NEW CIRCULAR ECONOMY MODEL FOR FOSTERING USE OF ALTERNATIVE WATER SOURCES IN CERAMIC INDUSTRIAL ENVIRONMENTS. REWACER

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1. INTRODUCTION

The purpose of this paper is to publish some of the main results obtained within the framework of the REWACER project - *Development of a new circular economy model to ensure circularity of reclaimed water from WWTPs to industrial sites* - funded by the Valencian Agency for Innovation (AVI) under project number *INNEST00/19/072.* The project has involved several research centres (Instituto de Tecnología Cerámica (ITC-AICE) and the Instituto Tecnológico de la Energía (ITE), as well as companies in the ceramic sector (Estudio Cerámico and the SAMCA group), and a water management company (FACSA), which has led co-ordination of the project with the support of ITC-AICE.

REWACER's main objective is to analyse the technical and economic feasibility of supplying the water demanded by the ceramic sector from an alternative source to the one used today, i.e. using treated water from urban Wastewater Treatment Plants (WWTPs). Consequently, it aims to foster the re-use of water in the province of Castellon and promote the ceramic industry's decoupling of its processes from the freshwater network, thereby encouraging the use of alternative water sources in the ceramic industrial sector and enhancing the sector's adaptation to climate change, all this based on the development of a new service model of water supply from WWTPs to industry.

2. BACKGROUND

A characteristic of the Spanish ceramic industry is its **significant geographical concentration** in the province of Castellon, where 83% of companies **are located,** accounting for 94% of national production. Most of those companies are sited over the Plana de Castellon aquifer (part of the Mijares-La Plana de Castellon water harvesting system). According to the latest available production data (for 2019[1]), it is estimated that the ceramic industry consumes about 9 hm^3 of water per year. Castellon is one of the Spanish provinces that most depend on underground resources to supply its water demands (100% of industrial and urban supply comes from aquifers). More than 110 WWTPs operate in the province, handling an annual volume of 52 hm^2 of water, of which 48.39 hm^3/year[3] are discharged directly into the sea and only 3% of those waters are re-used (mainly for agricultural and not industrial use). That is despite the fact that the water harvesting system has high exploitation indexes (WEI) and significant water stress in certain areas. Furthermore, a number of studies forecast a 12% reduction in rainfall in the province by 2033, thus reducing available water resources and jeopardising guaranteed supply of the province's demands[4].

Such is the context in which the REWACER project has arisen, in an attempt to generate and include alternative water sources in the province that ensure the area's economic development and enable the ceramic sector to maintain its position as the second most important economic force in the Valencia Region[5].

Consequently, the research in REWACER consists of establishing the necessary bases for the future development of a circular water economy model in the province of Castellon. This new model would focus on supplying the ceramic industry's demand for water using effluent from WWTPs of sufficient purity to guarantee the quality of ceramic end products. For that purpose, suitable water qualities and prices have been established and possible supply networks designed. This paper presents those results and assesses the costs and benefits.

3. METHODOLOGY and RESULTS

This research has been carried out in three stages, each one producing results and outcomes, as described in the following table and detailed below.

IMPLEMENTATION STAGES	Results
STAGE 1: Characterisation of the study area	Selection of WWTPs and companies Definition of the water quality required per process. Design of distribution networks.
STAGE 2: Evaluation of costs and benefits.	Estimation of costs. Analysis of industrial economic benefit.
STAGE 3: Feasibility of the CE model	Determination of the viability of a future circular water economy model for the province of Castellon.

***Table 1** - Description of the project stages and the results obtained from each.*

3.1 STAGE 1 CHARACTERISATION OF THE STUDY AREA

3.1.1 SELECTION OF WWTPS, COMPANIES AND WATER QUALITIES

This task consists of three parts: characterisation of WWTPs, characterisation of water for ceramic companies, and determination of the water quality required by the ceramic industry.

In the first place, an assessment of the 115 WWTPs existing in the province of Castellon was performed, selecting only those with secondary treatment, for which technical data sheets were compiled and the quality parameters of the effluent they generate classified. The following data were collected on these sheets: location, volume of treated water, effluent (treated and discharged) flow rates, treatment process (technologies used), source of the water, as well as identification of industrial discharge points that might affect the process and quality of the final effluent.

Those data were then used to establish criteria for classifying secondary treatment WWTPs considered suitable for the supply network of the circular economy model. These criteria were: volume of effluent production, chemical profile in the effluent, lack of spot discharges, and their location close to the ceramic industrial sector. This assessment revealed a total of just 15 plants that could supply the ceramic industry.

Secondly, the water requirements of the ceramic sector were assessed. The idea was to analyse in detail the consumption rate and quality required by the ceramic sector in each production process. To this end, a series of technical sheets were compiled per company to collect the following data: name, location, processes on site (spray-drying, body making, glazing, etc.), water consumption per process, water reused or not per process, water source (well or public network), production volumes and identification of water quality required for each process. A group of 129 companies were assessed either by direct questionnaires, ITC-AICE's own work with companies, or a review of the literature[6], to contrast all the data thus collected. To establish each company's individual water consumption, their production output was used - this datum was taken from sales data for the entire sector and the sectorial price per square metre.

Finally, the standard or quality of water required by the ceramic industry was assessed by a literature survey[7] [8] [9], which enabled us to determine two main groups of water quality required by the sector: a superior quality designated C1, and a second standard that does not call for outstanding quality, designated C2. All these results were contrasted and validated by the two ceramic companies participating in the project - SAMCA and Estudio Cerámico.

