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Sustainability of non-renewable resources: the case of marble in Macael (Spain) [1]

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Abstract

This study analyzes the evolution of a region whose economy is based on marble—a natural, non-renewable resource—which has also managed to improve its protection of the environment. A development plan promoted by the local government in the 1980s made it possible to assess local extraction companies and provide them with better technology, consequently increasing the yield of reserves and the quality of the final product, while also extending the life cycle of the deposit. Furthermore, new companies began to emerge which made use of materials that had previously been discarded. Finally, investments in research were responsible for introducing new artificial composite substitutes to the market. These actions have helped to reduce product extractions and improve its sustainability.

Keywords: Sustainable development, natural resources, mining production, marble, Macael.

1. Introduction

Countless studies have analyzed the impact that exploitation of renewable and non-renewable resources has on the development of a region, mainly because the depletion of a resource is quite frequently linked to serious social and personal consequences. Ever since the earliest works were published, the literature has insisted on the fundamental premise, in the case of renewable resources, that harvesting rate should not surpass

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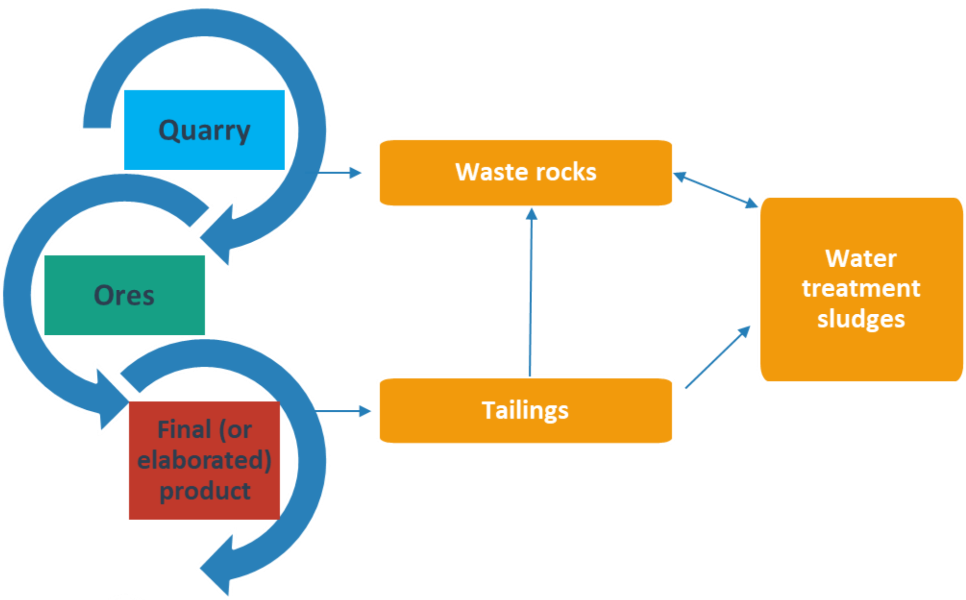
resource recovery rate (Daly, 1991). As recovery is not possible in the case of non-renewables, the practice of quasi-sustainable consumption is encouraged, maintaining that the rate of creation of renewable substitutes compensates for the extraction rate (Bastianoni et al., 2009). This concept can be understood in the strict sense, which involves investing a portion of the profits generated by the non-renewable resource in renewable substitutes that fulfill the same needs as the material that is becoming increasingly more scarce, with the intention that the renewable material will be in conditions to generate an equal profit when the non-renewable has finished its life cycle, (El Serafy, 1989). On the other hand, the concept can be understood in the broader sense, whereby investments are made in any other initiative capable of guaranteeing the sustainability of an area's income (Daly, 1991; Basu and Pegg, 2020). Whichever the case, a factor of vital importance is the life cycle of the non-renewable resource, which depends on its reserves and the expected extraction rate.

Other works, such as those of Lafforgue (2008) and Le and Le Van (2017), propose models for studying the effects of natural resources on sustainable growth (specifically non-renewable resources) and well-being. Both approaches confirm the key role of research and innovation in this field. In addition, other valuable contributions analyze the ecological responsibility of companies that extract non-renewable resources (Harris, 2007), offering proposals to deduce the negative impacts on the environment caused by the activity from production value (Li et al., 2013). Other works study the importance of utilizing a forecasting methodology when initiating a new extraction project (Chopard et al., 2019), taking people into consideration above all (D'Angelo and Pijpers, 2018). Finally, some authors focus on the promotion of social and human development initiatives implemented in the extraction sector (Harvey, 2014).

Other publications focus attention on the exploitation of by-products (Abu Hanieh et al., 2014; Marras and Careddu, 2018; Ashish, 2019; Aydin and Arel, 2019; Bostanci, 2020). Some works propose what could be called the *valuation approach*, which considers by-products secondary resources rather than undesirable materials, in keeping with the circular economy and the principle of efficiency (Nzihou and Lifset, 2010; Bocken et al., 2016; Kirchherr et al., 2017). Utilizing waste—recovering and reutilizing materials already extracted—reduces the environmental impact generated and decreases the consumption of the raw material, thus extending the life cycle of the deposit (Careddu et al., 2013). Furthermore, such practices can help to improve the local economy by creating opportunities for business and employment (Godfrey et al., 2007). In order for waste to become an asset and generate profits, it is often necessary to create and apply innovative technologies.

