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Main opportunities considering Circular Economy in the Portuguese Ornamental Stone Sector

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Master in Studies of Environment and Sustainability

Supervisor: PhD Isabel Duarte de Almeida, Professora Auxiliar Convidada do ISCTE – Instituto Universitário de Lisboa

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Abstract

The main objective of this research was to analyze the OS cluster firms' opportunities to consider the Circular Economy as a part of their corporate strategy. Barriers and drivers were identified, and a qualitative-quantitative analysis could be performed with the help of the multi-criteria optimization software M-MACBETH, resulting in a numeric indicator that provides an objective means to compare projects or opportunities of adoption of CE by a company. This score is a function of the qualitative factors that characterize the project or opportunity, and its main use is in the selection of potentially successful initiatives of adoption of CE.

Keywords:

JEL Classification: Q53(Recycling - Circular Economy), C61(Multicriteria Optimization), Q56(Sustainability), Q01(Sustainable Development), Q30(Ornamental Stone Sector).

Resumo:

O principal objetivo desta pesquisa foi analisar as oportunidades das empresas do cluster OS para considerar a Economia Circular como parte de sua estratégia corporativa. Barreiras e drivers foram identificados e uma análise qualitativo-quantitativa pode ser realizada com a ajuda do software de otimização multicritério M-MACBETH, resultando em um indicador numérico que fornece um meio objetivo para comparar projetos ou oportunidades de adoção de CE por uma empresa. Essa pontuação é função dos fatores qualitativos que caracterizam o projeto ou oportunidade e sua principal utilização é na seleção de iniciativas potencialmente bem-sucedidas de adoção de CE.

Palavras-chave:

JEL Classificação: Q53(Economia Circular), C61(Otimização Multicritério), Q56(Sustentabilidade), Q01(Desenvolvimento Sustentável), Q30(Sector de Rochas Ornamentais).

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List of abbreviations

CE: Circular Economy

CSR: Corporate Social Responsibility

ESG: Environmental Social and Government

Mt: Million Tons

NPV: Net Presente Value

OS: Ornamental Stones

ROI: Return on investiment

SME: Small and Median Enterprise

SWOT: Strength, Weaknesses, Opportunities, Threat

TIR: Internal rate of return - Taxa interna de retorno

Acknowledgements

First of all, I would like to thank my unofficial Co-advisor, also known as my father, Himilcon, who inspired and supported me from the very beginning in this master's degree process, and thinking about it from the moment I was born, deserving a special space in this dedication and on the walk of fame for the special people in my life.

Just like my mother Conceição and my sister Letícia, who also always supported me in everything I needed, I miss you a lot and I dedicate this thesis to you both.

I want to thank my friends, who have always been with me, and Lucca for putting up with me and being part of this immigration process and studies with me.

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I would also like to dedicate this thesis in memory of Fausto Fanti, better known as Renato, or Blondie Hammet. also, in memory of John Dunsworth, a.k.a. Mr lahey, because the happiness they brought to my life and that of many people is immeasurable, like the stars of the universe, leaving here my tribute and my grateful thanks.

Ending like this, I leave a sentence that has accompanied me for years, which serves as a consolation, confusion, and motivation at the same time.

“The way she goes” Ray.

Chapter 1: Introduction

1.1. The Ornamental Stones sector worldwide

The Ornamental Stone (OS) sector is in a tremendous increase over the decades, as it can be noticed by the increase from the amount produced of 1,8 Mt in the decade of 1920, to the 154,5 Mt produced worldwide in the year of 2019 as shown by the data collected from (ABIROCHAS, 2021).

The estimated production of 150 Mt of OS in 2020 may have been achieved, with a volume exceeding 1.8 billion M2 per year. (ABIROCHAS, 2018).

The 2000s was marked by the multiplication of international trade fairs, together with the modernization of mining, processing, and finishing technologies in the OS sector, in addition to the diversification of commercial products and the consumer bubble in the USA market and the expansion of imports from the Chinese market. With the bursting of the USA housing bubble and the global crisis, in mid-2008 the world scenario was taken over by the decrease in credit, with a greater competition dispute between exporters and an increase in supply pressure from large producers. As of 2010, this negative scenario showed signs of recovery, both due to the rise of the USA economy and real estate market, and the Chinese real estate market, with a further slowdown in 2014 and 2015 (ABIROCHAS, 2018).

Regarding the players (cf. Figure 1.1), in 2019, China was the world's largest producer and importer of stones, being the largest exporter of single and special processing stones (ABIROCHAS, 2018). In the same year, India exported the most OS in physical volume, although making lower profits than countries like Italy, which, with a physical volume of 0.2% of India's total volume, made a 7% higher profit. (ABIROCHAS, 2018).

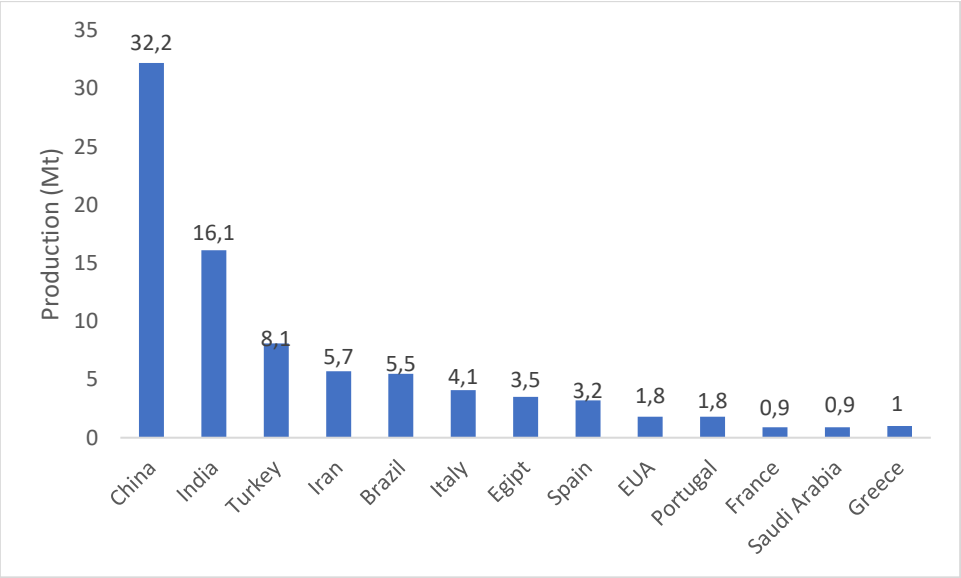


Figure 1.1: Largest OS producing countries of 2017 (Source: Adapted from Montani, 2018)

As for the segments of the sector, (Montani, 2018 apud Dorigo, 2020) points out in its annual report on the OS sector that marble and carbonate stones are at the top of the market, with the annual production of 57.8%, followed by granites, quartzites with 38.6% of the total produced, and followed by other types of stones such as slates with 3.6% (see Table 1.1).

Table 1.1: World OS industry: main uses in total production (Source: Adapted from Montani, 2018)

Applications	1000 (m² equivalent)	1000 (t)	Total Percentage (%)
Floors	497.700	45.600	30
External coating	124.425	11.400	7,5
Stairs	41.475	3.800	2,5
Internal coating	207.375	19.000	12,5
Special Jobs	373.275	34.200	22,5
Subtotal of construction	1.244.250	114.000	75

1.2. The O.S. sector in Portugal

The importance of the OS sector in Portugal is evident, as demonstrated by the wealth of historical monuments and stone buildings, dating from the 15th century to the present, creating and sustaining a market that has not stopped growing since then. (Silva and Almeida 2020).

Natural stone reserves in Portugal amount to around 410 million cubic meters, of which granite alone represents a share of 274 million cubic meters, most of which located in the north, while the marble and limestone deposits are in the center and south from the country. (Carvalho, Lisboa, Casal Moura, Carvalho, Sousa & Leite, 2013).

Three groups of OS are most common on the Portuguese industry:

- the Marbles and Limestones,
- Granites, and
- Shales.

They have different applicability both indoors and outdoors, but the main characteristics of each are:

Marbles: Vast variety of utilizations, that can be either placed indoors or outdoors

Granites: Excellent physical-mechanic characteristics

Shales: In most of the cases have compatible physical-mechanical characteristics and can be used in indoors and outdoors, but, in some cases, there are some restrictions on the use of some of the typologies in situations of strong exposure to ice. (Amaral et al., 2013).

1.3. Lifecycle and production process

The production process of an OS is divided in Blocks production, Slabs production and surfacing, Pieces productions and finishing, according to Marbles and Ornamental Limestone in Portugal (2007) demonstrated on Figure 1.2: Production process.

- **Blocks production:** First the blocks are divided into raw, irregular, prepared and blocks of specific size. The dimensions are measured in height, width and length of the raw blocks, useful measures of a raw block and commercials measures of a raw block. It's classified on

the geometrics characteristics as measuring criteria, shape, and volume. Also, the last requisites as denomination visual aspect, apparent volumetric mass, open porosity, bending resistance and others measures when needed.