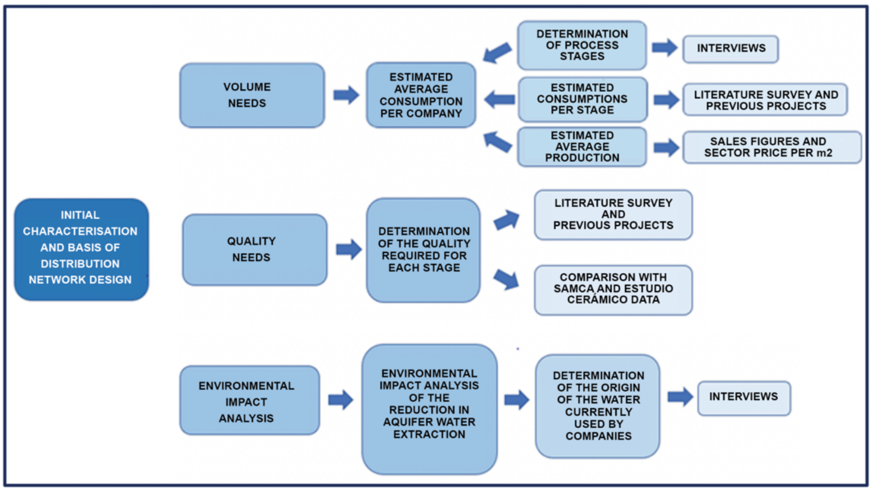

Figure 1. *Method used to collect all the information*

As a result of this analysis, two standards of required water quality were defined:

- C1: Medium-high quality: water reclaimed with REWACER tertiary treatment technologies (in a WRS water regeneration station)
- C2: No high-quality requirement: water direct from the WWTP.

The treatment technologies chosen to obtain C1 water quality are not included in this paper, which only mentions the costs associated with those technologies in the cost estimation stage when assessing the overall feasibility of the proposed solution.

The following figure shows how water quality and water consumption were classified by process.

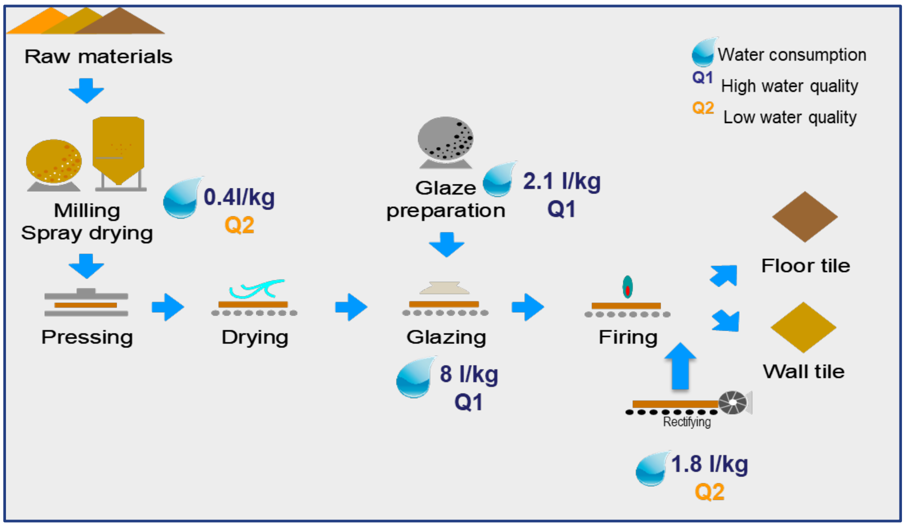

Figure 2. *Processes, water consumption and quality required at each stage.*

All the information collected from both companies and WWTPs was entered into a database (Excel), which enabled us to classify, select and experiment with different configurations in the design of the networks. It also made it possible to create interactive maps that display all the information at a glance, as seen in the following figure.

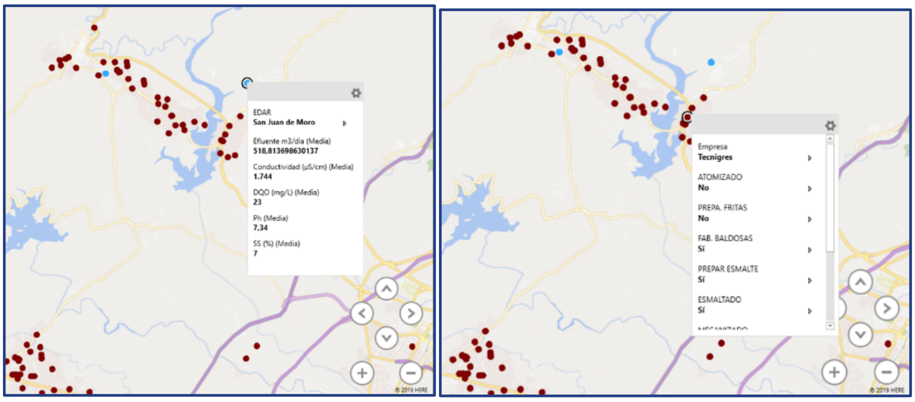

Figure 3. *Map using the information collected from WWTPs and companies*

3.1.2 PROPOSED WATER DISTRIBUTION NETWORKS

Once the study area had been defined, the next stage was to identify the distribution networks that were eligible to form part of the future circular economy model, where suitable areas for application were identified, along with possible water distribution networks from the WWTP to the industrial site.

Firstly, the criteria for selecting suitable companies to be included in the design of the network were defined, namely the ability to supply 100% of the demand in terms of the quality and volume of both C1 and C2 water required by the company, where priority was given to those with the highest water consumption (> $15m^3/h$) and nearest location (distance to the WWTP). With this criterion, about 80 companies were selected for consideration in the networks.

Since the location of those companies is fairly concentrated, 4 geographical areas were defined: A (Alcora-Sant Joan de Moró district); B (Villarreal-Almazora district); C (Nules); and D (between Cabanes, Vilafamés and Vall d'Alba). Different possible distribution networks were defined within each area. The table below shows each area with its defined networks, the supplying WWTP, and the number of companies included in the network.

AREA A		AREA B		AREA C	AREA D		
Network A.1	Network A.2	Network B.1	Network B.2	Network C.1-C.2	Network D.1	Network D.2	Network D.3
Sant Joan de Moró WWTP supplying 2 companies	Alcora WWTP supplying 5 companies	OBVA WWTP supplying 19 companies	Almazora WWTP supplying 3 companies	Nules WWTP supplying 8 companies	Villafamés WWTP supplying 2 companies	Cabanes WWTP supplying 2 companies	Vall d'Alba WWTP supplying 1 company

Table 2 *– Districts and networks defined within each area.*

Hereunder is a detailed description of each geographical area with its identified networks and the main supply volumes and requirements.