In addition, and more directly related to the present study, numerous works focus on minimizing the environmental impact of the stone industry, and particularly marble, both in its extraction phase and processing (Careddu and Siotto, 2011; Furcas and Balletto, 2014). As highlighted by Taha and Benzaazoua (2020), many different types of waste are produced during the life cycle of a quarry (Figure 1), and the decision of how to manage them depends on numerous factors. Many solutions tend to be specific to each location and are therefore difficult to apply in other cases. For example, a country's level of economic development may directly influence the scope of the actions necessary (Gitari et al., 2018; Elghali et al., 2019).

Figure 1. Life cycle of a marble quarry and types of waste



Source: Own elaboration

Despite appearing decades ago, the circular economy has gained momentum in recent years in the academic world and in political, economic and social spheres (Pearce and Turner, 1989). This economic model seeks to extend the time that materials and resources remain in the economy and reduce the generation of unusable waste to a minimum. Recently, several contributions have been published in this line, including works by Lacy and Rutqvist (2015) and Webster (2015), as well as those of the Ellen MacArthur Foundation (EMF, 2015).Similarly, a number of other studies have also addressed the topic of waste from mining activities (Tayebi-Khorami et al., 2019). As for government involvement, at the end of 2015 the European Commission published the EU Action Plan for the Circular Economy (EEA, 2016) —an ambitious program whose objective is to reduce the generation of waste to a minimum. Nevertheless, a great deal must be done to achieve this goal.

Breakthroughs in research must ultimately be translated into decisions and objectives which can then be disclosed to direct and indirect actors worldwide, at both macroeconomic and microeconomic levels. Every institution and company must establish actions and specify measures to fulfill the basic principles of sustainability: zero irreversibility, sustainable harvesting, sustainable emissions, sustainable selection of technology and precaution. Education and awareness campaigns are essential for society to realize that such efforts are necessary. However, these initiatives involve a challenge which, in many ways, is still far from being overcome.

Spain is one of the global leaders in the natural stone market. More specifically, it is the seventh world producer and the second producer in the European Union, following Italy (Spanish Ministry for Ecological Transition and the Demographic Challenge, 2018). Marble is the stone with the highest production in Spain, accounting for around 70% of dimension stone production. This sector is of great importance to producer regions, constituting an economic driver in provinces such as Almeria—an area that has become a leader in the marble sector, both nationally and internationally. Nearly half the marble extracted in Spain comes from Almeria, which is also one of the main regions in the processing of this mineral. Few studies in the literature have analyzed actual successful cases of regions with economies based on non-renewable endogenous resources (Careddu et al., 2017). These examples of success correspond to regions that have incorporated alternative economic activities, allowing them to diversify production and supply and extend the life of their local deposit—in short, they constitute economies that have made progress towards achieving sustainable development. The present study fills this gap in the literature by analyzing the evolution of the marble sector in this region and the measures taken to successfully improve environmental sustainability and protection. Thus, after presenting the historical factors that hindered the exploitation of this resource, this work analyzes the complete development plan carried out in the 1980s which was promoted by the public administration. Indeed, it was this initiative that allowed the general restructuring of the sector, transforming a group of companies into an industrial district (Aznar Sánchez et al., 2015), eventually giving rise to new activities that have helped to reduce environmental impact and significantly extend the deposit's life cycle. What is more, the study analyzes the specific case of one of the new companies that, by using alternative resources, has become the top multinationals in artificial composite products (Aznar Sánchez et al., 2017).

With this aim, the present work is structured as follows. The next section presents the evolution and current state of marble mining in Macael. The following section examines the case of the most successful company in the area, Cosentino—a worldwide leading multinational. Next, the discussion section presents the measures analyzed and the results obtained. Finally, the main conclusions are summarized, along with possible future research lines.

2. The case of marble in Macael

Most of the companies related to dimension stone in the province of Almeria (located in the southeast of Spain) are found in the area known as the "Marble District" (*Comarca del Mármol*), which includes five towns (Macael, Olula del Río, Fines, Cantoria and Purchena). Within said district, Macael is one of the main sites for marble mining and processing (Figure 2).

Figure 2. Macael location in Spain

Source: Own elaboration

2.1. Evolution of the sector

For many centuries, marble extraction in Macael followed the concept of common goods. Free access to the resource for residents presented no real difficulties: the amount available was substantial, the volume extracted did not endanger its depletion and, in general, members of the community, which were few, respected the basic rules that tradition had always imposed on the sector.