- **Slabs production and surfacing:** Depending on the final product, the first sawage can be done with either the sawing machines or the carving blocks machinery. The surfacing treatment is made with the polishing machinery, the bushhammer and with the flaming machine.
- **Pieces production:** The secondary cuts are made with the disc's machines, using a diamond disc for the cutting, using either one or multiple discs.
- **Finishing:** For Tiles or bands the Edge grinding machine is used to make floors or coatings. For the slabs, it is used the Head polisher and the rectified edger to make measure works as stairs steps, sills, or floors and coverings. For the special treatments is used the Lathe, milling machine, Water jet cutting machine and the decorative engraving machine for the decorative panels, furniture, funerary art, tops, columns and balusters.

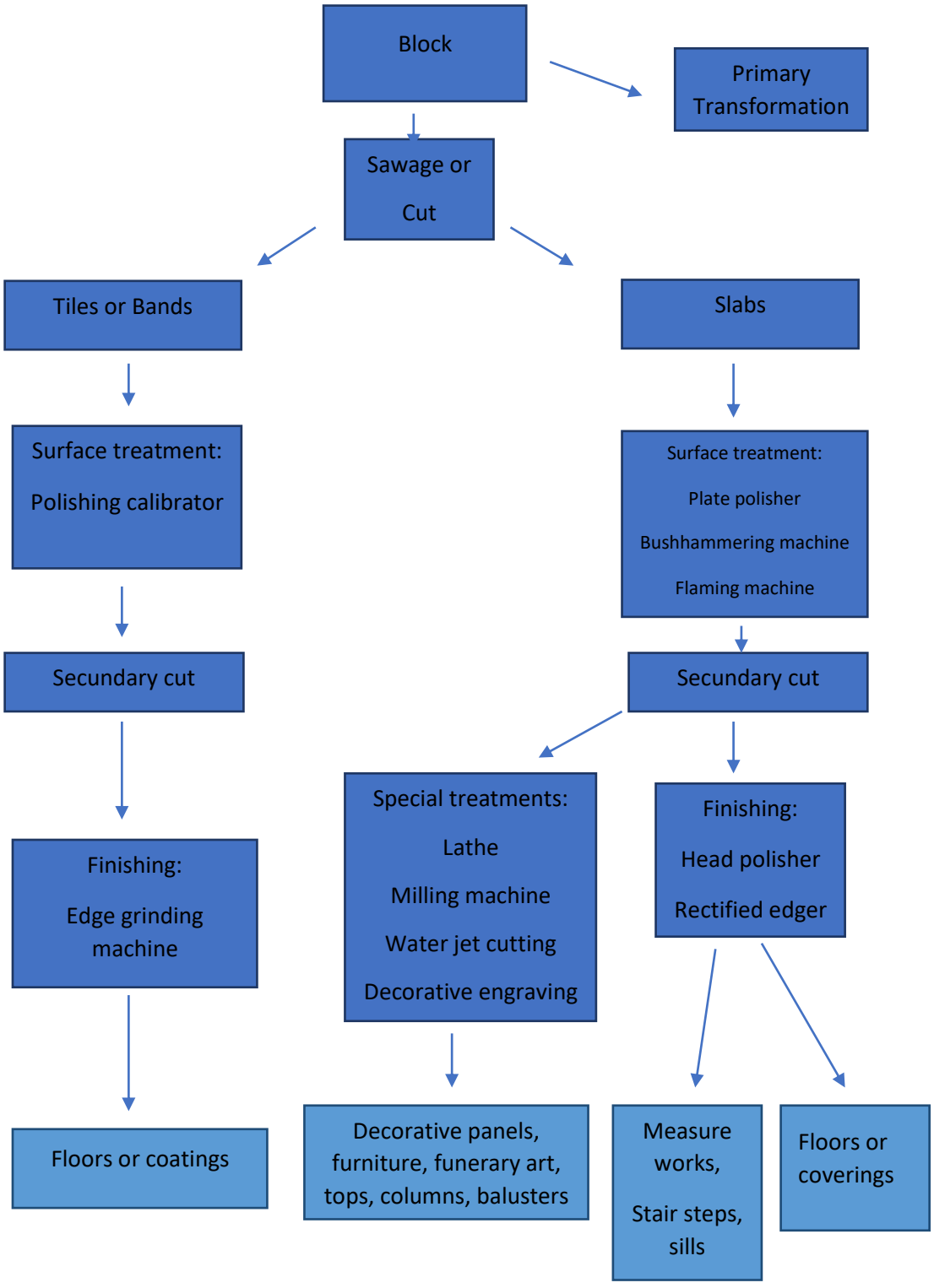


Figure1.2: Production process (Source: Marbles and Ornamental Limestone in Portugal 2007)

1.4. The Portuguese O.S. supply chain

1.4.1. Industry overview

The Portuguese natural stone production is diversified, ranging from marble and limestone quarried in the South and Centre of the country to granites in the Centre and North of Portugal. The country also has an important stone manufacturing base, with factories located near Lisbon (Pero Pinheiro) and in the main quarrying centers. The country is also a manufacturer of specialized equipment and machinery for the stone industry.

The industry is fragmented, being composed mostly of family-owned businesses and the companies may be classified in two main types (Silva, 2014):

- **Small businesses:** most of them are ashlar workshops or transforming factories, which end up specializing in a single type of stone.
- **Big companies**: they have their own equipment for sawing and production of a wide variety of final products, with different types of finishes, and these companies have the capacity to process and process materials from outside Portugal.

In the end of 2018, 2112 establishments operated in the O.S. sector in Portugal , most of them (1693 establishments) of transformation, and 410 of extraction, having a number of 13.380 workers operating on the country (ASSIMAGRA 2020).

1.4.2. Stakeholders

In Portugal, the OS sector is represented by 2 large business associations, namely, ASSIMAGRA, with its associates located in the Alentejo and Central Portugal, and ANIET, located in the North of the country, also existing in Portugal other smaller associations such as Associação da Calçada Portuguesa, among others (Silva 2014).

The largest importers of Portuguese OS in 2018 and 2019 were China and the USA, being the markets with the greatest growth potential, even with Portugal's import share being below the import quota of these countries (ASSIMAGRA 2020).

Another category of stakeholders which are important contributors to the sector, are the architects and prescribers, who determine a large piece in the choice of buying certain types, colors, and textures of stones dictating a choice of consumer purchase (Silva and Almeida 2020). These stakeholders play the role of a link between sellers and buyers. Even though they are almost invisible, the choice of which material should be acquired comes from them (Silva 2014).

From the Government side, an important stakeholder is the Innovation Agency (ADI) which is the national agency for support and financial incentive to the development and monitoring of Innovations in the OS sector in Portugal, being responsible for monitoring and issuing official opinion on national projects. (Silva 2014).

In addition, the Portuguese sector follows international standards such as ISO 14040-44 and ILCD Handbook guidelines for the specific use of stones in the sector (Bianco 2019). In this regard, regulatory, standardization and certification organizations also play an important role as stakeholders.

The integration of stakeholders in the CE process turns out to be a process of continuous improvement, based on concepts such as lean thinking proposed by (Silva 2014). The transition to the CE is not only a sudden break and sudden change of the production system, but a continuous improvement of projects with continuous support, learning and improving with past mistakes, seeking a multidisciplinary team that takes *knowledge and good practices to the entire supply chain* (Silva 2014).

1.4.3. Portuguese Market and market drivers

1.4.3.1. Market overview

In 2020, the OS industry generated around 400 million euros, representing 91% of exports from the Portuguese mineral market. Marbles and limestones accounted for 25% of exported minerals. (DGE 2021)

The Portuguese natural stone sector, including extraction and processing, based on data provided by the INE (Portuguese Statistic Institute), had, in 2020, a total turnover of more than 1.023 billion Euros with an average growth rate since 2017 of 4%. The companies represented by ANIET (Portuguese association of the extractive and manufacturing industry), that includes all the extractive sector (quarries, mines, and manufacturing), had a turnover of more than 3.200 billion Euros according to the same source[1].

From 2019 to 2020, there was a decrease in the production of Slate (-16.75%), ornamental granite (-1.36%) and Marble (-10.77%) compared to 2019, along with the corresponding decrease in exports (see Figure 1.3 and Table 1.2), but with a small increase in the number of workers in the sector, with a total number of 2863 workers linked to the OS industry registered, 3 more compared to 2019 (DGEG 2021).

[1] Portuguese Natural Stone, a very competitive sector, Posted on November 12, 2021, https://constructionmaguk.co.uk/portuguese-natural-stone-a-very-competitive-sector/, access on 08/04/2022

Figure 1.3 Exports evolution. (Source: DGEG, 2021).

