] 2030 with fresh targets for installed renewable power and emissions reduction.

3. OBJECTIVE

In order to achieve those environmental goals, replacing natural gas with hydrogen, biomethane or electricity - all of renewable origin - applied to the thermal stages of ceramic production will lead to a multiplication of energy for the process to operate with those natural gas substitutes.

Faced with the **ceramic sector's decarbonisation challenges**, the aim of this paper is to define possible alternatives for achieving those goals and to estimate the cost of implementing a whole new energy generation and distribution infrastructure in order to achieve them.

4. THERMAL CONSUMPTION IN THE CERAMIC INDUSTRY

In order to understand the enormous magnitude of eliminating or replacing thermal energy in the ceramic process, the Castellón ceramic industry's current natural gas energy requirements for its basic processes are detailed below.

According to the latest data published by the CNMC (*Spanish National Markets and Competition Commission*), corresponding to the year 2020, Castellón province was Spain's largest consumer of natural gas at national level. The tables below (Table 1/Table 2) show energy consumption data for the Valencia Region for 2020 and the ceramic sector's energy consumption for 2019-2023.

		Castellón	Valencia	Alicante
Oil	(GWh/yr)	70	1,291	767
Natural Gas	(GWh/yr)	13,837	2,616	1,058
Electricity	(GWh/yr)	2,233	2,884	1,500
Renewables	(GWh/yr)	233	756	291

***Table 1**. Energy consumption in the Valencia Region, 2020. Source: IVACE.*

CERAMIC INDUSTRY ENERGY CONSUMPTION					
Year	2019	2020	2021	2022	2023
Production output	510 Mm^2	488 Mm^2	587 Mm^2	500 Mm^2	≈425 Mm^2
Natural gas (GWh/yr)	14,100	13,430	17,000	14,870	≈12,124
Electric power (GWh/yr)	1,400	1,390	1,800	1,730	≈1,256
Total (GWh/yr)	15,500	14,820	18,800	16,600	≈13,381
Gas consumption as % of national total	3.54%	3.73%	4.49%	4.08%	
CO_2 EMISSIONS GENERATED (Mt $_{CO2eq.}$)					
Valencia Region	8.72	8.16	8.00	7.80	-
Industrial ceramic sector (ICS) (approximation)	2.70	2.40	2.80	2.60	-
ICS emissions as % of total for Valencia Region	33%	33%	34%	32%	-

***Table 2.** Energy consumption in the ceramic industry (ICS) 2019-2023. Source: ASCER.*

From the data given in Table 1 in 2020, the ceramic sector accounted for approximately 97% of all the gas consumed in the province. According to the data in Table 2, in the year 2022, it accounted for 4.08% of the total at national level, which confirms the prominent role it plays in Spain's natural gas balance as a whole.

Therefore, the emission of greenhouse gases (GHG) from the ceramic sector compared to the total for the Valencia Region is over 30% in the years 2019 to 2022.

Such significant energy consumption rates and the resulting GHG emissions occur in the basic processes involved in the manufacture of ceramic products:

- Clay spray drying without co-generation
- Ceramic tile drying
- Ceramic tile firing

5. DECARBONISATION ALTERNATIVES

In the basic processes listed in the previous section, the decarbonised thermal technology scenarios assessed in this paper are as follows:

- Clay spray-drying: use of 100% hydrogen/biomethane burners (depending on the alternative) as fuel to heat the large volumes of air involved in the process of spray-drying clays at temperatures of around 500ºC, as suitable commercial alternatives to using natural gas burners are commercially available. Electrification has not been considered, as evidence already exists of the difficulties involved in replacing the current technique with electrical resistances.
- Ceramic tile drying: use of 100% hydrogen/biomethane burners (depending on the alternative) as fuel or use of electrical resistances. This equipment heats the air to temperatures of up to 200ºC and takes advantage of hot gases from the kiln as it cools, which are filtered and fed into the dryer, thus avoiding energy consumption, except in the starting stage prior to kiln start.
- Ceramic tile firing: use of 100% hydrogen/biomethane burners (depending on the alternative) as fuel, electrical resistances or a mixed technology. With a flame temperature of 2,000ºC, reduced to 1,200ºC in the kiln combustion chamber, which is co-ordinated with hot air recovery from its own cooling system.