However, by the 19th century this panorama had drastically changed. A substantial and continuous increase in demand and the free and uncontrolled access to the resource led to a chaotic state of affairs, more so due to the lack of organization of logistics (e.g., size and management of quarry boundaries, dumping of mine waste, road construction and conservation) than the volume of the extractions. In a matter of decades, marble in the region could have quite easily suffered its own "tragedy of the commons"— as certain goods belong to everyone, they do not belong to anyone and are ultimately unusable due to disorganized exploitation (Sala López, 1996). Similarly, applying the concept that would appear 150 years later, marble could have suffered the consequences of unsustainable development. Although this was certainly a possibility, the presence of other determining factors cannot be overlooked, as they helped to withstand dire circumstances and even make sector failure highly unlikely. Indeed, the strong commitment of the local community to the resource, the free access to marble only for local residents, the existence of rules that were respected and a "very personal and close territorial element linked to management" (Carciofi and Azqueta, 2012) leave room for discussion as to whether tragedy would have been the most probable ending, as proposed in Hardin's thesis (1968), or if the system would have achieved sustainable exploitation of the resource, more in keeping with the arguments of Ostrom (1990). In fact, the fate of this region would take another course.

The 20th century in Spain brought drastic legislative and social changes that had significant repercussions. New laws sought to establish guidelines in order to make the transition from a work scheme common to preindustrial society to one more suitable to the times lying ahead. One of the most influential reforms was the support that public institutions received from the central government, among them town councils (Aguilera, 1987). In the case of the study area, one of the effects of the new law codes during the second half of the 1930s was the termination of administrative dependence on the neighboring town of Baza, which had begun in the 15^{th} century. After more than 300 years, Macael had regained control of its mountains. This change in the legal framework made it possible to restrict free access to the resource and demand a selection process of who could receive a license to extract marble, thus avoiding the hypothetical tragedy of the commons.

Ultimately, however, the community failed to seize the opportunity to correct the mining practices which would eventually wreak havoc on the environment and the sector itself. Some of the conditions that were harming the sector included small quarries which prevented opportunities to exploit economies of scale, rudimentary mining methods that limited productivity, closed access roads to quarries which restricted movement and the accumulation of waste accumulated in unsuitable locations, in some cases occupying dry riverbeds and future mining areas. Despite these obstacles and other problems linked to disputes over quarry ownership, marble mining continued in the area for a century and a half, during which time quarry owners were more concerned with product demand, which was indeed the most powerful factor, than with resolving other issues. In the second half of the 20th century, the processing phase of the sector featured restrictive business conditions: small-sized companies; obsolete machinery and antiquated processes which implied high costs and low productivity; and the remote location of processing workshops in towns, which also adversely affected the quality of life of residents (Carretero Gómez, 1995).

By the early 1980s the marble industry was immersed in a severe crisis due to its own internal problems and the state of the general economy. With the aim of escaping this situation, the Global Action Plan was implemented, an initiative created by the Industrial Support Institute of Andalusia (*Instituto de Promoción Industrial de Andalucía*) to modernize sectors. In 1983, with the participation and support of local institutions, the Plan was set in motion and the problems that had long hindered the marble industry started to be solved and brought under control (Barzelay and O'Kean, 1989).

The industrial restructuring that took place radically changed the business panorama. In terms of mining, and within the framework of the Action Plan, the Spanish company Adaro conducted an in-depth study of the area which resulted in two works: The Study of Marble in Macael and The Master Plan for Marble in Macael. Among other recommendations, these works advised creating "exploitation units"—areas with very similar characteristics comprised of various quarries—which, by sharing different tasks, would allow more manageable mechanization of processes, a more consistent supply of marble, enhaced organization of mines and increased safety. Indeed, these measures would successfully improve the exploitation of the reserves, lower mining costs and an extension of the life cycle of the deposit (Carretero Gómez, 1995).

The findings of the Master Plan are also interesting as relates to the proliferation of dumps and their indiscriminant locations, which caused serious problems. First, many were located on top of extractable marble (Adaro, 1985). Second, dumps located in dry riverbeds posed serious threats as they could act as barrier dams during torrential rains, possibly provoking flash flooding that could seriously endanger lives and property (Adaro, 1985-1986). In any case, as the dumps had a very wide base, the risks of a large-scale disaster due to a sudden discharge of reserved water were low. Only some of the dumps could be exploited for raw material due to the extensive mixture of the materials accumulated and the difficulty of obtaining the raw material at a low cost (Adaro, 1985). The study proposed designating locations for dumping with the aim of minimizing and addressing these problems. It also suggested creating a supervisory office for managing the measures suggested, coordinating research work and assuming technical consulting functions as well as the role of public administration intermediary (Carretero Gómez, 1995).

By innovating and diversifying products, the restructuring of the sector allowed companies to change direction and update their technology. Many small businesses that produced material for construction, and which could barely compete in the market, moved towards ornamental products. For many years, these companies focused exclusively on exploiting by-products, mainly ground materials, but soon, drawn by the purity of calcium carbonate and its numerous applications, several micronization companies established themselves in the area.