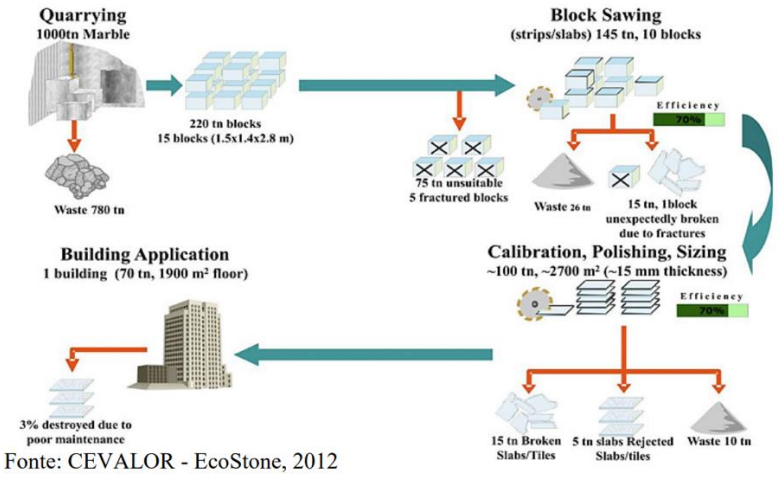
Table 1.2Extraction evolution. (Source: DGEG, 2021).

Ornamental Stones	2020		2020/2019	(%)
	(t)	(10^3)	Volume	Value €
Slate	51.596	6.711	-16,75	-16,2
Ornamental granite and similars	1.441.777	41.844	-1,36	1,2
Marbles and Limestones	1.130.420	81.490	-10,77	-20,7
Limestone for paving	814.295	31.839	15,48	75
Rustic Stone	336.950	10.372	54,2	117
Total	**3.745.038**	**172.256**	**1,7**	**-1,6**

1.4.3.2. Market drivers

Environmental licensing regulations, public pressure for sustainable exploitation of natural resources, availability of suitable or state-of-the-art technologies drive the industry towards more efficient processes, transparent governance, and social responsibility. The Figure 1.4 shows a scheme how the Portuguese ornamental stone industry works, although with new machinery the losses are smaller, the industry still produces a considerable amount of rejects.

Figura 3.2 - Cadeia de produção das Rochas Ornamentais



Fonte: CEVALOR - EcoStone, 2012

Figure 1.4: Ornamental Stones production chain. (Source: EcoStone, 2012).

Studies carried out by (Pinto, 2009), state that there are several types of waste in the RO sector, so, from the supply chain point-of-view, changes are urgently needed for companies to have a more sustainable footprint and with less waste through the avoidance of practices such as:

- *Oversupply to the customer*
- *Unecessary transportation*
- *Excess stock*
- *Excessive waiting time*
- *Unnecessary movements of materials and people*
- *Products or services with defects of failures*
- *Over Processing such as unnecessary controls and inspections*

Moreover, in addition to the requirements imposed by the legal framework, it is increasingly important to consider other issues that go beyond the strict scope of Corporate Social Responsibility (CSR) and may involve different operational risks that also threaten the reputation of economic players.

These issues, broadly included in the so-called Social License to Operate (SLO), are still poorly understood by all parties involved in the licensing process, requiring careful analysis to create suitable conditions for the establishment of levels of mutual trust and shared responsibility. (Mateus 2019)

Elements of a simplified SWOT analysis of the sector may be drawn from the (Stone Industry in Portugal in 2019, LitosOnline.com) and (Martins, D., Análise Reflexiva do Setor dos Minerais de Construção em Portugal):

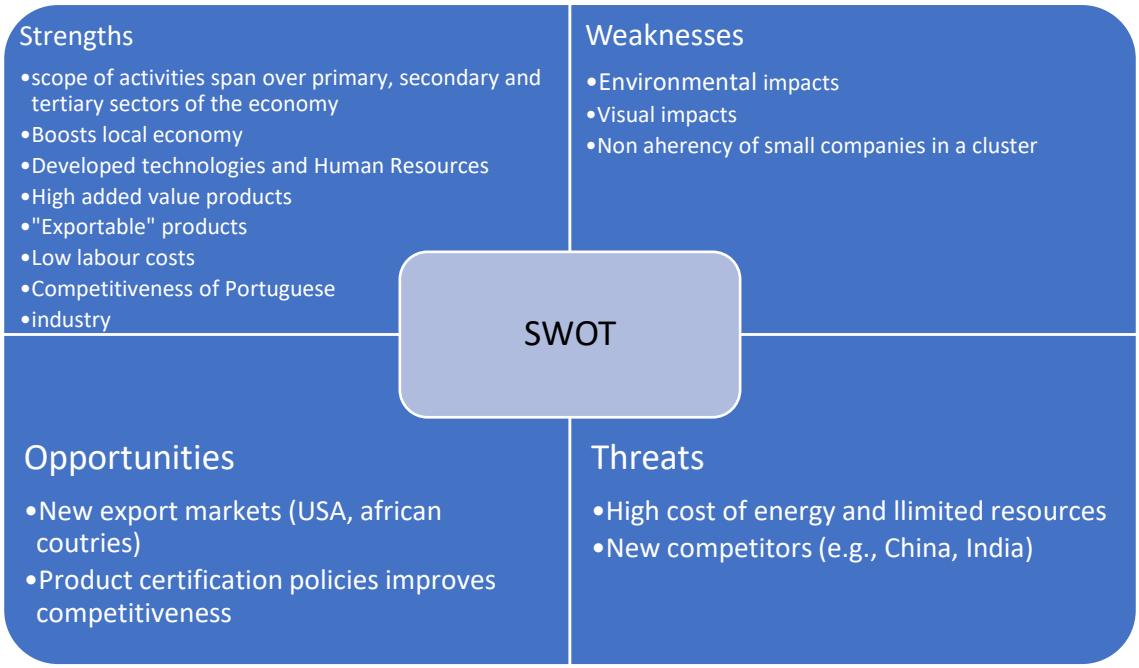


Figure1.5: SWOT Analysis

From the Weaknesses perspective, the environmental impacts and low production efficiency point to methods of reducing the waste, which will improve even further the competitiveness Strength. In the same manner, the Threat of high cost of energy requires new machinery that use less energy and have higher performance.

All this effort will create room for new Opportunities, mainly in the sense of developing Environmental, Social and Governance (ESG) policies and goals.

These goals are used for a myriad of specific purposes with the ultimate objective of measuring elements related to sustainability and societal impact of a company or business. Research shows that such intangible assets compose a growing percentage of future enterprise value.

All these aspects of the OS sector point toward making business and profits while being environmentally sustainable, reducing impacts on climate change, and reducing pollution and waste generation.

In this regard, CE (introduced in chapter 2) comes as an interesting solution to confront global challenges like climate change, biodiversity loss, waste, and pollution.

Chapter 2: Circular Economy – Literature Review and Problem Statement

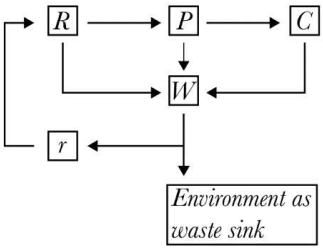
2.1. Circular Economy

2.1.1. Historical Background

The ideas leading to the concept of Circular Economy (CE) date back to the 1970s, as described by the address of a President of the American Association for the Advancement of Science: "*The object of the next industrial revolution is to ensure that there will be no such thing as waste, on the basis that waste is simply some substance that we do not yet have the wit to use... In the next industrial revolution there must be a loop back from the user to the factory, which the industry must close. … If American industry should take upon itself the task of closing this loop, then its original design of the article would include features facilitating their return and remaking*." (Ekins, apud Spilhaus, 1970).

By the late 80s, the concept further evolved as articulated in a paper by Frosch and Gallopoulos for Scientific American Magazine: "*The traditional model of industrial activity in which individual manufacturing processes take in raw materials and generate products to be sold plus waste to be disposed of should be transformed into a more integrated model: an industrial ecosystem. In such a system the consumption of energy and materials is optimized, waste generation is minimized and the effluents of one process … serve as the raw material for another process. The industrial ecosystem would function as an analogue of biological ecosystems*." (Ekins, apud Frosch and Gallopoulos, 1989)