On the basis of these assumptions, the ceramic industry has four alternatives (currently at the research and industrial development stage) for replacing fossil fuels to reduce or even eliminate CO_2 emissions:

I. The thermal energy required by the process is exclusively generated by H_2 combustion.
II. The thermal energy required for the firing and drying process is generated by electrical resistances.
III. A combination of both options, where part of the thermal energy required by the firing process is generated by H_2 combustion and another part by electrical resistances.
IV. The thermal energy required by the process is generated exclusively by biomethane combustion (green CH_4)

<table>
<tr><th rowspan="2">ALTERNATIVE</th><th>I</th><th>II</th><th colspan="2">III</th><th>IV</th></tr>
<tr><th>ALL HYDROGEN</th><th>MIX A</th><th colspan="2">MIX B</th><th>ALL BIO-METHANE</th></tr>
<tr><td>Spray-drying process</td><td>100%</td><td>100%</td><td colspan="2">100%</td><td>100%</td></tr>
<tr><td>Firing process</td><td>100%</td><td>100%</td><td>80%</td><td>20%</td><td>100%</td></tr>
<tr><td>Drying process</td><td>100%</td><td>100%</td><td colspan="2">100%</td><td>100%</td></tr>
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	Hydrogen
	Electrification
	Biomethane

Table 3. *Alternatives under study*

Table 4 shows a breakdown of the Spanish ceramic industry's thermal needs for an annual production of 425 million square metre tile (estimated production for the year 2023), broken down into the main processes:

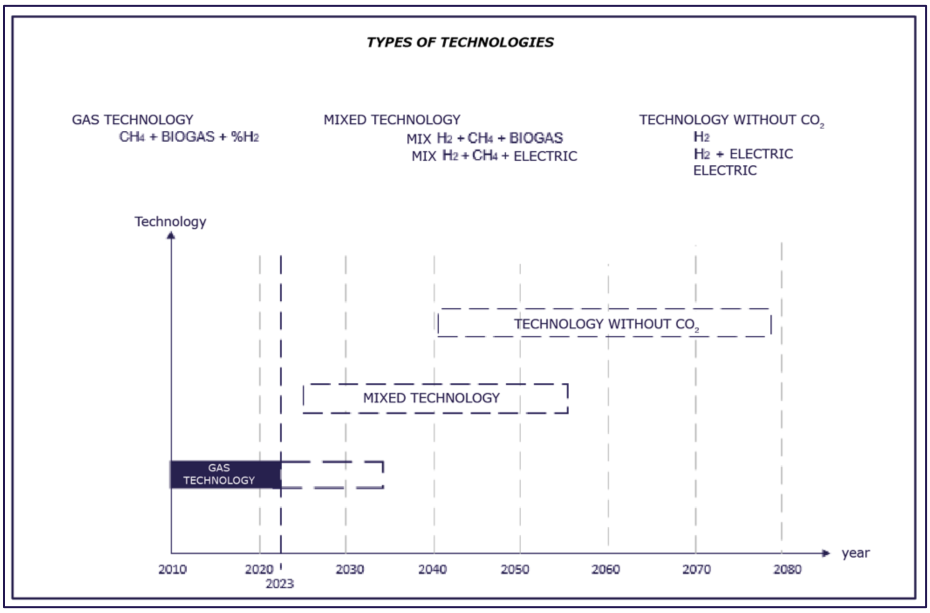
CERAMIC INDUSTRY		
Net weight	22	*kg/m²*
Production	425,000,000	*m²/yr*
Weight	9,350,000,000	*kg/yr*
Total energy	1.30	*kWt/kg*
Spray-drying process	0.52	*kWt/kg*
Drying process	0.16	*kWt/kg*
Firing process	0.62	*kWt/kg*
Sector's total thermal energy demand	12,124	*GWh/yr*

***Table 4**. Thermal energy demands in the ceramic process. Source: author.*

To fully replace natural gas with green fuel solutions or to electrify the sector firstly requires the availability of those solutions to be reliable and constant. That is, being able to meet the energy demand while the process is running (365 days a year, 24 hours a day, 7 days a week).