Both the Action Plan and other subsequent initiatives insisted on the need to offer a high-quality end product and to transform the area into a processing center that imported raw stone from other locations (domestic and foreign) and produced finished products locally (Carretero Gómez, 2004). This approach reduces local extractions and improves sustainability while also providing added value.

2.2.Life cycle of the deposit

One of the points addressed in the Adaro study (1985) was the evaluation of the marble reserves in the area, which were calculated at 50 million cubic meters, of which 30 million were considered extractable, nearly half of which is located in the Macael mountains. It also estimated that 27 million of the total reserves is white marble and 23 is gray marble. These estimates correspond to "visible or confirmed reserves", which means the real figures are assumed to be much higher. Based on these data, in a scenario exploiting 50% of the reserves, with an annual production of parallelepiped and irregular blocks[2] of 654,000 tons, the Master Plan calculated an average deposit life cycle of 104 years, in the case of all types of marble, and 56 years for only white marble if it were to be extracted exclusively (Adaro, 1985-1986). Obviously, these calculations are subject to change depending on whether new reserves are discovered, annual production significantly changes or improved mining methods appear, which would yield more efficient extraction percentages. With a slightly different calculation based on the same reserves figures and exploitation percentage, similar results are found by taking 1991 as the start year, with the Master Plan practically finished. Considering the proportion of marble extracted according to color as of 1991 (white marble extractions accounted for 90% of the total) and slightly larger annual extractions, white marble reserves were concluded to have a 52-year life cycle (Table 1).

Table 1. Life cycle of deposit in the Macael mountains (start year 1991)

Marble	Reserves 1985 (thousand m^3) (1)	Reserves 1985 (thousand t) (2)	Reserves blocks 1985 (thousand t) (3)	Extraction blocks 1985-1991 (thousand t) (4)	Reserves blocks by end 1991 (thousand t)	Estimated annual extrac. (thousand t)	Deposit life cyle (years)
White	27,143.7	73,288.0	36,644.0	3,959.2	32,684.8	630	51.9
Gray	23,652.7	63,862.3	31,931.2	439.9	31,491.3	70	449.9
Total	50,796.4	137,150.3	68,575.2	4,399.1	64,176.1	700	91.7

Sources: Adaro (1985-1986) (1), Macael Town Council (4) and own elaboration. (2) Marble density 2.7 gr/cm^3, (3) Assuming exploitation of 50%.

However, such forecasts require periodic updates that consider deposit evolution; mining techniques and the market, and all the aspects the latter involves (e.g., changes in demand, appearance of new competitors, as well as introduction of substitute products). In recent decades, certain changes have occurred that are positively impacting the deposit's life cycle. Firstly, new marble beds have been discovered. Secondly, extraction techniques have greatly

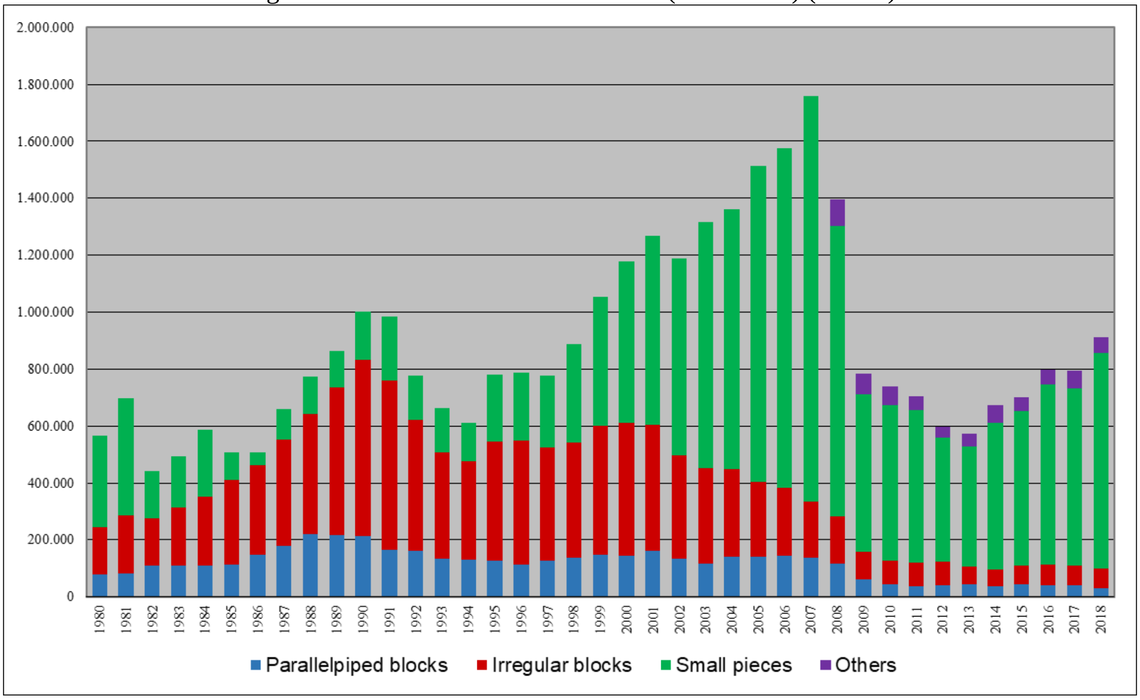
[2] Pieces of marble large enough to be used for obtaining construction material.