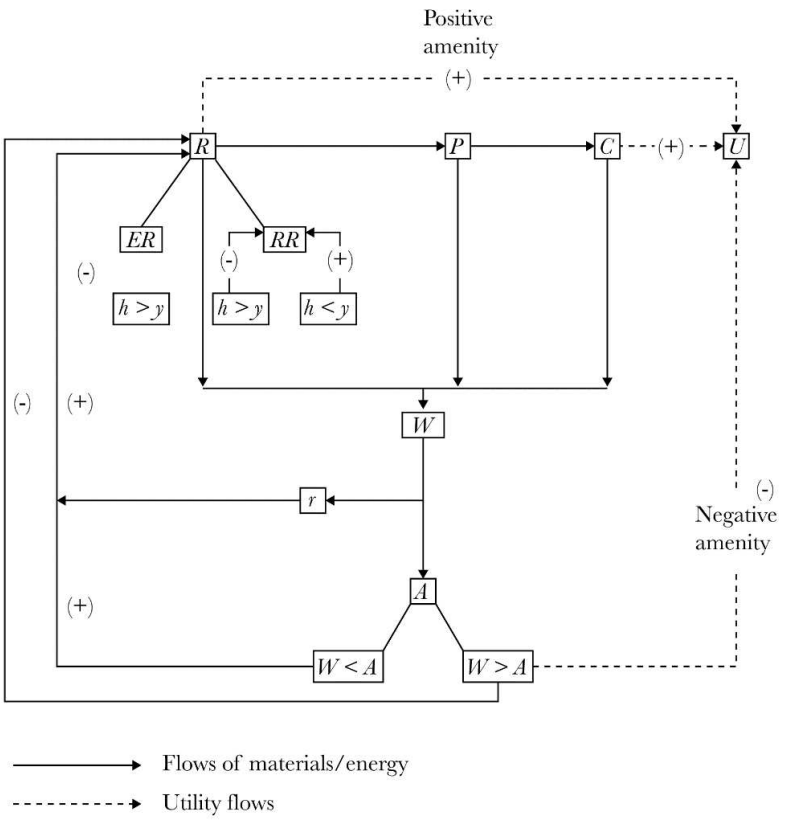
In the 90s, Pearce and Turner (1990) contrast (circular) natural systems with (linear) economic systems, as described by the simple CE diagram is shown in Figure 2.1(a), and further developed to the complete diagram in Figure 2.1 (b) (Ekins, apud Pearce and Turner, 1990).



R=resources, P=production, C=consumption, U=utility, W=wastes, r-recycling

Source: Pearce and Turner 1990: 38

(a) Simplified diagram



R=resources, ER =exhaustible resources, RR= renewable resources, P=production, C=consumption, U=utility, W=wastes, A=assimilative capacity, r-recycling, h=harvest, y=yield (=0 for ER)

Source: Pearce and Turner, 1990, Figure 2.4: 40

(b) Complete diagram

Figure2.1: Circular economy diagrams by Pearce and Turner (Source: Pearce and Turner 1990)

Finally, in 2010, Ellen MacArthur set up the Ellen MacArthur Foundation (EMF). Partnering with a number of large companies and the McKinsey consultancy, EMF produced in 2013 three publications 'Towards The Circular Economy', that contained the celebrated 'butterfly' diagram,

which is reproduced in Figure 2.2 (Ekins, apud EMF 2013), representing the circularity of products, services and the cascade energy flow of inputs and outputs on a circular business.

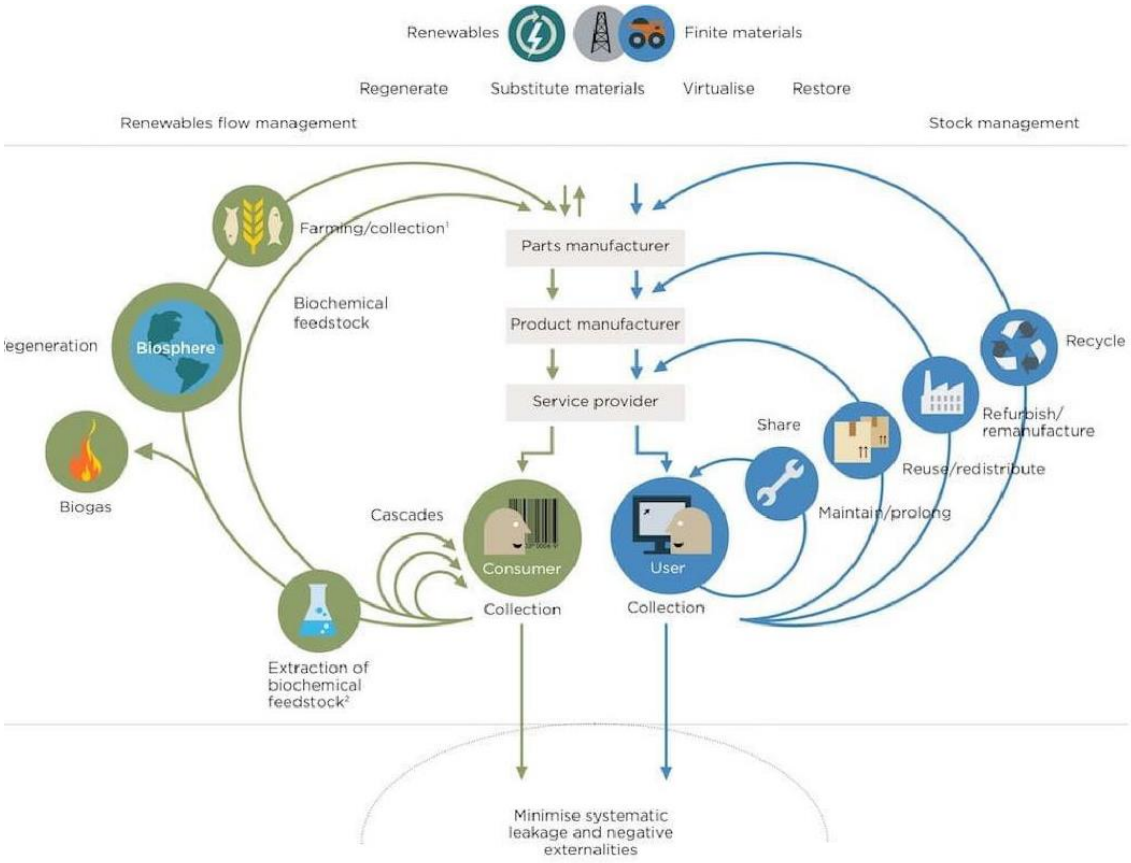


Figure2.2: The Circular Economy “Butterfly” Diagram (Source: McDonough & Braungart, 2010).

2.1.2. Concept and impacts on sustainable economy

Circular economy is an economic form of production-consumption systems that optimize produced services or material by switching from the traditional linear model of production to material and energy cyclical flows, using renewable energy sources and contributing to natural, economic, and social dimensions in a way that nature can tolerate the use of natural resources respecting their natural ecosystem cycles. (Korhonen 2018).

As Porter and Linde (1995) indicated, a corporate environmentalism doesn't have to be a *trade-off between ecology and economy*, but be committed to bring innovations, reduce productions costs, and develop better value for the customers.

The aim of CE is to create business models that are energetically viable and closed (in loops), with a minimum entry of raw material, prolonging the lifetime of the product, and using techniques to repair, reuse and recycle the old materials so they can get in the market again, producing the minimum waste possible and valuing the tailings produced (Silva and Almeida 2020).

The recycling concept may be divided in two categories: upcycling and downcycling. Both follow the principle of recovering and reutilization of the used material, but while in downcycling the material converted has a lower quality then the new one, the upcycling, however, provides a higher quality material (Kaupp, 2021), as it is seen from the tailing products of OS or rock wools.

Depending on the scope of application (micro, meso and macro), CE seeks to achieve different goals:

- At the **Micro** level (products, consumers, and companies) the effort is to improve company's processes and products on the route of sustainability, and the adoption of C.E principles as the benefits and positive impacts of C.E on the company's reputation and costs reductions are acknowledged.
- At the **Meso** scale industrial eco parks are examples of industrial symbiosis, resulting in economic and environmental advantages.
- At the **Macro** scale (cities, regions, and nations) the priority is to achieve sustainable development, ensuring environmental preservation, economic prosperity and social equity, thus ensuring that future generations will enjoy the same natural resources that we currently use (Saidani 2018), (Prieto-Sandoval et al., 2018).

From the perspective of the OS industry, CE may fit into the three levels, ranging from the adoption of recycling practices to the cooperation among different companies within the supply chain and identification of possible symbiotic opportunities (e.g. ceramic industry), and going even further in the direction of cooperating regions and countries in the effort to reduce waste and sharing technologies to jointly exploit common resources.

2.1.3. Business Models and Barriers to CE on the O.S Industry

At the heart of the decision process of a firm to adopt CE is the Business Model to be applied, along with the risks perceived by the novelty of the subject and the costs of its deployment. Here, the term *business model* is used to describe how a firm creates, captures, and delivers value. In other words, it is a firm's competitive strategy. (OECD, 2019).

Five models are identified and described in (OECD, 2019):

- **Circular supply models** replace traditional material inputs derived from virgin resources with bio-based, renewable, or recovered materials, which reduces demand for virgin resource extraction in the long run

- **Resource recovery models** recycle waste into secondary raw materials, thereby diverting waste from final disposal while also displacing the extraction and processing of virgin natural resources

- **Product life extension models** extend the use period of existing products, slow the flow of constituent materials through the economy, and reduce the rate of resource extraction and waste generation

- **Sharing models** facilitate the sharing of under-utilised products, and can therefore reduce demand for new products and their embedded raw materials

- **Product service system models**, where services rather than products are marketed, improve incentives for green product design and more efficient product use, thereby promoting a more sparing use of natural resources

Regarding practical implementation, a combination of models could be necessary for concrete situations.