It must also be considered that adapting or replacing thermal production equipment will call for techniques and technologies that are not currently available at the level of competitive industrial plants, especially in the firing process.

Graph 1 below shows a possible technological development towards carbon neutrality by 2050. Today, it is difficult to confirm which technology will finally be developed and will enable the ceramic industry to neutralise emissions while maintaining its competitiveness with respect to other countries unaffected by this plan.



***Graph 1.** Technologies in the ceramic sector. Author's estimation.*

6. ELECTRIC POWER FOR ALTERNATIVES

Having established the alternatives for achieving the goals imposed by the European Union and focusing on industry decarbonisation, it is clear that whichever alternative is chosen, the sector's energy needs will be multiplied. Switching from natural gas from underground fields to hydrogen that has to be produced calls for a colossal consumption of electricity and/or for electrical equipment which, in turn, entails massive infrastructures in terms of generation, transmission and distribution.

Note that these new energy requirements to replace natural gas - (hydrogen/biomethane/electricity production, depending on the alternative chosen) - are added to current electricity consumption (Table 2– row 5) by electric motors and receivers that remain in service.

6.1. ELECTRIC POWER GENERATION

Our current infrastructure does not have the electricity generation and transmission capacity needed to meet EU criteria and the objectives set out in the *PNIEC*. It will require large capital outlays to implement a new electricity infrastructure (generation plants, substations, lines and transformation centres).

Moreover, such new infrastructure will have to supply green electricity to the new consumption points in the ceramic sector, whether these be hydrogen or biomethane manufacturing plants (Alternatives I, II, III and IV) or ceramic plants with electrical equipment (Alternatives II and III).

The three electricity generation options considered in this study are:

- Photovoltaic farms
- On-shore wind farms
- Nuclear power plants

Photovoltaic farms

Since solar energy is not a constant source of energy, it will have to be supplemented with an auxiliary electrical energy storage system. Such storage systems, known as BESS (Battery Energy Storage System), store energy in rechargeable batteries until it is needed.

They are currently used on a small scale in distribution grids to stabilise parameters (frequency and voltage) and as a short solar energy back-up, but they offer low performance and high cost. However, in order to be considered as an alternative and to become a manageable system, the need for a BESS with a capacity of 3 days without sunshine has been defined.

According to the Spanish Technical Building Code (RD 314/2006[ii]) and Royal Decree 14/2010[iii], Castellón province belongs to Zone IV. Assuming the new installation is immobile, the equivalent hours per year are estimated at 1,632 hours' sunshine, obviously much lower than the 8,760 operating hours per year in a 24/7 work schedule.

On-shore wind farms

Given that wind energy is not a constant and stable source either, a BESS storage system with rechargeable batteries similar to the one considered for solar energy will be included in this study and in the cost estimations, also for 3 days without wind.

In the IDAE[iv] wind resource analysis for the Valencia Region, a range of net equivalent hours is calculated at between 2,075-2,275 hours per year, which is also lower than the 8,760 hours in a year. The same document also estimates potential wind power for each Region and, for Valencia, it is considered to be 9 *GW*.

Nuclear power plant

Nuclear power is a highly controversial energy source because of the risk of leakage and the waste it generates. However, according to the latest draft that is to amend the delegated Climate Regulation, the inclusion of nuclear power plants as part of the green taxonomy would be acceptable, so that, in sustainable finance programmes, this technology will be equated to renewable energies.

Once the regulation is approved, all nuclear power plants will be considered "green" if they have building permission prior to 2045 and if they guarantee they are able to treat radioactive waste. This electricity generation technology operates all hours of the year in a constant and stable manner and does not require an additional BESS system.