improved, allowing beds to be mined which would not have been economically profitable with previous methods, ultimately increasing extraction percentages. Thirdly, new market niches have opened that allow marble considered waste until a few decades ago to be commercialized, such as the use of small size marble stones for garden decoration and micronization processes for pharmaceutical, cosmetic and food industries. Fourthly, incorporation of new processing machinery has increased the yield from blocks of marble, thereby increasing cubic meters obtained. For example, the ability to cut sheets at a thickness of only a few millimeters, which are then glued to panels of very light materials to achieve adequate strength, offers opportunities for new applications such as wall cladding on ocean liners. Lastly, the most important change, particularly in the Macael area, was the advent of new marble substitutes in the 1990s which have drastically helped to reduce extractions of this natural resource.

According to the data provided by the Macael Town Council, the 1980s were a period of constant expansion in terms of extractions of parallelepiped and irregular blocks, reaching a total of 833,095 tons in 1990. However, extractions decreased during the first part of the 1990s (mainly due to the economic recession), with an average extraction of 534,873 tons between 1993 and 1999, much lower than the 654,000 and 700,000 that had been used years before to calculate the life cycle of the deposit (Table 1). Surprisingly, extractions of parallelepiped and irregular blocks continued to fall at the start of the 20th century, at the height of economic expansion and construction. In 2007, the final year of the economic boom, the sector reached 333,449 tons—56.6% of what had been extracted in 2000. The recession of 2008 further accentuated this reduction, dropping to 95,529 tons in 2014—a figure that has hardly risen since, once again during a time of economic recovery.

Another important change was the increased exploitation of marble wastes. For decades, materials generated during the mining and processing of parallelepiped and irregular blocks, composed mostly of marble, was commonly discarded. However, in the 21st century, marble wastes were no longer considered by-products and instead became a highly valuable raw material, proving useful in the manufacturing of aggregates and micronized products. Since 2010, these materials account for about 85% of all marble extracted (Figure 3).

Figure 3. Marble extractions in Macael (1980-2018) (in tons)



Source: Macael Town Council

3. The company Cosentino. A different paradigm

The sector of non-renewable resource extraction has been receiving increasing pressure to incorporate sustainability into its decision-making processes (Harris, 2007). The company Cosentino is an example of how several businesspeople with extensive knowledge about the product and market, and a special skills set, took advantage of the opportunities offered by the Global Action Plan of 1983 and made a commitment to achieving the most environmentally responsible operations possible. At the beginning of the 1980s, the company was merely one of the dozens of small businesses that operated in the Macael Marble District. Well aware of the limitations of the local stone, the Martínez-Cosentino brothers undertook a strategy based on research and innovation, targeting foreign markets and seeking out new market niches. Their objective was a product which: 1) maintained the characteristics of marble and, in general, natural stone 2) was easy to handle; 3) could be obtained at a lower cost; and, 4) could be produced in a variety of colors. After their first product failure, in 1990 the company responded with the commercialization of Silestone, an artificial composite that revolutionized the market of kitchen countertops. It soon became successful in the United States, and a few years later it was being sold around the world.

Cosentino was the leader behind an innovative technology that completely transformed the normal operations of what, until then, had been the "Macael Marble Cluster". Eventually, the area came to be known as the "Stone Cluster", a name which alludes to both the natural product and the artificial composite. A different company could have carried out the gestation and initial phases of the innovation, yet once the new product had triumphed, entry barriers (e.g., the innovation patent and the high initial investment) prevented others from following suit, and Cosentino became a monopolist. Marble gradually lost importance in the company's sales, which were dominated by artificial composites whose primary raw material was completely unrelated to marble and its waste. Thus, the natural material that gives the district its name, which has been the way of life of its inhabitants for centuries, began to share prominence with new products that, despite creating competition, improved marble's prospects for sustainability.

In the year 2000, Cosentino was on the threshold of becoming a large company, with nearly 250 workers and turnover of 46.9 million euros (SABI, 2019). Loyal to its strategy, while releasing new products on the market (among others, *Silestone anti-bacterial worktops* in 2004 and *Dekton* in 2013) and searching for new niches, the company also introduced novel commercialization methods (*Cosentino Centers, Cosentino City*), consolidating its presence in several countries and entering markets in others, opening delegations, sales centers, logistics facilities and processing factories. It would eventually become the worldwide leader in artificial composites.