Area A: comprises two networks, one per treatment plant. The supply source for one network is the Sant Joan de Moró WWTP and for the other, the Alcora WWTP, which together are able to supply all the water demanded by 7 companies with a volume of 1,410.4 m^3 per day. That would mean reusing 514,792.35 m^3 (0.51 hm^3) of effluent per year in this area, which therefore represents a 70% reusage rate of WWTP effluent in this area.

NET	**WWTP**			**Nº companies**	**Quality C1**		**Quality C2**	
	WWTP	Treated effluent, m^3/day	% reused		km. of pipeline	Max. flow, m^3/day	km. of pipeline	Max. flow, m^3/day
A.1	S. Joan de Moró	518.8	62.7%	2	2.67 km	178.91	2.67 km	146.74
A.2	Alcora	1399.94	77.5%	5	3.5 km	288.55	5.7 km	796.19
Total		**1919**	**≈70 %**	**7**	**6.17**	**467.46**	**8.37**	**942.93**

Table 3 *– Area A and the networks defined in the area*

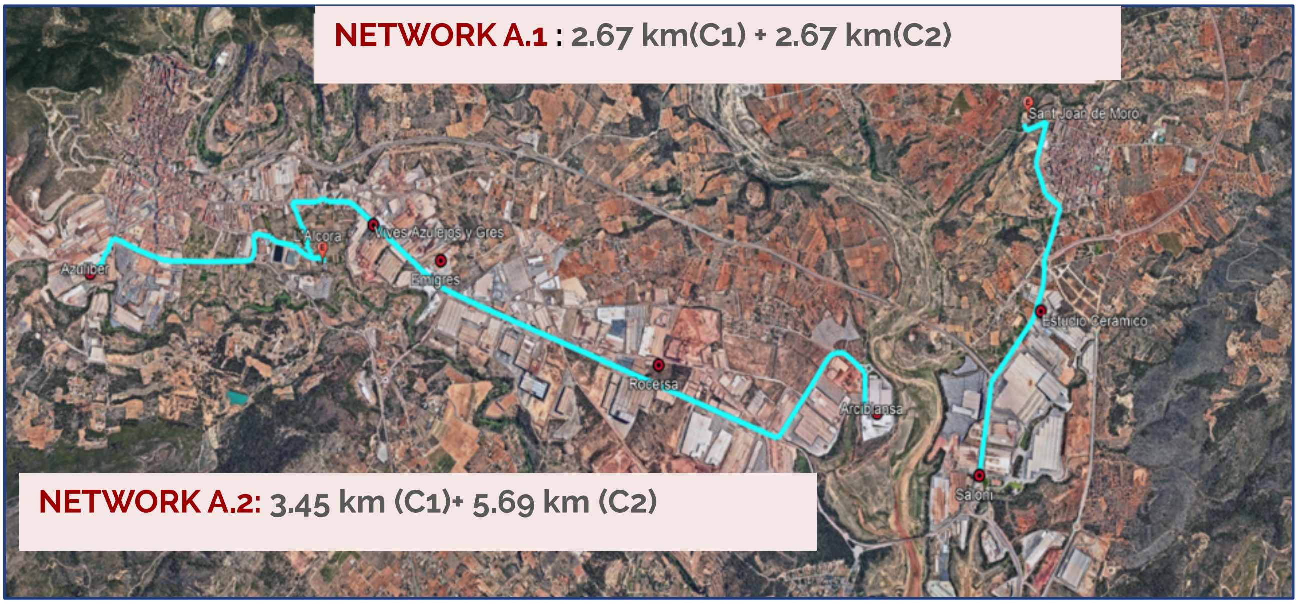

Figure 4. *Distribution networks in area A (network A.1 and A.2)*

Area B: comprises two networks, one per treatment plant. The supply plants in this area are the OBVA and Almazora WWTPs, which can supply the total water demand of at least 22 companies, with a volume of 5,055.8 m^3 per day. That would mean reusing an effluent volume of 1,845,367 m^3 per year (1.8 hm^3/year) in this area, i.e. 25% of treated effluents from the WWTPs in this area.

NET	**WWTP**			**Nº companies**	**Quality C1**		**Quality C2**	
	WWTP	Treated effluent, m^3/day	% reused		km. of pipeline	Max. flow. m^3/day	km. of pipeline	Max. flow. m^3/day
B.1	OBVA	10,598	36%	19	16.4	1261.54	16.7	2565.1
B.2	Almazora	9,218.34	13.3 %	3	3.83	958.75	3.83	270.44
Total		**19,816**	**≈25 %**	**22**	**20.23**	**2220.3**	**20.53**	**2835.5**

Table 4.- *Zone B and the networks defined in the zone.*

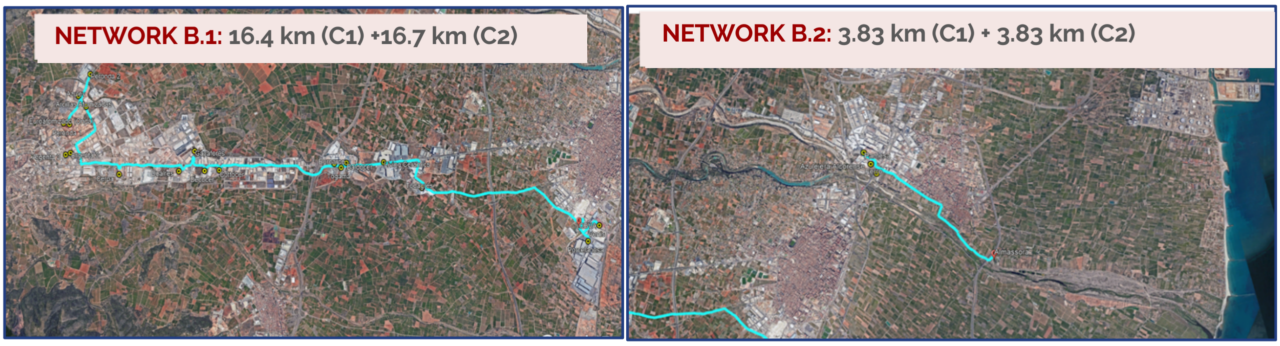

Figure 5. *Distribution networks in Area B (network B.1 and B.2)*

Area C: comprises two networks, both supplied by the same treatment plant - the Nules WWTP, which is able to supply the total water demand of at least 8 companies, whose demand for water is 3,103.4 m^3/ day. This would mean reusing a volume of 1,132,741 m^3 of effluent per year (1.1 hm^3 per year) in this area, thus achieving an 86% reuse rate of the effluent from the Nules WWTP.