The report concludes that (OECD, 2019) "*achieving a genuine transition to a more circular economy will be unlikely if circular business models continue to occupy small economic niches. Policy can play an important role by addressing the market failures, policy misalignments and status quo biases that currently hinder the competitiveness of these business models, including:*

- *costs of production and consumption activities reflected in market prices;*
- *collaboration within and across sectoral value chains, through e.g. fostering industrial symbiosis clusters, […];*
- *coherent and fit for purpose regulatory frameworks;*
- *promotion the supply of circular products ("supply-push measures") or demand for them ("demand-pull measures").* "

Regarding barriers to the adoption of CE, (Mishra et al., 2022) provide an extensive list of possible barriers that were used in their study that confirmed the existence of seven dimensions of barriers to the adoption of CE practices. Table 2.1, below, reproduces their results and possible obstacles applicable to O.S. industry.

Table 2.1: Barriers to the adoption of CE in industry. (Source: adapted from Mishra et al., 2022)

Dimensions	**Proposed Measurement Items**
Knowledge and Skills Barriers	Unavailability of qualified professionals to guide for environmental management practices
	Lack of capability to replace fossil fuels with renewable energy sources in different processes.
	Lacks a skilled workforce to understand how energy can be produced from by-products to support day to day

	operation
	Unawareness of life cycle assessment method to measure environmental impact linked with all the stages of a product's life
	Unawareness of the potential benefits of industry symbiosis practices (Exchange and/or sharing of resources, services and by-products between companies)
Technological Barriers	Lack of access to proper technology to support energy-efficient processes
	Inadequate technology to support upcycling (converting materials into new materials of higher quality and increased functionality)
	Unavailability of technology management programs to retain or restore equipment to the desired level of performance
	Rigidity of the existing system and technology to restructure to an environmentally friendly one
	Lack of access to affordable green technology
	Inability to produce eco-design for promoting a circular economy business model
Cultural Barriers	Lack of encouragement of design for disassembly/recycling (Design that considers the need to disassemble products for repair, refurbishment or recycling)

	Lack of collaboration with suppliers to develop product design with a focus on its environmental impacts during the whole lifecycle
	Lack of implementation of efficient take-back systems to ensure that the products are recovered from the consumer after the end of life and proceed to be remanufactured
	Lack of support in the procurement of raw materials with low environmental impact
	No collaboration with logistics providers for implementing circular economy practices
Financial Barriers	Focus on short term goals with less risk
	Lack of reward for consistent recycling of recyclable materials
	Limited financial assistance for implementing a circular economy model
	Lack of funding to train employees to promote circular economy practices
	Lack of funding to engage in Research & Development to promote circular economy practices
	Lack of fund to do day-to-day circular economy operations
Strategic Barriers	Perception of sustainability as a cost and not as an

	investment
	Top management lacks the necessary expertise to implement circular economy practices
	Lack of performance framework to assess the effectiveness of circular economy practices
	Absence of a mechanism to encourage, motivate and appreciate the employees for their green activities
	Lack of support from top management for sustainability initiatives
Government & Regulatory Barriers	No strict compliance to implement circular economy practices
	Technical support to offer recyclable solutions is seldom provided by the regulatory authorities
	Industry-specific training program on waste minimisation is seldom provided by the regulatory authorities
	Lack of implementation of predictive maintenance to assess the future failure point of a machine component
	Financial assistance for circular economy practices implementation is seldom provided by the regulatory authorities
Market Barriers	Lack of promotion to aware firms about socially responsible consumption

	Lack of certainty for additional demand for eco-labelling of products (An ecolabel identifies products or services has been designed to do less harm to the environment than similar products or services)
	Lack of willingness where customers are not willing to pay premium prices for eco-packaging
	Uncertainty about the outcome of green initiatives in terms of profit margin
	Scarcity of green materials to prevent sustainable practices

More specifically to the sector of OS, one of the biggest problems is the refurbishment of machinery with the intention of reducing the consumptions of water and energy, besides enhancing the performance, and lowering the rejects and noises, as these factors may have an elevated deployment cost, and may not look attractive to SME's (Small and Medium-sized Enterprises) on a first look (Silva 2014).

But as it can be seen on Tables 2.2 and 2.3, from (Silva, 2014), the comparation of traditional and new leanstone machinery exhibit notable results in reducing time, enhancement of productivity, lowering of the need of raw materials and higher energetic efficiency.

Table 2.2: Traditional vs Leanstone layouts. (Source: adapted from Silva 2014)

	Kitchen top layout	Facades/floors layout	Thick thickness layout
Emilination of tasks that do not add value to the dorduct	75%	85%	80%
Reduction of delivery time	33,33%	50%	33,33%
Productivity increase	30%	40%	85%
Gains in the optimization of raw materials	15%	70%	30%
Gains in energy efficiency	40%	50%	50%

Table 2.3: Traditional vs Leanstone equipment. (Source: adapted from Silva, 2014)

	Solancis	Rui Pedra	Pereira & Ladeira	Transgranitos
Emilination of tasks that do not add value to the dorduct	85%	80%	75%	80%
Reduction of delivery time	50,00%	50%	33,33%	33,33%
Productivity increase	40%	30%	30%	85%
Gains in the optimization of raw materials	70%	60%	15%	30%
Gains in energy efficiency	50%	60%	40%	50%

The shift from linear to CE must also include digital and virtual services, thus reducing the produced objects or services to what was demanded, ending up in reduction of production, transportation, and stocking costs (Van Renswoude, 2015 apud Kaupp, 2021).

In this regard, aversion from (or real difficulties in) using Internet based technologies, mainly by elderly people, may be an important factor that act as a supplementary barrier to CE (Neves, S and Marques, A., 2022).

2.1.4. Engagement of the OS sector companies in CE

Circular Economy is a business model that create value on closed loops, but these loops do not concern only one company but can be applied through the whole supply chain network on an industry symbiosis. (Antikainen & Valkokari, 2016).

In Portugal, this fact can be proven by the improvement on the OS industry through the gathering of companies in clusters, as the Cluster Portugal Mineral Resources, that started in 2004 (Silva 2014), (Agostinho and Isabel 2020).

In the same direction, in 2005 the first stage of the Jetstone Consortium was started, gathering companies and academic research centers that resulted in the Mobilizing Project Jetstone.

After the 2008 crisis, the sector of OS started the Inovestone Moblizing Project. The project outcomes were "*the design and development of nine lean and flexible prototypes and six types of test and quality control equipment, all validated in a manufacturing environment and currently used by dozens of plants (…)"* (Agostinho and Isabel 2020).

A concrete example of symbiosis comes from the use of limestone. This is one case of OS that can be used in innumerable ways, not only on construction but in other many sectors. It can be used to do cement and mortar and can be use on paintings and roofing tar. Other uses of limestone include construction of roadways and in the asphalt concreted. In different sectors, limestone powder is used to neutralizing acid soils in agriculture fields and it helps to improve the soil quality. Moreover, limestone can be used to manufacture plastics *products, tiles or toothpaste*, when a white pigment or a low-price filler it is needed (Kaupp 2021).

Some interesting (although not Portuguese) studies show industries symbiosis in processing stone waste used for construction and building materials as a replacement for limestone filler, sand or stone dust in the manufacturing of cement-based building materials in Espírito Santo, Brazil (Zulcão, 2020) showing a significant reduction of environmental impact on the production.

Other studies from Brazil show the development of lightweight aggregates from the mixture of crushed of OS (granites and marbles) and clay that can be used in thermic and acoustic isolation, in drainage works, light landfills and infrastructure, besides hydroponic culture and landscaping decorations (Souza, 2020).

Studies conducted by (Leite, 2019) and (Lopes, 2020) in Sorocaba, Brazil, indicate that cutting and polishing residues of crude marble plates can be incorporated as aggregates in mortars in the replacement of sand without altering the physical-mechanical properties, and with the study of the life cycle evaluation, it was proven that this practice contributes to the reduction of environmental impacts from the perspective of the product life cycle.

Studies from the 2005 Symposium of OS in Brazil show the potential of dried powder of marble after the removal of Fe (iron) from the rejects of the cutting process, obtaining promising results

for manufacturing of ceramics; red ceramics (tiles, bricks and tiles); structural blocks and floor for paving; and mortars. (Pontes, 2005)

Using the concept of upcycled (re-used materials that have the same value as new after transformation) the ROCKWOOL is a pioneer on the circular business models in Europe. The company, from Denmark, produces a stone wool that can be infinitely recycled. With the potential to grow, the company plans to be in 15 other countries by the end of 2022, including Russia and China.[2]

Paper and notebooks also can be made by recycling materials as the company Paper on the stones shows, using waste materials from construction rubble and stone waste, besides the agricultural waste, using exactly zero water to produce stone paper and be CO_2 neutral.[3]

Stonethica is another example of upcycling reuse of marble waste by building marble panels with unique design to be used for floors, walls, kitchen counters, bathrooms and interior design, assembled in slabs using a non-toxic resin, with the recycled content between 98,6% and 99,4%. It can be found in the European Union, in the USA and the United Kingdom.[4]

A myriad of other examples could be included here, just to demonstrate that CE is turning into a tangible reality worldwide and, specifically, in Portugal. Stakeholders are becoming more and more aware of the benefits of adopting CE practices while governments are helping the industry sector by means of investment programs that bridge the gap between high initial costs and lack of resources for crossing the technological barriers.