Table 2. Marble District. Companies in the stone sector in 2018

Name	Exploitation revenue		Employees	
	Millions (€)	%	Number	%
Cosentino SA	548,316	92.3	2,068	82,2
Triturados Blanco Macael SA	6,833	1.2	35	1,4
Mármoles Gutiérrez Mena SA	4,455	0.7	47	1,9
Cuellar Arquitectura del Mármol	4,430	0.7	42	1,7
Mármoles Antonio El de Pura SL	3,549	0.6	15	0,6
Hermasa & Cosaga Mármoles SL	3,237	0.5	22	0,9
Mármoles Camar	2,712	0.5	27	1,1
Mármoles La Vina	1,524	0.3	11	0,4
Arianal SL	1,070	0.2	7	0,3
Mármoles Pérez García	1,038	0.2	13	0,5
Mármoles Luis Sánchez SL	997	0.2	8	0,3
Caicedo Stone SL	995	0.2	10	0,4
Natural Stone Tino SL	959	0.2	25	1,0
Rest of companies (53)	13,915	2.3	186	7,4
Total	594,030		2,516	

Source: SABI (2019). Own elaboration utilizing only the 66 companies for which the database offers information from 2017 to 2018.

In 2018, there were 309 companies in Almeria dedicated to the mining and processing of ornamental rocks (SABI). Of them, 232 (75.1%) operated in the towns of the Macael Marble District, constituting the most important stone cluster in Andalusia. Turnover data for the 66 companies in the SABI database from 2017 and 2018 show that the cluster consists of one large dominant company, Cosentino (obtaining revenues of approximately 548 million euros, representing 92.3% of the sector, with 2,068 employees), 12 small companies, of which only six have more than 20 workers, and a large group of micro-enterprises (Table 2). Around 95% of Cosentino's turnover comes from artificial composites (e.g., Silestone and Dekton), which places it in a unique position considering the main activity of the other businesses is focused on the extraction, elaboration and processing of marble.

One of the research lines of the company involves the search for methods that allow the principles of the circular economy to be applied in its processes so the materials and resources utilized may remain in the economy for as long as possible, thereby minimizing the generation of waste.

4. Discussion

Many regions whose economies are based on non-renewable endogenous resources have entered an irreversible economic recession, resulting in diminished well-being and depopulation due to inadequate exploitation, resource depletion or competition from new substitute products. Some quintessential cases are those of numerous coal-mining towns and Riotinto (Spain), which is known for its copper mines. This area was unable to create alternative activities to sustain employment, apart from visits to inactive mines. Nonetheless, it is worth bearing in mind that each case is somehow unique and requires a specific plan to study its sustainability, considering the endogenous resource itself, the needs it covers, the population characteristics (e.g., strong roots in the region) and the country's level of development and available means, among others. In addition, such plans must adopt a long-term approach, which not only demands an honest commitment to work towards sustainable development but also an efficient public administration. The literature contains numerous works which address these topics in relation to specific cases

(Mitchell and O’Neill, 2017; Peña and Lizardo, 2018; Schilling et al., 2020).

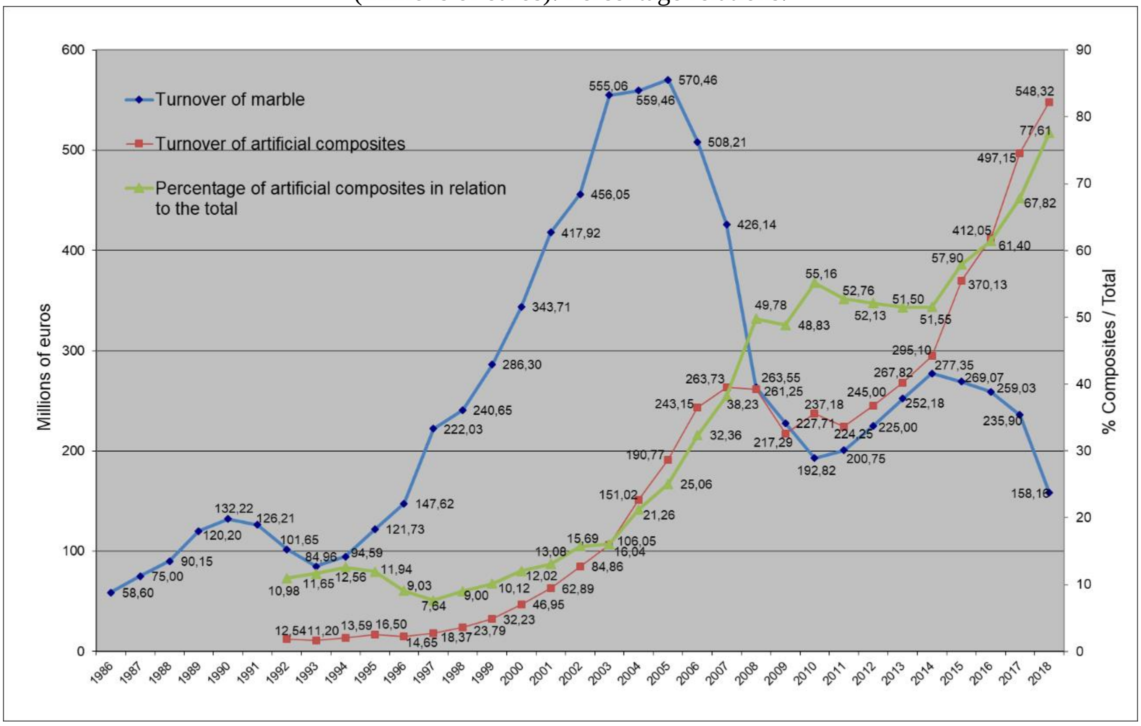
As for the present study, the socioeconomic sustainability of the marble district has notably improved since the 1980s. The Action Plan carried out during said decade solved many of the problems facing the marble industry, adversely affecting sustainable development and posing the threat of depopulation, which has occurred in other places either due to the depletion of endogenous resources or inadequate exploitation. One indicator that demonstrates the positive results of the Action Plan is population growth, rising from 16,698 inhabitants in 1981 to 20,244 in 2011 (an increase of 21.2%), making the area one of the only inland communities in the region (Andalusia) with this positive trend.