6.2. CONSUMPTION ACCORDING TO ALTERNATIVES

A simplified overview follows of the possible electricity supply sources and the availability criteria, and their use is analysed in the decarbonisation alternatives (see Section 5: Decarbonisation Alternatives).

Hydrogen/electrolysers: Alternatives I and partial in II & III

Electrolysers are technically extremely complex industrial equipment designed to produce hydrogen by electrolysis, i.e., breaking down the water molecule into its two elements: hydrogen and oxygen, by means of an electric current.

The equipment consumes approximately 50 kWh of electricity for each kg of H_2 produced and, as long as a renewable source of electricity is used for its operation, the hydrogen generated will be labelled green. The equipment would be set up at each ceramic factory or set of associated factories in a stand-alone structure.

In the 2030 objectives of the draft update of the PNIEC for 2023, 11 GW of electrolysis is due to be installed, compared to the 4 GW in the previous PNIEC, which accounted for 10% of the European Union's total capacity, illustrating that Spain is strongly committed to hydrogen fuel.

Biomethane/plants: Alternative IV

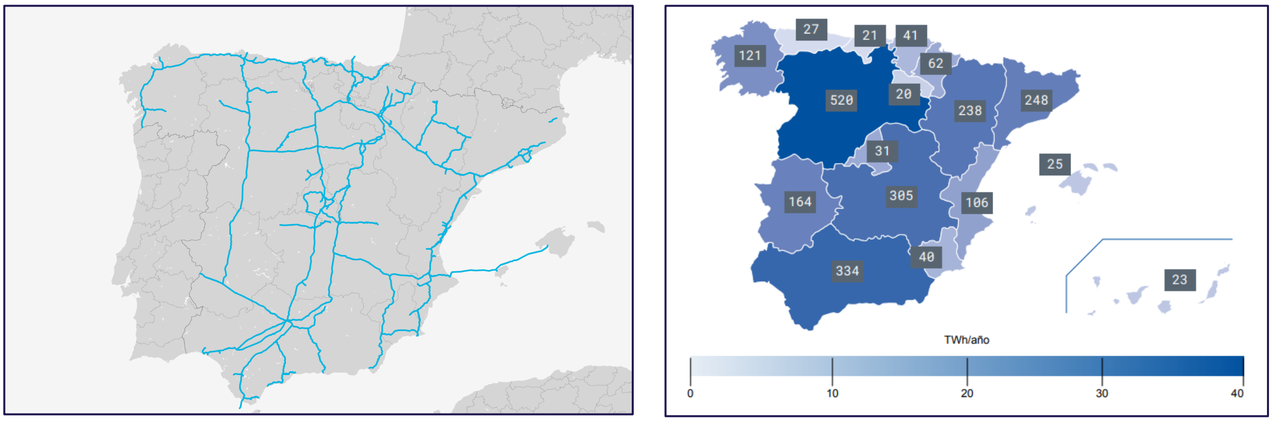
This interesting alternative replaces natural gas with biomethane, which has similar characteristics and thermal properties. With this energy source, in principle, neither the gas infrastructure nor the thermal processing machinery would need to be changed, as biomethane is injected directly into the transmission grid.

However, this is a little-used technology in Spain, given the scant supply of biomethane in Spain. On a national level, a total of 9 biomethane plants are in operation, generating just 0.42 TWh/year[v]. However, due to the presence of agricultural, livestock and organic waste and the small amount of electricity required to produce it, the number is already growing with a total of 68 plants projected or already under construction.

In the SEDIGAS[vi] report published in January 2023, it states that Spain's potential for biomethane gas could reach up to 163 TWh/year, which would require 2,326 new plants that would meet up to 43% of current national demand for fossil fuel (natural gas). The estimated investment in plants and gas grids or networks is 43,844 M€.

Although investments in plants and electricity consumption are moderate, implementing biomethane as a thermal source is no easy task because:

1. Even at maximum use of all potentially available waste, it would not meet the entire national demand for energy.
2. A capillary grid needs to be built linking all biomethane plants to the distribution grids.