NET	WWTP			Nº companies	Quality C1		Quality C2	
	WWTP	Treated effluent, m^3/day	% reused		km. of pipeline	Max. flow, m^3/day	km. of pipeline	Max. flow, m^3/day
C.1	Nules	3,588.92	86. 5%	5	5.7	398.95	4.8	409.02
C.2				3	7.8	34.95	7.37	2,260.28
Total		**3,589**	**86.5 %**	**8**	**13.5**	**433.9**	**12.17**	**2,669.48**

***Table 5**.- Zone C and the networks defined in the zone.*

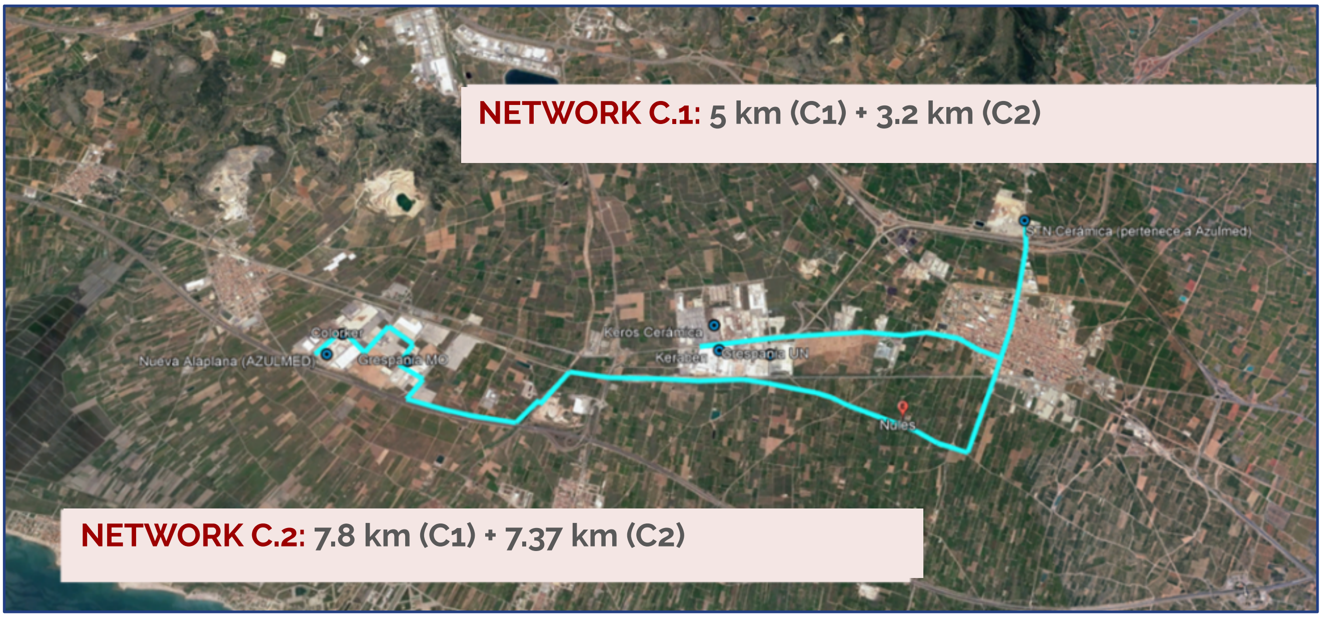

***Figure 6.** Distribution networks in Area C (network C.1 and C.2)*

Area D: comprising three networks, one per treatment plant. Water supply comes from the Villafamés, Cabanes and Vall d'Alba WWTPs, which are able to supply the total water demand of at least 5 companies, with a demand volume of 860.3 m^3 per day. This would mean reusing a volume of 314,020.5 m^3 of effluent per year (0.3 hm^3 per year), i.e. 77% reuse of effluent from the WWTPs in this area.

NET	WWTP			Nº companies	C1		C2	
	WWTP	Treated effluent m^3/day	% reused		km. of pipeline	Max. flow, m^3/day	km. of pipeline	Max. flow, m^3/day
D.1	Vilafamés	284.16	68.5%	2	1.95	77.27	0.5	117.27
D.2	Cabanes	341.05	63.7%	2	3.7	111	4.1	106.39
D.3	Vall d'Alba	448.44	100%	1	-	0	3.9	448.44
Total		**1074**	**≈77 %**	**5**	**5.65**	**188.27**	**8.5**	**672.1**