The Action Plan, which was extensively thorough, proposed objectives and promoted studies in a wide range of fields. It was responsible for providing better knowledge of available resources and how they could be properly exploited. The plan also introduced resizing quarries, unifying labor and incorporating new services and suitable technology. Thanks to these measures, it was possible to improve mining, reduce costs and increase productivity. In the area of processing, the industrial restructuring carried out facilitated the resizing of companies to adapt them to the needs of the market. Furthermore, it provided companies with more advanced technologies and relocated facilities from town centers to industrial estates, which lowered pollution (e.g., visual, acoustic, dust) inside town limits. The construction of bypass roads contributed to improving the quality of life of the local communities as well. In addition, the plan was responsible for the rehabilitation of quarries and dumps, as well as instating the controlled removal of sludge resulting from cutting and polishing marble. Despite the increased activity of companies that utilize by-products from quarries and elaboration factories, and that of service companies that remove sludge, it is precisely these fields where a great deal of improvement could still be made.

The measures linked to the Action Plan also proved essential to the future success of certain businesspeople in the sector, the case of Cosentino being the perfect example. Aware of the new demands of the market, the company focused research on obtaining new artificial products that satisfied trends in the demand. Emerging from these efforts, among others, were Silestone in 1990 and Dekton in 2013, manufactured in the area using external raw materials. As they are marble substitutes, these products have contributed to significantly reducing the company’s extractions without affecting employment and, consequently, without causing depopulation. The dilemma is what would happen in the medium or long term if Cosentino relocated. It must not be forgotten that it is a first-generation company with substantial overhead costs as a result of its location.

The success of artificial composites and their percentage of the sector's sales are remarkable (Figure 4). Whereas by the mid-1980s 100% of sales came from marble, this figure reached only 22.4% in 2018. The evolution of marble extraction in the area has had a significant impact on the sector, decreasing from an average of 595.8 thousand tons annually in the 1990s to 466.3 thousand tons during the years of the economic boom at the beginning of the 21st century, and to an average of 111.8 thousand tons during the 2010s. This last figure has remained stable since 2014 despite the economic rebound and the recovery of the construction sector in recent years. In addition, the small pieces of marble that were once by-products designated for dumping have gained their own value as raw materials in the manufacturing of aggregates and micronized products.

Figure 4. Macael Marble District. Turnover for marble and artificial composites between 1986 and 2018 (millions of euros). Percentage relations.



Source: Own elaboration with data from AEMA (2019) and SABI (2019)

By recalculating the life cycle of the deposit based on the reserves evaluated in 1985 by the Master Plan and assuming an exploitation percentage of 50%, while also considering all the changes in the sector, the result becomes quite different. Thanks to the technological improvements adopted in recent decades, including investments in research and development that led to the discovery of substitute products now manufactured in the district, the life cycle—understood as the reserves of parallelepiped and irregular blocks—would rise from the 56 years originally calculated for white marble (which would be reached in 2041) to 244 years, with 2018 as the start year (Table 3). This calculation assumes that 90% of the marble extracted will continue to be white, which has recently been the case. Without focusing on any one type of marble, the average life cycle of the deposit would be slightly less than 500 years.

Table 3. Life cycle of the Macael deposit

Marble	Reserves blocks 1985 (thousand t) (1)	Extraction blocks 1985-2018 (thousand t) (2)	Reserves in 2018 (thousand t)	Annual extraction forecast blocks (thousand t)	Life cycle of deposit (years)
White	36,644.00	12,180.13	24,463.87	100	244.64
Gray	31,931.15	1,353.35	30,577.80	11	2,779.80
Total	68,575.14	13,533.47	55,041,67	111	495.87

Sources: (1) Adaro (1985-1986). Assuming a marble density of 2.7 gr/cm^3 and an exploitation of 50%. (2) Macael Town Council.

Logically, these are ceteris paribus calculations and should therefore be reviewed periodically, understanding that, unfortunately, changes will take place in the long term that are very difficult to evaluate in the present. Some such changes may include the discovery of new marble reserves, improvements in mining and processing technologies and changes in market conditions (both in demand and supply).