2.2. Problem Statement and Research Questions

[2] Economia circular - construído para durar (rockwool.com)
[3] Mission - Paper / on the Rocks (paperontherocks.com)
[4] Stonethica | From Waste to Wow (https://www.stonethica.com/)

The main objective of this research is to analyze the OS cluster firms' opportunities to consider the CE as a part of their corporate strategy.

The analysis of OS firms' engagement in the CE (programs/projects/innovation/business models) seeks:

(i) To identify its connections with the corporate strategy, the actual activities involved and the supply chain network, ensuring circularity.

(ii) Within the recovery and recycling context, to look for industrial symbiosis (potential) in the OS cluster companies.

(iii) To recognize the links between CE engagement and improved performance in the OS cluster companies.

With these objectives, the following Research Questions should be considered:

RQ1: How do OS companies implement a CE?

RQ2: How does CE relate to OS corporate strategy?

RQ3: What are the sustainability programs adopted for implementing circular supply chains?

RQ4: Which stakeholders and Industrial Symbiosis do contribute the most to the implementation of a circular supply chain in OS sector?

RQ5: What are the drivers and barriers to the integration of a sustainability and CE model?

RQ6: What are the main opportunities for OS cluster firms through a CE?

Chapter 3: Research Methodology

3.1. Methodological approach

The objective of this research is to understand the drivers and factors that lead companies to adopt CE in their corporate strategies. In this sense, it is important to know their motivations, understand their decision-making processes and criteria to decide why to adopt CE.

Following the concepts presented in (Creswell 2013) the research was planned under a *pragmatic worldview*, designed with a qualitative approach, and based mainly on *interviews* with the interested public, that is, true entrepreneurs and/or executives responsible for corporate decisions on a day to day and operational basis.

In fact, pragmatism as a worldview calls for an emphasis on the research question and use whatever approach at hand to understand the problem. It is not a scientific search of cause-and-effect explanations to prove preconceived theories and hypotheses. Instead, the focus is put at understanding the problem itself in its concrete down-to-earth situations.

Moreover, as demonstrated in chapter 2, the vast literature dedicated to the factors and barriers on adopting CE points to issues that range from economic reasons to the lack of government support, including the difficulty in training human resources.

Such a diversity of factors suggests the need of a **qualitative** methods approach, the main factors and opportunities among a comprehensive list drawn from literature review should be pinned out through a first round of interviews followed by a multicriteria procedure where the factors are to be ranked.

Finally, an indicator was proposed based on the numeric expression of some of the measurable factors as a mean to identify attractiveness regarding CE adoption opportunities. Such indicator could be, in future works, validated through the study of successful and unsuccessful cases of CE adoption.

Following our pragmatic planning, the choice of the sample is of paramount importance, since it will be fundamental in gaining a depth of understanding of the problem. In this regard, as pointed out by (Palinkas et al. 2015), purposeful sampling should be applied to maximize the chance of success.

With a strategy with an *emphasis on similarity* (since our subject refers to the Portuguese O.S. sector) based on *typical cases* (that is, on what actually happens with regard to the decision to adopt CE as a corporate strategy), the sample should focus on companies' decision makers and experts rather than customers or other stakeholders.

The companies themselves should range from small family businesses to large companies with, as much as possible, even distribution with respect to those that have and have not adopted CE (this will favor case studies to validate the research findings).

3.2. Methodology application

The research was carried out with the objective of understanding how the CE is being implemented by OS companies in Portugal, what are their incentives and barriers, what are the main opportunities and eventually provide a verdict on which opportunities are more attractive for future investments of companies in the sector.

To this end, in the second half of 2022 an interview was prepared by means of a Google Forms semi-guided questionnaire and sent individually by e-mail to selected decision-making officers of companies that integrate the cluster Portugal Mineral Resources.

The questions were formulated taking into account the Research Questions and exploring the concepts, success factors, barriers, opportunities and other relevant information identified in the literature review (chapter 2).

The main structure of the questionnaire is as follows:

- *RQ1: How do OS companies implement a CE?*
- *What is your company's main activity?*
- *Which of the following concepts (5Rs) better apply to your vision of CE?*
- *Which step(s) of the OS production chain is (are) better suited to CE?*
- *How do (could) you involve your suppliers in the CE cycle?*
- *RQ2: How does CE relate to OS corporate strategy?*
- *Which performance indicators (ROI, TIR, NPV) are most important w.r.t. adopting CE?*
- *What are the most important factors to guarantee the success of the adoption of CE in your company?*
- *RQ3: What are the sustainability programs adopted for implementing circular supply chains?*
- *In what level(s) (micro, meso, macro) does your company implements CE?*
- *Are you acquainted with incentive programs related to CE?*
- *Has your company participated in CE support programs? Which ones?*
- *RQ4: Which stakeholders and Industrial Symbiosis do contribute the most to the implementation of a circular supply chain in OS sector?*
- *Choose and rank (power x interest) the stakeholders which are relevant to the decision of adopting CE in your company*
- *Do you have any knowledge of possibilities of industrial symbiosis related to your company business?*
- *How may your company's stakeholders help in the development of fruitful industrial symbiosis?*
- *RQ5: What are the drivers and barriers to the integration of a sustainability and CE model? (Choose from list)*
- *RQ6: What are the main opportunities for OS cluster firms through a CE? (Open question)*

Although the answers were qualitative, the structured, multiple-choice nature of the questionnaire, there was a Likert scale questions with fixed and limited number of possible

responses, allowed the identification of most selected choices as a the most relevant factors to the problem under investigation.

Finally, these factors were introduced in M-MACBETH as *criteria* and were qualitatively ranked in degree of *attractiveness*, that is, the relative degree of importance regarding success of CE adoption by a company.

The MacBeth method is a non-numerical method that use the decision-maker pairwise comparisons, making a quantitative model of values and you can compare the items using only qualitative inputs to help on decision-making and offering suggestions to continue the projects. (Bana e Costa et al., 2003).

To make comparisons, the decision maker compares by pairs 2 criteria at the same time, using a scale with 7 categories to compare the differences, which would be: 'no', 'very weak', 'weak', 'moderate', 'strong', 'very strong' or 'extreme' (Marques 2015).

When the questionnaire answers were inconclusive regarding the relative weight of two criteria, the judgement was decided based on the literature review or just common sense.

The output of this process is the list of relative weights of the chosen criteria, so that each criterium is assigned a number (between 0 and 100%) where the sum of all number is 100%.

As an example, if 5 factors (F1, …, F5) were identified as relevant from the interviews,

a) These factors are entered in the MACBETH program as *criteria* along with their qualitative levels. Suppose the factor is "Stakeholder Interest". Levels could be [High, Medium, Low]. If the factor is "Training opportunities available". Levels may be [YES, NO]

b) Then, these criteria are ranked, that is compared two by two regarding their attractiveness ('no', 'very weak', 'weak', 'moderate', 'strong', 'very strong' or 'extreme')

c) The program, then, would output 5 weigths (W1, W5) with W1 + W2 + … + W5 = 100 related to each Factor.

d) Once this procedure is carried out, one is able to compare real world opportunities (such as government incentive programs, symbiosis opportunities, etc.). For the sake of clarity, suppose there are two opportunities Op1 and Op2. In MACBETH a Table of *options* (opportunities to be compared) may be created. For each opportunity Op (a line in the table) the corresponding

qualitative values of the factors F are entered. The program, then, automatically computes a final *grade,* that is*,* a numerical value corresponding to the sum of the weighted factors, assigning a final score to each option.

In that way, MACBETH provides systematic a way of numerically comparing options that are defined upon qualitative criteria.

This procedure was applied to the questionnaire answers and the final weights and score table were created (see chapter 4), so that a numerical indicator is available to compare CE adoption opportunities as part of a company's corporate strategy.

Chapter 4: Research Results

4.1. Summary of questionnaire answers

The questionnaire was answered by three persons, from different companies and the answers are summarized in the tables 4.1, 4.2 and 4.3 that follow:

Table 4.1: Answer questionnaire.