Table 6 *- Zone D and the networks defined in the zone.*

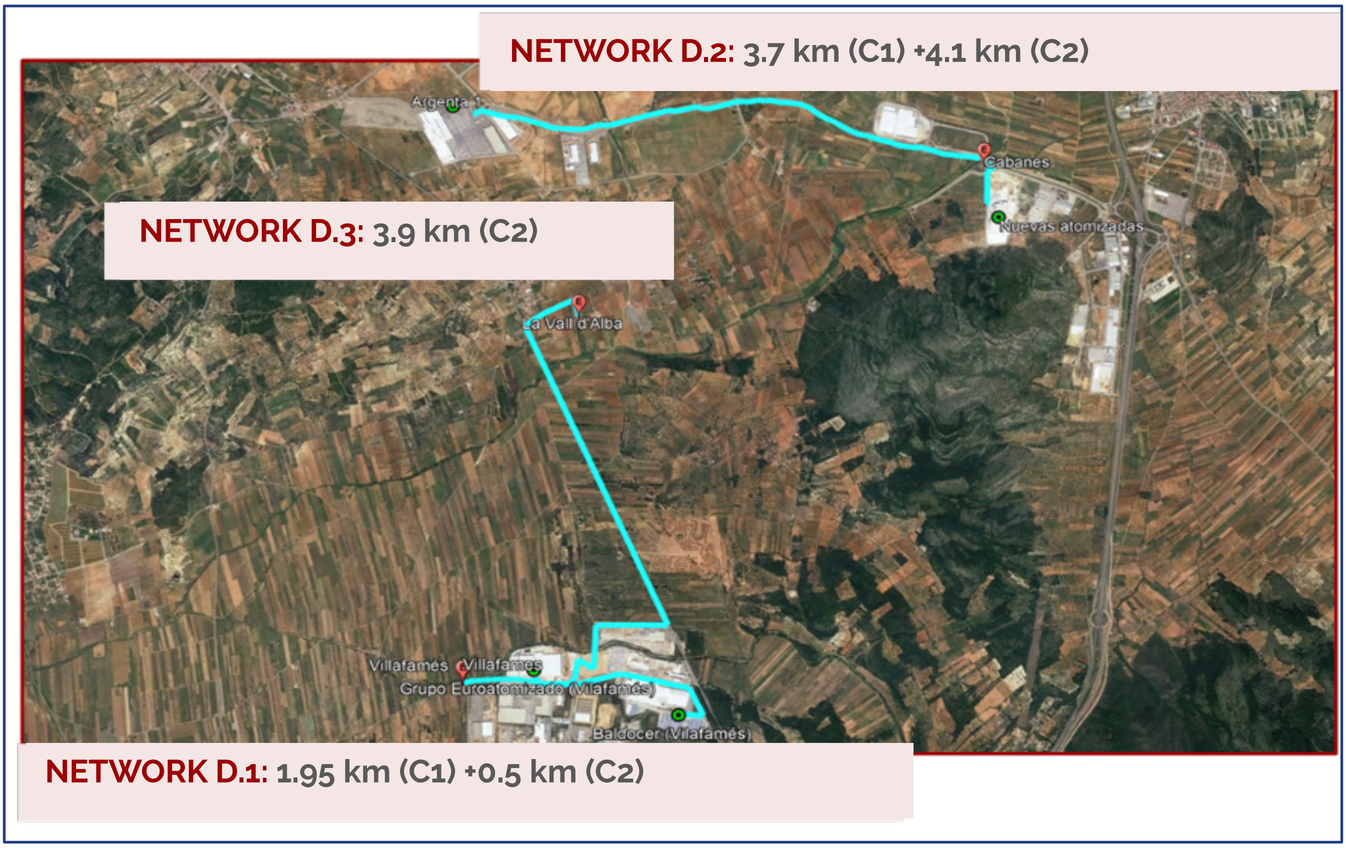

Figure 7*. Distribution networks in Area D (network D.1, D.2 and D.3)*

As an outcome of this design, 9 suitable distribution networks from 8 urban wastewater treatment plants (WWTP) have been proposed to use their effluent to supply the total water demand of 42 companies in the ceramic sector, which would mean ceasing to use 4 hm^3 per year of water from the La Plana de Castellon aquifer, a figure that represents almost 50% of the total water demanded by the ceramic sector in the province of Castellon (estimated at around 9 hm^3/year).

3.2 STAGE 2: ASSESSMENT OF COSTS AND BENEFITS

3.2.1 ESTIMATED COSTS

Having defined the areas, supply networks and companies to be connected to the networks, the next stage involved identifying the hydraulic characteristics and sizes of those networks on the basis of flow rates to be pumped, pipe diameters, length of pipe sections to each company - split by C1 and C2 -, and water pumping from WWTPs to the industrial sites. These statistics were calculated for each of the networks in the design and from there, the costs of water distribution could be worked out.

NET	WWTP	Nº Comp-anies	Quality C1			Quality C2			Buffer tank
			Total km. of pipeline	Pump rate, m^3/day	Pipe Ø (mm)	Total km of pipeline	Pump rate, m^3/day	Pipe Ø (mm)	(m^3)
A.1	S.J. Moró	2	2.69	8.95	110	2.69	7.34	110	330
A.2	Alcora	5	3.5	12.96	63	5.7	28.92	110	1100
B.1	OBVA	19	16.4	17.35	110	16.7	18.81	110	3830
B.2	Almazora	3	3.8	47.94	160	3.8	13.52	110	1300
C.1	Nules	5	5.7	31	160	4.8	80.5	160	3120
C.2	Nules	3	7.8	2.5	75	7.4	51.4	200	
D.1	Vilafamés	2	1.95	3.86	75	0.5	5.9	90	200
D.2	Cabanes	2	3.7	4.2	75	4.2	4.95	55	220
D.3	Vall d'Alba	1				3.9	22.4	160	430
		42	**45**			**49**			

Table 7*- Hydraulic characteristics of each network.*

Furthermore, the costs of the entire solution proposed by REWACER were also estimated, meaning that different assessments were carried out individually for each parameter under consideration:

- The water regeneration station (WRS) to obtain water quality C1 (this paper does not address the treatment technologies required to obtain such quality of water, but does include their cost in its overall cost estimation)[10,11]
- Capital investment in infrastructures required[12]
- Amortisation of WRS and networks
- Operation and maintenance costs.

Treatment costs only refer to C-1 water quality, which requires a WRS, but not to C2 quality. The costs associated with each parameter identified and analysed for each quality of water are given below:

	WRS, €/m³	Distribution, €/m³	WRS amortisation, €/m³	Network amortisation, €/m³	Total cost, €/m³	Proposed charge rate, €/m³
C1	0.4814	0.1	0.058	0.0731	**0.71**	**0.786**
C2	0	0.1	0	0.0731	**0.173**	**0.192**

Table 8.- *Estimated costs for each water quality.*

Costs have been estimated for:

- Cost of tertiary treatment technologies identified in REWACER,
- Cost of infrastructure required for distribution networks (considering that 45 km of piping for C1 and 49 km for C2 have been designed),
- WRS and distribution networks amortisation costs. Total capital costs, plant amortisation period (25 years), and interest (at 2%) were considered.
-

The formula used was as follows:

Formula	Where:
$\text{Amortisation (A)} = C^* \dfrac{i^*(1+i)^n}{(1+i)^n-1}$	*C: Investment costs* *i: Interest rate* *n: no. of years' amortisation*

- WRS and Network operating and maintenance costs[13,14]: The cost of water distribution, i.e. of pumping water to industrial sites, was estimated at €0.10 per cubic metre.
- Proposed Water Charge Rate[15]. The following formula was used to establish a reasonable charge rate: Cost / 1-Industrial margin (10% industrial margin).