A *B*

Figure 1 *– A: Gas distribution infrastructures in Spain 2023. Source: ENAGAS*
B: Location of potential biomethane plants. Source: SEDIGAS

Electricity: Alternatives II & III

Currently, most existing electric kilns are small in size and production capacity, with use limited either to testing and research or to special artisanal series. Electric roller kilns are also used at ceramic plants operating with comparable temperatures and cycles, but with very little impact (thin ceramic slabs).

The new electricity distribution grid will feed thermal process equipment directly. If the technology is to be adopted, production equipment must be redesigned in structure, and its electrical systems adapted to handle large-scale industrial projects (+10,000 m^2/day) and tile thicknesses between 9 and 10 mm.

However, the manufacture and operation of such large-scale industrial electric kilns will not be commercially available until new electricity transmission and distribution grids are implemented with the investments estimated in this paper to supply such electrical services.

7. ENERGY NEEDS IN EACH ALTERNATIVE

Table 5 summarises the technical results (energy needs) obtained according to the alternative under study. It shows a significant increase in energy needs as well as the enormous amount of hydrogen needed to replace natural gas.

The following procedure was followed to obtain the results:

- Definition of current thermal needs per process (Table 4)
- Transfer of current thermal requirements to hydrogen/biomethane requirements
- Calculation of the electric power needed to generate new hydrogen/biomethane fuel.
- Calculation of electric power needed for the electrified equipment in each alternative.

	KILOGRAMS OF HYDROGEN	ELECTRIC POWER REQUIRED TO PRODUCE THE FUEL
	kgH_2/year	*TWh/year*
Alternative I	363,771,330.90	18.19
Alternative II	146,813,541.62	13.83
Alternative III	285,144,523.06	16.60
	BIOMETHANE	
	Volume required (m^3/year)	*Electric power required to produce it (TWh/year)*
Alternative IV	998,587,164	*0.69*[vii]

Table 5. *Sector energy consumption as a function of each alternative under study.*

Based on the calculated new requirements and ensuring constant electrical power for the generation of hydrogen/biomethane or its direct use in electrified equipment, the power produced by the generating sources is calculated per alternative, taking into account the provisions of Section 6.

	SOURCE OF ELECTRIC POWER GENERATION			
	Solar	Nuclear	Wind	Units
Alternative I	16.55	2.42	10.80	*GWp*
Alternative II	12.58	1.84	8.21	*GWp*
Alternative III	15.11	2.21	9.86	*GWp*
Alternative IV	0.64	0.09	0.41	*GWp*

Table 6. *Power of generating source for each alternative under study (includes 3 days' BESS)*

Alternative IV, which requires by far the least amount of electricity, uses other limited organic resources for its production. Section 5 indicates that only 43% of current natural gas consumption could be replaced by using all the available resources at national level. Therefore, in order to cover current demand, MIXING IN THE GAS GRID will be required.

8. ECONOMIC RESULTS

The economic impact of decarbonising the ceramic sector is shown below (Graph 2)[viii], as an increase associated with the cost of the end product (€/m^2), which the new electricity infrastructure would imply for exclusive thermal use by the industry.

It is assumed that the generating sources are built in Castellón (ceramic district-cluster) to reduce distance and transmission losses between generation and consumption. To calculate the costs, the following items have been considered:

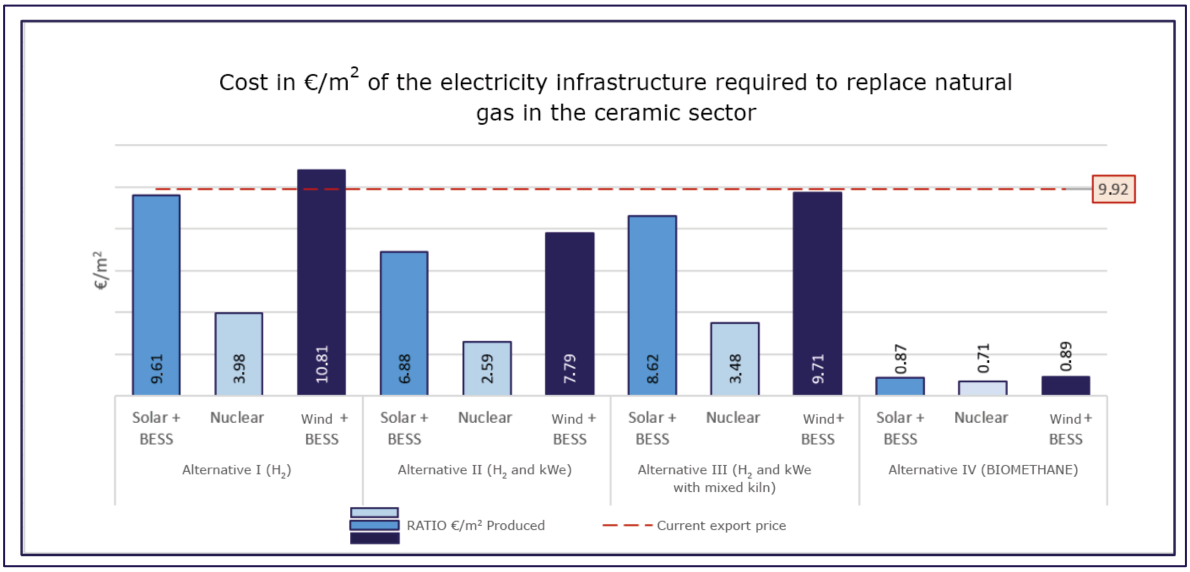
- CAPEX (capital expenditure solely on infrastructure)
- OPEX (annual maintenance - 5% capital expenditure)
- Service life of:
  - Generating source (20 years solar/wind plants and 60 years nuclear power plants)
  - Distribution infrastructure (60 years)
  - Electrolysers and biomethane plants (20 years)
  - Electricity storage (15 years).
- Capital expenditure, total, yearly or by €/m^2 ratio, must take the service life of each element involved into account.

Not included in the above costing:

- Current cost €/m^2 (specific for each factory) excluding thermal energy used
- Cost €/m^2 of adapting current capital assets (no commercial data available)

	Alternative I			Alternative II		
	Solar	Nuclear	Wind	Solar	Nuclear	Wind
Power plant output (GWp)	16.55	2.42	10.80	12.58	1.84	8.21
CAPEX (M€)	36,215	21,125	41,420	25,802	14,330	29,759
OPEX (% CAPEX)	1,811	1,056	2,071	1,290	716	1,488
Total cap. investment (M€)	71,654	74,579	81,629	51,090	53,314	58,674
Total yearly investment (M€/yr)	4,086	1,691	4,594	2,923	1,102	3,309
Cost €/m^2 produced						
Cost energy source	2.17	2.67	4.58	1.65	2.03	3.48
Cost storage-BESS	5.84	-	4.75	4.44	-	3.61
Cost sub-station	0.18	0.03	0.12	0.14	0.02	0.09
Cost hi-voltage power lines	0.03	0.03	0.03	0.03	0.03	0.03
Cost transformation plants	0.16	0.02	0.10	0.12	0.02	0.08
Cost charging stations	1.23	1.23	1.23	0.50	0.50	0.50
TOTAL	**9.61**	**3.98**	**10.81**	**6.88**	**2.59**	**7.79**
	Alternative III			**Alternative IV**		
	Solar	Nuclear	Wind	Solar	Nuclear	Wind
Power plant output (GWp)	15.11	2.21	9.86	0.64	0.09	0.41
CAPEX (M€)	32,441	18,662	37,194	6,246	5,667	6,447
OPEX (% CAPEX)	1,622	933	1,860	18	14,42	18
Total cap. investment (M€)	64,201	66,873	73,310	6,595	5,990	6,806
Total yearly investment (M€/yr)	3,664	1,477	4,128	369	303	379
Cost €/m^2 produced						
Cost energy source	1.98	2.44	4.18	0.05	0.03	0.10
Cost storage-BESS	5.34	-	4.34	0.14	0.00	0.11
Cost sub-station	0.17	0.02	0.11	0.00	0.00	0.00
Cost hi-voltage power lines	0.03	0.03	0.03	0.01	0.01	0.01
Cost transformation plants	0.14	0.02	0.09	0.00	0.00	0.00
Cost charging stations / biomethane plants	0.96	0.96	0.96	0.67	0.67	0.67
TOTAL	8.62	3.48	9.71	0.87	0.71	0.89

Table 7. *Summary of economic calculations (includes 3 days' BESS)*



Graph 2 – Cost in €/m² of the electricity infrastructure required to replace natural gas in the ceramic sector.