Person 1

Chief Financial Officer, 5 years of experience.	
◦ Extraction company, national/export	
◦ EC	supply of leftovers, collection, re-use, repair
◦ All steps can use EC	
◦ EC at the company	USE, TRANSFORMATION OF BY-PRODUCTS
◦ Suppliers	
◦ Business Mod.	Circular supply; recovery/recycling; underutilized MP share
◦ EC at the company	Process improvement with use of more evolving environmental equipment

◦ Programs you know	-
◦ Programmes in which you participate	-
◦ KNOWLEDGE Barriers	lack of professionals to guide; com. fossils; Qualified labor; lack of life cycle assessment method to measure environmental impact (indicator)
◦ TECHNOLOGY Barriers	Unavailability of technology management programs to retain or recover equipment at the desired performance level
◦ CULTURAL Barriers	Lack of collaboration with suppliers; Lack of support in the acquisition of processing machinery with low environmental impact
◦ Government and Regulatory Barriers	There are no strict rules for EC; there is no technical support; there are no training programs
◦ MARKET Barriers	Lack of promotion for conscious companies; certification of sustainable extraction and production; will of customers who are not willing to pay higher prices
◦ Incentives	TAX
◦ Strong Stakeholders Favor	Employees, Shareholders, Environmental, Water;
◦ Strong Stakeholders Against	Competitors, Energy
◦ Symbiosis	don't know

◦ Main economic indicator	ROI and COSTS
◦ Important Factors	budget; sustainable management; participation of stakeholders; understanding; training/training; quality check; stock management; Emissions; collaboration with supply chain; reverse logistics; educate customers; innovative practices; Transfer. Technological; use media to understand customer requirements; layout; monitor market changes; information management; Industrial Ecology; structure (ReSOLVE); customer feedback; life cycle analysis; incentives and rewards; identify performance measures for benefit analysis; government policies/regulations;
◦ Neutral factors	Planning; commitment to senior management (? but want shareholder engagement); training and motivation of employees (?!?)

Table 4.2: Answer questionnaire. Person 2

Innovation Project Manager, 11-15 years of experience	
◦ Extraction company, national marble/export	-
◦ EC	supply of leftovers, reuse of waste and material used
◦ Steps	Disassemble; Removal of debris
◦ EC at the company	Brand creation and product design, identified the

	source material, rejected marble
◦ Suppliers	Equipment repair.; reduction of consumables; reuse of national MP; Refusal of imported MP; reduction in transport
◦ Business Model	Circular supply; waste recovery; Sharing
◦ EC at the company	Improved processes and products to increase sustainability, reduce debris, leftovers, reduce environmental impacts and reduce costs (Demonstration of marble applications rejected by its pattern or color, production of marble equipment intended for combrable)
◦ Programs you know	CIRCO and EEN
◦ Programmes in which you participate	You don't use support programs. But it does projects (without support) with research entity
◦ KNOWLEDGE Barriers	lack of professionals to guide
◦ TECHNOLOGY Barriers	lack of access to technologies to support efficient processes
◦ CULTURAL Barriers	lack of efficient recovery system with the consumer after the end of life; without collaboration with logistics sector
◦ Government and Regulatory Barriers	there is no training program
◦ MARKET Barriers	lack of certification; consumer's willingness to pay higher prices

◦ Incentives	That supervisory and regulatory authorities knew the concept of circular economy
◦ Strong Stakeholders Favor	Shareholders;
◦ Strong Stakeholders against	Clients; environmental construction
◦ Symbiosis possible	Extraction sector and processing sector
◦ Symbiosis, stakeholder role	owners and management of companies from one sector and another, in sharing the same concern
◦ Main economic indicator	ROI
◦ Very Important Factors	Planning; sustainable management; participation of stakeholders; brand image; understand the benefits of EC; training; training of employees; quality check system; supplier's commitment to recyclable materials; educate customers; innovative practices; rewards and incentives; identification of performance measures; government policies/regulations.
◦ Important Factors	commitment to senior management; stock management; carbon emissions; coordination with supply chain; Transfer. Technological; media; monitor market changes; layout of the installation; use media to understand customer requirements; layout; monitor market changes; information management; Industrial Ecology; structure (ReSOLVE); customer feedback;
◦ Neutral factors	reverse logistics; life cycle analysis;

Table 4.3: Answer questionnaire.
Person 3

University Lecturer/Researcher, 30+ years of experience	
◦ University	-
◦ EC	Supply of leftovers; reuse of MP; MP recycling; reparation; reduction of leftovers
◦ Steps	All
◦ EC at the company	just search
◦ Suppliers	reut./recycle/repar/reduc in equipment; consumable deduction; reuse./recycle./reduc. national MP; Reduction./refusal foreign MP; reduction. in transport
◦ Business Models	recovery of resources; increased service life; Sharing; service
◦ Implementation of EC	participation in regional, national or international programmes that foster sustainable development (We have ongoing research projects aimed at this goal.)
◦ Programs you know	PRR, Portugal 2030
◦ Programmes in which you participate	Yes (see above)

◦ KNOWLEDGE Barriers	lack of professionals to guide; capacity to replace fossil fuel; qualified OM; environmental impact assessment method; knowledge of the benefits
◦ TECHNOLOGY Barriers	lack of technology management program
◦ CULTURAL Barriers	lack of efficient recovery system with the consumer after the end of life;
◦ Government and Regulatory Barriers	there are no strict rules for implementing EC practices
◦ MARKET Barriers	lack of promotion for conscious companies; certification; consumer's willingness to pay higher prices; uncertainty about profit margin with EC
◦ Strong Stakeholders Favor	Media, community;
◦ Strong Stakeholders against	Shareholders, customers, competitors, trade unions, energy and water sectors
◦ Possible symbiosis	Use of by-products from other industries (e.g. cork); link between RO and/or construction companies and aggregates;
◦ Symbiosis, stakeholder role	Owners/Shareholders/Investors should seek business opportunities aimed at integrating by-products from other industries into their companies.
◦ Main economic indicator	implementation cost, ROI
◦ Very Important Factors	Planning; commitment to senior management; participation of stakeholders; brand image; understand the benefits of EC; training; training of employees; stock

	management; layout of the installation; customer feedback; life cycle analysis; rewards and incentives; identification of performance measures; government policies/regulations.
◦ Important Factors	budget; sustainable management; quality check system; coordination with supply chain; supplier's commitment to recyclable materials; educate customers; innovative practices; Transfer. Technological; media; use media to understand customer requirements; monitor market changes; information management; Industrial Ecology; structure (ReSOLVE);
◦ Neutral factors	carbon emissions; reverse logistics;

4.2. Answers to the Research Questions

From the answers obtained in the questionnaires, we can attempt to address the research questions.

RQ1. How do OS companies implement a CE?

The CE process can be insert in all stages of production when the final products are OS, from the extraction and cleaning of the quarries, in the dismantling and removal of rubble for heaps until the sale to the consumer, also with packaging design and enduring business models.

Starting with the process of extracting the raw material, Supply Chain companies can get involved in the preparation of the pickling, using new and technological machinery for the removal of blocks and in the transport, the use of the removed rubble to fill deactivated quarries

to a crushing plant for subsequent valuation and sale of unused material. EC can also be included in the raw material transformation process, using the waste from the primary and secondary cutting processes, and surface treatment and finishing.

The main sectors/companies of the Supply Chain in the OS industry are divided between the extraction of the raw material that takes place in the quarrier, including its transport to the factory, and the transformation of the raw material, occurring already in the factory.

In the extraction phase of this raw material, we can mention the most important points that the CE can be introduced:

- Preparation and Pickling
- Removal of blocks and transport
- Removal of rubble for heaps
- Removal of rubble to fill disabled quarries
- Removal of rubble to a crushing plant to value the material
- In the raw material transformation phase, we can mention the most important points:
- Primary cut
- Secondary cut
- Surface treatments
- Finishes

RQ2. How does CE relate to OS corporate strategy?

The main factor seems to be related to the construction of a brand image of the company before its customers. In fact, the subjects such as sustainable development and ESG (Environment, Social, Governance) become essential to a company's reputation and credibility. Nevertheless, financial support through incentive programs and lack of skilled people remain important barriers to the adoption of CE.

RQ3. What are the sustainability programs adopted for implementing circular supply chains?

Portugal has sustainability support and incentive programs that companies can take advantage of, namely: CIRCO, EEN, PRR and Portugal 2030. All of them were known by the interviewees although not used by them, except for the academic respondent.

The **CIRCO** program (Creating Business through Circular Design) is a program that trains companies through design to develop products, services and circular business models through workshops aimed at small and medium-sized companies. At the beginning of 2022, the participation of 17 companies in Portugal alone was reported, with a forecast of training up to 100 companies by the end of 2022.

The **EEN** (Enterprise Europe Network) led in Portugal by IAPMEI is a project to support SMEs and start-ups to integrate into new international markets, with innovations, digitalization, and sustainable growth of companies. The Project has an approved period from January 2022 to June 2025. With a project that facilitates the entry of SMEs to European and international markets, the project was designed together with the Single Market Program (SMP), providing support for companies and innovations, increasing competitiveness and sustainability in European companies.

The **PPR** plan (Recovery and Resilience Plan) proposes to act to recover the Portuguese economy, using the transition to a digital and sustainable economy. With a plan to distribute more than 16 million euros to help leverage Portuguese projects. Having three main pillars, namely resilience, climate transition and digital transition, the project intends to implement a set of reforms and investments to leverage economic growth after the pandemic, acting in the areas of housing, tourism, health, among others, for the period of execution until 2026.