3.2.2 ASSESSMENT OF THE ECONOMIC BENEFIT FOR INDUSTRY

After analysing the costs required to implement the REWACER solution and establishing possible charges for C1 and C2 standard water, the feasibility for the ceramic industrial sector and for the water operator of implementing such a service was assessed. This was performed by means of an economic analysis of the distribution networks designed in order to lay the foundations for the subsequent development of a new business model that would enhance the use of water from WWTPs by the ceramic industry.

As part of this project, the likely economic benefits for both industrial sectors involved were evaluated and quantified:

- For the ceramic industry, from two viewpoints: firstly, use of the newly designed networks and the proposed charges and, secondly, benefit of using higher quality water (C1) than is currently used by today's production processes.
- Water board industry: implementing this new distribution of alternative water sources (C1 and C2).

3.2.2.1 CERAMIC INDUSTRY

ASSESSMENT OF THE BENEFIT OF DISTRIBUTION NETWORKS

A costing study was performed for each of the networks defined above, in which the cost and benefit was identified for each individual company included in each network, i.e. quarterly water consumption and consumption costs were reckoned.

To quantify benefits jointly, as a whole, it was decided to analyse each designed network individually, since pipe sections can be added together while distribution, water regeneration and pumping costs are taken severally for each network[16]. The following figure shows the results of the cost of supplying companies with C1 and C2 water in each of the networks.

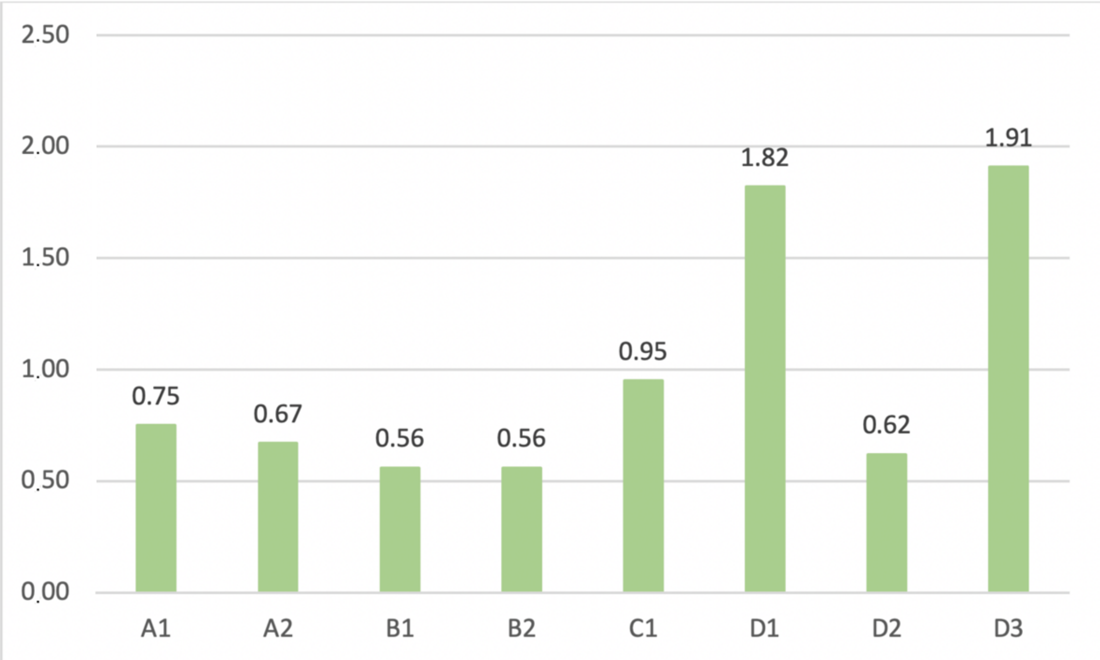

Figure 8. *Cost of water for the ceramic industry by area (water supply).*

The overview offered by Figure 8 reveals a high degree of dispersion in costs per m^3 for each defined geographical network. Networks D1 (Vilafamés), D3 (Vall d'Alba), and C1 (Nules - the C1 and C2 networks are calculated together because it is the same network with two branches) are the ones with the highest costs, whereas the lowest cost networks are B1 (Onda), B2 (Almassora), and D2 (Cabanes).

To enable a comparative analysis with today's situation, the current mains water supply rates in each municipality in the defined areas (supply nets) were taken as the reference and compared with the proposed supply costs for C1 and C2. Figure 9 shows that, for each quality of water, the costs of distributing both water qualities are slightly lower than for today's mains water and would therefore bring cost savings for companies connecting to the new networks defined herein.