9. CONCLUSIONS

Having analysed the technical and economic results presented, one of the key factors is the choice of fuel:

- Whether the choice is for 100% hydrogen, electrification of the equipment, or a combination of both, it would imply substantial change, redesign and industrial experimentation, entailing extra investment not accounted for in this paper, over and above the capital outlays already mentioned in Section 8: ECONOMIC RESULTS.
- If biomethane were chosen, it would not imply changing the thermal equipment. However, the entire biomethane production sector would only meet 43% of the country's current thermal needs, which means that natural gas and biomethane would have to be mixed in the gas infrastructure, thus breaking the principle of decarbonisation: a solution that might be acceptable in a transition period while thermal equipment is being replaced by new "green" equipment.

Another key factor is the electricity-generating technology. In other words, the choice of energy source depends on whether to develop a storage system for renewable energies that can make up for the shortcomings of current systems (inefficient, high maintenance costs and short service life) or whether to opt for nuclear energy, a reliable and emissions-free system, but nevertheless controversial.

One more factor that is often under-emphasised in studies proposing hydrogen as an energy source is that the electrolysis process calls for large volumes of water. With current electrolysis techniques, 12 litres of water are needed to generate 1 kg of hydrogen (10 litres of deionised water and 2 litres rejected in the purification process)[ix]. For Castellón province, with regard to the water that evaporates in the spray-drying process, that would imply ensuring the following extra water consumption by the new electrolyser plants:

ADDITIONAL water consumption		
Alternative I	4.37	*hm³/yr*
Alternative II	1.76	*hm³/yr*
Alternative III	3.42	*hm³/yr*

It should be noted that any alternative for decarbonising the ceramic sector would, to a greater or lesser extent, entail large financial outlays, new technologies not yet developed at industrial level, and changes in strategic plans.

In the same vein, it is to be feared that the competitive capacity of the European ceramic sector will be reduced compared to that of substitute products and to other manufacturers, as not all competitors expect a programmed neutralisation of GHG emissions.

10. NOTES

[i] *National Integrated Energy and Climate Plan (PNIEC) 2021-2030 (https://www.miteco.gob.es/es/prensa/pniec.aspx)*

[ii] *Royal Decree 314/2006 of 17 March 2006, approving Spain's Technical Building Code.*

[iii] *Royal Decree-Law 14/2010 of 23 December, establishing urgent measures to correct the tariff deficit in the electricity sector.*

[iv] *Resource analysis. Wind Atlas of Spain. PER Technical Study 2011-2020*

[v] *Map of GASNAM biomethane production plants*

(https://gasnam.es/terrestre/mapa-de-plantas-de-produccion-de-biometano/)

[vi] *SEDIGAS Biomethane Power Report 2023*

(https://estudio-biometano.sedigas.es/wp-content/uploads/2023/03/sedigas-informe-potencial-biometano-2023.pdf)

[vii] *Table taken from the "COMPARATIVE STUDY OF ENERGY NEEDS OF HYDROGEN AND ELECTRIFICATION APPLICATIONS IN THE CERAMIC SECTOR. ECONOMIC QUANTIFICATION OF INVESTMENT IN ENERGY INFRASTRUCTURE AND OPERATING COSTS" carried out in collaboration with the Spanish Ceramic Tile Manufacturers' Association (ASCER).*

[viii] *Energy required to produce biomethane from biogas.*

[ix] https://www.canaldeisabelsegunda.es/-/planta-de-hidrógeno-verde-para-2024.