Portugal 2030 is an agreement established between the government of Portugal and the European Commission, with the strategic objectives of: a smarter, greener, connected, more social and closer to citizens Europe. The plan will cover the year 2021 to 2027, with a global budget of 23 million euros, with this amount coming from different responsible bodies. (https://portugal2030.pt/portugal-2030/)

RQ4. Which stakeholders and Industrial Symbiosis do contribute the most to the implementation of a circular supply chain in OS sector?

The stakeholders were ranked by the interviewees and the most important ones were the Owners/Shareholders, the Government, Environmental, Water, Energy and Construction sectors, Clients, Media and Suppliers.

RQ5: What are the drivers and barriers to the integration of a sustainability and CE model?

As the main incentives for companies to adhere to circular business models, we can mention that the interviewees emphasize tax incentives and express the desire that supervisory and regulatory entities become aware of the concept of CE and its benefits for society in terms of sustainability.

Training programs and courses specifically oriented to companies or potential customers are also measures that facilitate and attract the adhesion of companies and stakeholders to the CE market, as an example of the CIRCO program already mentioned.

The barriers of CE integration are even stronger than the incentives, so we can mention as a barrier of knowledge and skill the lack of professionals to guide the work, the difficulty to replace fossil fuels, lack of skilled labor, lack of a method of evaluation of the life cycle to measure the environmental impact (key indicator) and the lack of knowledge of the benefits on adopting the CE.

Unavailability of technology management programs to retain or recover equipment at the desired performance level, or that can support efficient processes are also important barriers.

Lack of support in the acquisition of processing machinery with low environmental impact and the lack of access to technologies to support efficient processes are paramount as difficult barriers to surmount.

Regarding market barriers, we can mention the lack of promotion and education for conscious companies, certification of sustainable extraction and production, and the customers habits who are unwilling to pay higher prices.

RQ6. What are the main opportunities for OS cluster firms through a CE?

As mentioned in the interview, the owners and directors of the companies witch share the same concerns should look for opportunities seeking the integrations of subproducts of other industries on your own companies.

The use of waste, and the use and transformation of by-products, both from the extraction and in the part of the transformation already in the factory can be reused by companies, cited by an interviewee for cork companies, or civil construction and aggregates.

Although the literature review cites many initiatives in Brazil and elsewhere, it seems that the Portuguese OS sector is not yet fully benefiting from industrial symbiosis opportunities. Yet, the companies gather in clusters so that joint cooperation, research and sharing of experience becomes possible.

4.3. Building an indicator for the CE integration in the O.S. sector

From the questionary answers, the most voted points considering what are the most relevant factors that a company should consider as an attractive characteristic to join a CE project could be extracted and listed hereinafter:

I. Supporting government policies: Government regulation to promote the CE, subsequent subsidies and tax breaks can improve the adoption process of this economic model.

II. Identification of performance measures for the CE: Effective performance measures help analyze the benefits of the CE.

III. Rewards and Incentives for Greener Activities: Rewards and incentives boost worker morale to facilitate the implementation of environmentally sustainable activities.

IV. Training and coaching focused on adopting the CE (appropriate training sessions facilitate the process of adopting the CE).

V. Understand the exact implications of the CE: The economic and social benefits are needed to be understood explicitly for an effective adoption of the CE.

VI. Build a brand image: Having a brand image in the organizational culture within the CE boosts opportunities.

VII. Stakeholder participation is essential for the adoption of the CE.

From this result, we will choose 5 of the 7 factors for the qualitative comparison using the M-Macbeth software, as an example on how the program can help on a decision-making process, noting that the beta version of the program only can accept 5 factors (figure 4.1) and without further comparison with a real project, we cannot affirm that this weights can be used to measure on a decision making process.

Since factor number V, that is, the understanding of the implications of the CE, is correlated with factor number VII, which is the participation of stakeholders, we will choose to use only the factor number VII, and as factor number VI was not previously mentioned as one of the highly relevant factors in the literature review, we chose not to use it in this comparison, remembering that this exclusion is only due to the fact that the software version does not support more than 5 factors.

The figure 4.1 below shows the decision tree, utilizing the 5 factors discussed:

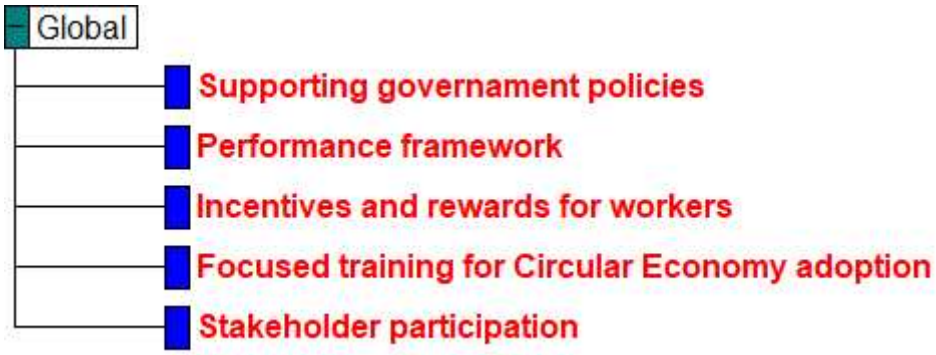


Figure 4.1: M-Macbeth decision tree

For the comparation of the factors, a judgment matrix is created, and the judgments were made by the decision maker, with the comparison between pairs of factors, between row and column, using the distance between the factors as the importance to be calculated. It is needed to choose an upper and lower levels references in terms of performance, giving the idea of a neutral, or good performance (da Cruz and Marques, 2013).

The factors are abbreviated, and its performances showed in the Table 4.4, and Figure 4.2:

- **Pol** – I. Supporting government policies (Yes – upper), (No- neutral).
- **STK**- VII. Stakeholder participation. (Strong – upper), (Collaborative), (Neutral – neutral), (Opponent).
- **TR**- IV. Training and coaching focused on adopting the CE (Yes – upper), (No- neutral).
- **P.F**.- II. Identification of performance measures for the CE (Yes – upper), (No- neutral).
- **REW**- III. Rewards and Incentives for Greener Activities for the workers (Yes – upper), (No- neutral).

Table 4.4: Matrix of Judgments for hierarchical model from M-Macbeth

	[Pol]	[STK]	[TR]	[P. F.]	[REW]	[tudo inf.]	Current scale
[Pol]	no	weak	strong	strong	strong	positive	40.62
[STK]		no	moderate	moderate	strong	positive	31.25
[TR]			no	weak	weak	positive	15.62
[P. F.]				no	weak	positive	9.38
[REW]					no	positive	3.13
[tudo inf.]						no	0.00

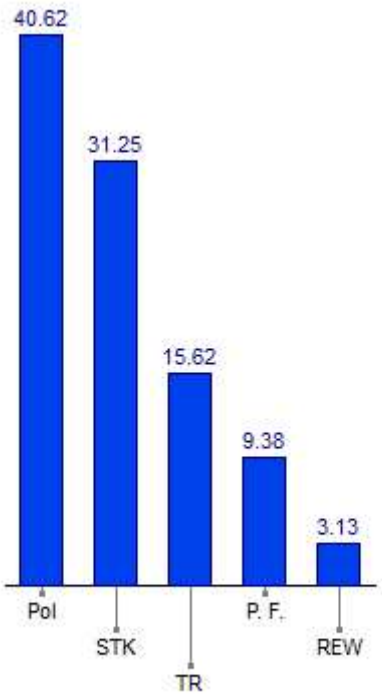


Figure 4.2: Histogram from M-Macbeth

From the results given on the comparison using the M-Macbeth software, the Supporting government policies obtained the highest weight compared to the other factors, with 40.62%, followed by the Identification of performance measures for the CE with 31.25%. With the lowest value, and least influence we can cite the Rewards and incentives for Greener Activities for the workers with 3.13%, followed by the Identification of performance measures for the CE with 9.38%.

Chapter 5: Conclusions

The main objective of this research was to analyze the OS cluster firms' opportunities to consider the CE as a part of their corporate strategy. Barriers and drivers were identified and, surprisingly, the lack of knowledge of the benefits of CE along with the lack of skilled labor were appointed as strong opponents to the adoption of CE by the companies. Of course, start-up costs and stakeholders commitment play essential role, as expected.

On the other hand, image brand, reputation and the adherence of the companies in a cluster were identified as the pushing-ahead factors in the direction of adopting CE.

Although the companies gather in clusters and join local, national, and international incentive programs, they do not seem to benefit in full of the possible opportunities of symbiosis at hand, possibly by the lack of information or of further support from governmental and non-governmental organizations.

From the interviews a qualitative analysis could be performed with the help of the multi-criteria optimization software M-MACBETH, resulting in a numeric indicator that provides an objective means to compare projects or opportunities of adoption of CE by a company. This score is a function of the factors that characterize the project or opportunity, and its main use is in the selection of potentially successful initiatives of adoption of CE.

Future work may validate this methodology by applying it to concluded successful and unsuccessful projects and programs and calibrating the indicator proposed here.

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