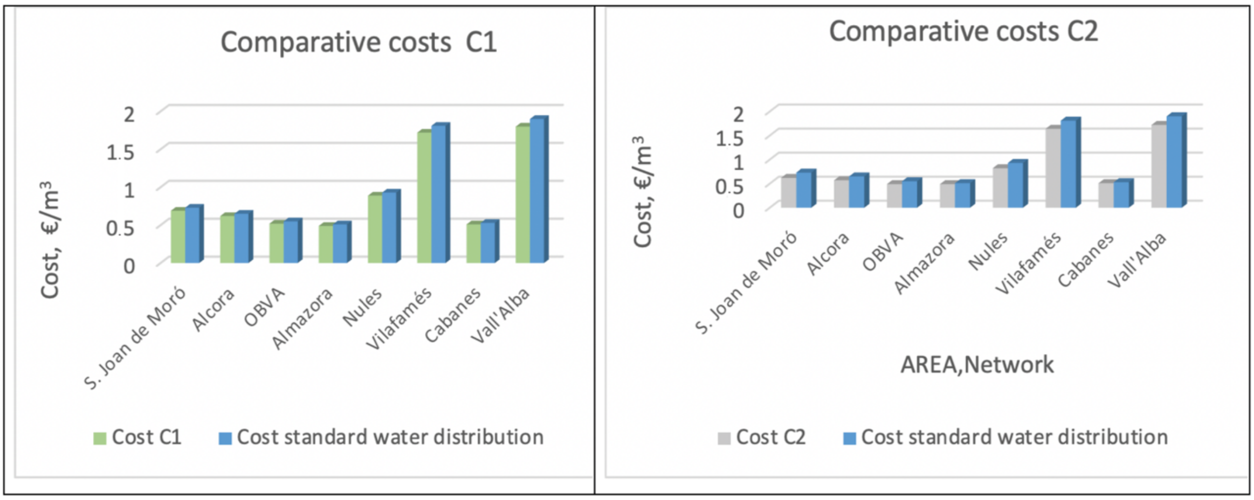

***Figure 9**. Comparison of C1 and C2 water prices for each network*

In order to identify the economic benefits and therefore encourage use of alternative water by the ceramic sector, an optimised valuation was made of the savings that companies could achieve with the prices of both types of water (C1 and C2) and from a point of view that guarantees their economic sustainability. To this end, each area and network were analysed, taking into account maximised savings criteria, i.e. a total cost saving of 10% compared to the cost they are currently paying, and a 5% reduction in the price of reclaimed water (C1). So (T1 x VC1) + (T2 x VC2) = 0.90 x cost of mains water (€), where:

T1 = C1 charge rate (€/m^3)
T2 = C2 charge rate (€/m^3)
VC1 = C1 water consumption (m^3)
VC2 = C2 water consumption (m^3)

The following figure shows the savings obtained for each network and the savings that companies could achieve per network on a quarterly basis in optimal conditions. As can be seen, the industrial margin is positive in all 8 networks assessed. The networks that generate the highest margins are Nules, Vall d'Alba and OBVA.

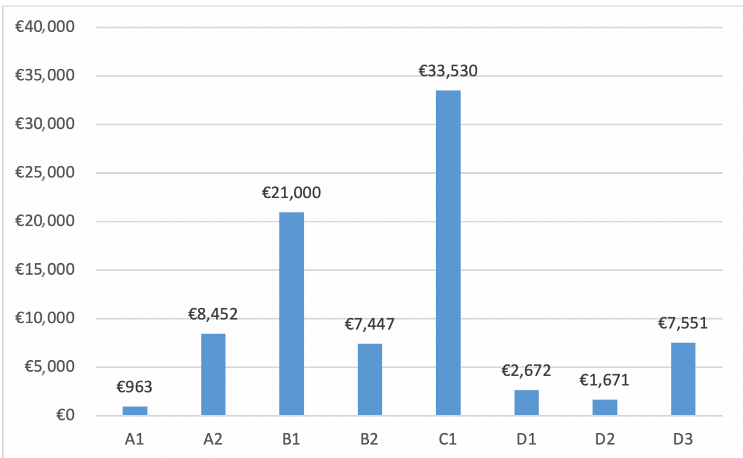

***Figure 10.** Economic comparison by area for optimised implementation (combined quarterly savings for ceramic firms)*

The dispersion of savings per network is due to the charge rates set for the different types of water (C1 and C2) and the volume demanded for each by the network in question. The aim is to encourage the use of unconventional water - both C1 and C2 - by the ceramic industry. The greater the consumption of C2 by companies, the higher the economic savings and thus the greater the profit from sales of end ceramic products.

ANALYSIS OF THE BENEFIT FOR CERAMIC PRODUCERS

The benefit a ceramic firm could achieve during its production process if it used the proposed alternative water source was evaluated, given that during the stage to validate water qualities C1 and C2 in the ceramic production processes, a certain improvement in material behaviour - and therefore in the production process – was noted when mainly C1 type water was used. Consequently, the economic benefit that two different types of companies could have if they used water quality C1 was also assessed. The study focused on a spray-drying company (with a production of 50,000 ton/year) and on the glaze preparation at a tile company (producing 2,860 ton/year of glazes), both of which are participants in this project and each has a different water supply source, i.e. the spray-drying firm is currently supplied with mains water, while the tile company draws water from its own well. The following table shows the considerations assessed for each of these companies.

Type of company	Costs associated with current water use	Cost incurred by adapting to the new water net, €	Savings from production	Cost of benefit, €/year	TOTAL savings in production by type of company
Spray dryer (50,000 ton per year)	Mains water supply	46,500	Direct: Deflocculant, Energy, Phosphate	171,168	461,048 €/year
			Indirect: water and gas	290,880	
Glaze preparation (tile company) (2,860 ton per year)	Sanitation fee Pumping well water	6,950	By having more homogeneous water (well water is subject to fluctuations in rainfall and water table), Taxes / fixed fees, Water extraction,	4,523	4,523 €/year

Table 9. *Production savings by two types of companies when using C1 water.*

As the table above shows, in both cases, the amortisation period to adapt their facilities to an alternative incoming water source is more than feasible, given that for the spray-dryer, it would be less than one year, while in the case of the glaze preparation at the tile company, a little over one year. That confirms the feasibility of implementing this new business model of a circular water economy for the province of Castellon.

3.2.2.2 WATER SUPPLY INDUSTRY

In addition, an estimate was made of the costs and revenues that the water supply company could see by implementing this new distribution service of an alternative water source, i.e. by distributing both C1 and C2 quality water from its WWTPs to ceramic firms, as defined here. This estimation was carried out from the point of view of confirming whether it would also be economically feasible for the company to offer such a service on the bases set down herein, and with the intention of forging a future water business model.

The cost/revenue estimation was made for each of the networks designed in an integrated way, i.e. supplying both C1 and C2.