The result has been four decades of great progress towards improving sustainability in the context of the Macael stone cluster. As displayed in Table 4, the specific measures implemented have helped to achieve the general principles of sustainable development.

Table 4. Principles of sustainable development

Principles	Progress achieved
Irreversibility zero principle Reduce to zero accumulative interventions and irreversible damage.	Measures to minimize accumulative interventions and reduce some that already exist (dumps, sludge, etc.) Reduction to zero is not possible due to the nature of the resource, but it is feasible to make progress in the rehabilitation of affected areas (extraction, dumps). Driven by the principles of circular economy (Cosentino).
Sustainable harvesting principle Harvesting rate of natural renewable resources equals the regeneration rate.	Not possible considering it is a non-renewable natural resource.
Sustainable extraction principle Extraction rate of non-renewable resources equals the creation rate of substitute renewables.	Notable progress in substitute products that have reduced extractions of the natural resource. Manufacturing of said products in the same district has avoided emigration, favoring economic and social sustainability. Importation of external products also contributes to reducing consumption of the endogenous resource.
Sustainable emissions principle Waste emission rate equals the natural capacity of ecosystems to assimilate emissions.	A great deal of waste cannot be assimilated, meaning the only option is to reduce it as much as possible. The installation of new companies that exploit waste has reduced accumulation (aggregates, micronized products, etc.). Continued improvements must be made in managing sludge produced during marble cutting and polishing, as well as in the rehabilitation of quarries and areas where the resource has been depleted.
Selection of sustainable technology principle Support for technology to increase the productivity of resources.	Industrial restructuring, both in mining and processing, and improvements in technology have notably increased the extent of resource exploitation
Precautionary principle The complexity, uncertainty and relationship between so many processes require discovering possible bottlenecks to avoid catastrophic repercussions—before it is too late.	Police intervention is necessary, more importantly that of town councils in the area (in relation to mining, specifically by Macael town council), to ensure compliance with legislation (national, regional and local) and that scheduled actions, designed to improve all the other principles, are carried out properly.

Source: Own elaboration

Evidently, there are aspects where progress has not been so extensive, for example, in the elimination of waste produced during the processing phase and the rehabilitation of quarries and areas where the resource has been depleted. In any case, as the precaution principle highlights, when dealing with an activity in full operation, not only can measures not become lax, it is necessary to find alternatives that allow improvements to be made for the sake of the environment.

5. Conclusions

In order to ensure that towns whose economies are based on non-renewable endogenous resources maintain sustainable development over time, and that economic ruin and depopulation due to resource depletion is avoided, it is essential to conduct a rational and quasi-sustainable operation and seek out new alternatives that might achieve sustainable economic and social development. Investing a portion of the revenue generated by non-renewable resources in activities that produce substitutes for the non-renewable product is a means of taking advantage of local know-how. The diversification of economic activities and the reutilization of outputs have proven to be highly effective in terms of product uses and geographic reach. Similarly, it has been demonstrated that research and technological renewal are necessary to achieve the ultimate goal: extend the life of the endogenous resource and attain sustainable local development.

For such changes in the sector to occur, collaboration with public administration is quite often necessary, as the latter can implement initiatives that improve services (e.g., infrastructures, communications, training) and provide funding. Nevertheless, it is always important to include the participation of all the agents involved in the sector to easily and actively take advantage of the know-how of individuals and the community over time, thereby progressively carrying out a clear, long-term plan.

There are numerous proposals for achieving sustainable development in areas with non-renewable endogenous resources. The present study focuses on the specific measures successfully implemented in the Macael Marble District (Almeria, Spain)—a real-life example that can serve as a model for other areas, adapting it as necessary. In this case, the economy of the study territory is based on a non-renewable resource (marble), and until only decades ago it was struggling with age-old problems related to exploitation processes and a low life cycle forecasts. However, the sector radically changed directions thanks to a development plan promoted by the public administration which laid the groundwork for drastic industrial restructuring. This new path supported research, attracted businesses that exploited by-products and established a suitable environment for the creation of an alternative industry devoted to artificial composites. Furthermore, said industry revolutionized the sector and allowed the diversification of economic activities in the area, while also significantly extending the life cycle of a non-renewable resource.

The present study shows the lengthy process that the marble sector has undertaken to improve its sustainable development. Many of the measures analyzed can serve to guide various interest groups (e.g., companies and different levels of public administration) involved in decision-making and the drafting of relevant policies. However, this work features some logical limitations, considering the analysis focuses on the marble sector of a specific region with its specific characteristics. Although the Macael case can be useful to other economies, future investigations could replicate the analysis in different regions and other companies with the goal of making comparisons. In addition, an analysis could be conducted over time in order to study the evolution of results. In any case, as an essential element in any local development plan, it is necessary to consider all parties affected (political authorities, companies, workers, local communities) while bearing in mind the evolution of demand, with the aim of discovering the best way to sustainably satisfy the needs of a society.

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