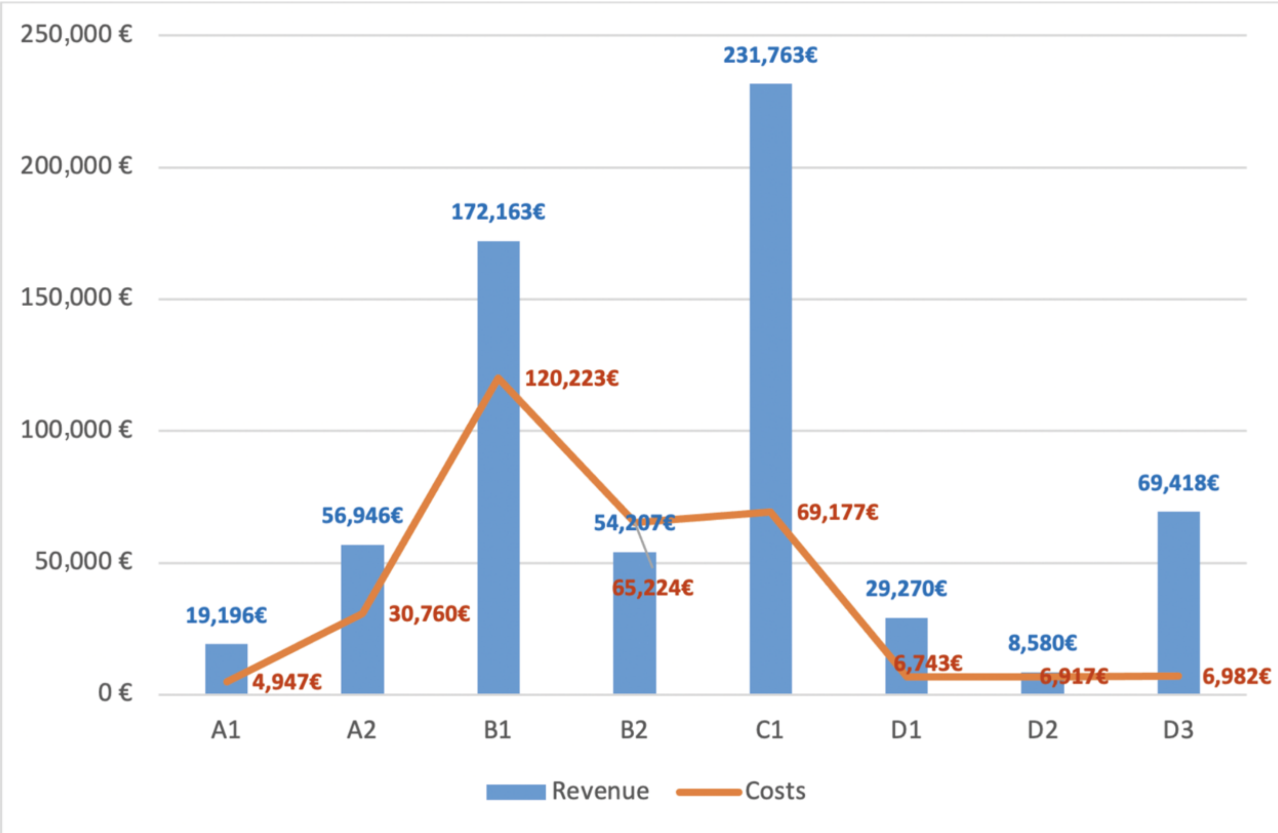

***Figure 12**. Costs and revenues for the water supply company (€/quarter) per network*

In conclusion, consumption by ceramic companies with the C2 rate produces significant revenues for the supply company and, in most cases, allows it to offset the possible deficit that offering the C1 price may incur in certain areas.

Nevertheless, it does demonstrate that this could be a profitable new service for the company.

3.3 STAGE 3: MODEL FEASIBILITY EVALUATION

The results presented above show the economic feasibility, from both the economic and production point of view, of using an alternative water source from urban wastewater treatment plants (WWTP) in ceramic industrial environments.

The cost of water for ceramic companies would be no higher than at present, and even provide savings on the cost of water (with a cost somewhat lower than today).

On the other hand, from the point of view of production, ceramic firms could reap economic savings by using a constant and homogeneous type of water, given that water of a suitable quality adapted to their needs is the most ideal for ceramic tile production processes, as it avoids the typical fluctuations in quality associated with water sourced from aquifers.

Therefore, initially, applying this model of circular water economy in the province of Castellon with water supplied from a WWTP to a ceramic industrial plant could be valid both economically and in terms of production quality.

Both C1 and C2 quality waters were tested in the different ceramic production processes with good results. The scope of this paper does not venture into that part and so the results have not been included here.

4. CONCLUSIONS

This paper is part of the work undertaken within the REWACER project, which has been made possible thanks to the joint efforts of both industrial sectors, i.e. the WWTP operating company and the ceramic sector, the main industrial consumer of water at local and provincial level. The work focuses on evaluating the feasibility of implementing a model circular water economy in the province of Castellon, to see whether the model can feasibly be introduced as a future service by the water supply company and whether it is technically and economically viable for the ceramic industry.

The results of the work presented show that implementing this possible model is feasible in economic terms and beneficial for both the water supply company and consuming companies. Using reclaimed water brings cost savings for ceramic companies, which can obtain quality water that fits their needs at a lower price than they are paying at present, thus significantly reducing their water bill and achieving greater economic return on the end ceramic product. In turn, the company that manages the WWTP can sell a product that currently has no market value and, therefore, could also obtain additional profits.

From the environmental point of view, it is important to remember that the La Plana de Castellon aquifer supplies 80% of the ceramic sector, among others, and is subject to water stress and over-exploitation. Implementing the results of this work would contribute to reducing that stress. In addition, it would help the ceramic sector to adapt to climate change in the face of threatened water shortages in the future due to foreseeably fewer water resources being available or to less water supplied by the Júcar water board in reaction to those diminished resources. On the other hand, providing an alternative water source would not jeopardise production growth, since it is linked to water consumption - the more square metres of ceramic tiles produced, the larger its consumption of water.

The ceramic sector is the main economic driving force in the province of Castellon, so any limitation of available water resources could affect the province's economy and its economic development.

It is worth highlighting another benefit of this proposal, namely its social and environmental implications, as reducing the extraction of groundwater by 4 hm^3 per year would contribute to the recovery of the La Plana de Castellon aquifer and would make a greater volume of water from the aquifer available for human use, among others.

We wish to conclude by highlighting the fact that the work presented here not only represents a sustainable model of water management for the province to fulfil the ceramic sector's demand for water, but also serves to protect groundwater courses and help them attain a healthy status, and to balance and harmonise local and regional development. In addition, this work can serve as a basis to be extended across the entire ceramic sector by following the method applied in this study.

5. ACKNOWLEDGEMENTS

We would like to express our gratitude to the Autonomous Government of Valencia (GVA) and the Valencian Agency for Innovation (AVI), which has financed this work within the framework of the REWACER project, number INNEST00/19/072 - *Development of a new circular economy model to ensure circularity of reclaimed water from WWTPs to industrial sites*.

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