TOWARDS INDUSTRY 4.0 | A CASE STUDY IN ORNAMENTAL STONE SECTOR

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Abstract

A movement to mobilize the Portuguese Ornamental (OS) sector to reduce waste and improve flexibility began in 2004. Boosted by R&D Mobilizing Projects in consortium and fostered by two of the Sustainable Development Goals (SDG9[1] and SDG12[2]), this mobilization resulted in a new generation of technologies, concepts and innovative practices, matching the needs of Portuguese OS companies, stressing an integrated approach to European Competitiveness that should be fostered by a sustainable industrial policy, combined with innovation and skills. Bearing in mind that the Sustainable Development Goals (SDG) are the blueprint to achieve a better and more sustainable future for all, and considering the importance of following the goals and guidelines of SDGs 9 and 12 in the industrial processes optimization achievement in the Portuguese OS sector, the following research question arises: What is the impact of the R&D Mobilizing Projects on the efficiency and image of Portuguese OS companies?

The objective of this research is to conceptualize an empirical framework based on a mixed methodology, to assess the efficiency and image benefits resulting from participation in these R&D Mobilizing Projects. Through applying the empirical framework to two case studies, it was concluded that for companies that since 2004 have been part of R&D Mobilizing Projects, the evolution in terms of improved energy and raw-material efficiency, soft skills and improved facilities is more positive than in other OS companies. Moreover, there are potential gains in efficiency and image of 9.62%, compared to companies that have never participated in this type of project. This results match with the EU's integrated climate and energy policy and an integrated approach to the sustainable management of natural resources, the protection of biodiversity and ecosystem services. The sustainable production and consumption revealed in the

[1] GOAL 9: INDUSTRY, INNOVATION, AND INFRASTRUCTURE - to build resilient infrastructure, promote sustainable industrialization and foster innovation.
[2] GOAL 12: RESPONSIBLE CONSUMPTION AND PRODUCTION - to ensure sustainable consumption and production patterns.

Portuguese OS sector are among the drivers for achieving objectives under both the SDG and the Lisbon strategy.

Keywords: Ornamental Stones, AEC, Lean Thinking, SDGs, Industry 4.0, Innovation; Optimization.

Acknowledgements

This work was supported by CEI – Companhia de Equipamentos Industriais and Inovstone4.0® **– Tecnologias Avançadas e Software para a Pedra Natural,** POCI-01-0247-FEDER-024535 INOVSTONE 4.0**.** The authors also acknowledge the financial support from National Funds of the FCT – Portuguese Foundation for Science and Technology within the project «UID/ECO/04007/2019».

1. Introduction

Businesses are shifting beyond traditional industry silos merging nowadays into network ecosystems, establishing new challenges and new opportunities towards innovation for many existing companies. Starting in 2004, the movement to mobilize the Portuguese OS sector to reduce waste and improve flexibility (Peres & Costa, 2006), following the SDG Indicators 9 and 12, has had as its main milestones R&D Mobilizing Projects in consortium, which have resulted in a new generation of technologies, concepts and innovative practices adapted initially to the needs of Portuguese OS companies (Ines Frazao, 2019). This innovative movement (Joana Frazao, 2018) emerged from a process of cross-fertilization and technology transfer between the footwear sector and the OS sector (Lusch & Vargo, 2006) (Camarinha-Matos, Afsarmanesh, & Antonelli, 2019), through the Facap[3], Fatec[4], Newalk[5], Jetstone[6] and Inovstone[7] Projects. These were decisive in making many companies in both sectors believe that evolving technologically would help them in their search for competitiveness (Antunes da Silva, 2014).

[3] https://www.ctcp.pt/inovacao/inovacao.asp?op=3&id=20&idmp=Ng==&idms=NDU=
[4] https://www.ctcp.pt/inovacao/inovacao.asp?op=3&id=27&idmp=Ng==&idms=NDU=
[5] https://www.compete2020.gov.pt/noticias/detalhe/Newalk
[6] https://www.ctcp.pt/inovacao/inovacao.asp?op=3&id=28
[7] https://www.inovstone.pt/#index

In this context, the following research question arises: What is the impact of R&D Mobilizing Projects on the sustainability, efficiency and image of Portuguese Ornamental stone companies?

The guiding research of this empirical study was based on the comparison of efficiency and image between a case-study including companies that have never participated in R&D Mobilizing Projects and another case-study including companies that have participated in these since 2004. Using a mixed methodology (Creswell, 2014), this research aims to conceptualize an empirical framework to assess the efficiency and image gains, resulting from companies' participation in R&D Mobilizing Projects. By applying the empirical model, the intention is to compare the performance of the case studies in terms of (i) energy efficiency, (ii) raw material efficiency, (iii) ability to attract soft skills, and (iv) improved facilities and image.

To select companies to participate in each of the case studies, an objective, non-random sample of convenience was used (Tashakkori & Teddlie, 1998).

2. Sustainable Development Goals (SDGs) and Sustainable Business Performance

On October 25, 2015, the United Nations adopted the 2030 Agenda for Sustainable Development and the embedded goals for sustainable development achievement (SDGs). The SDGs – a challenging set of 17 goals, 169 targets and 304 indicators - is one of the last decisive actions for "the change from *statistics as a governmental technique* to *indicators as a global governance technology*" (Reniger, 2016). The universality of 2030 Agenda is one of its main features and the SDGs should be relevant at all society levels, from global to local. In the global efforts towards sustainable development, and particularly in the process of localizing these efforts, technology and innovation have an increasingly important role. The adoption of the SDGs highlighted the commitment of world leaders to create a more sustainable path to equitable and inclusive development, as also stresses the immediate role of global business to guarantee sustainability acting in a more precautious and enlightened way towards social, economic and environmental issues, the previous three-pillar conception of sustainability.

In most countries, the economic development is primarily pushed by the industrial sector and covers a wide range of operational activities, such as exploration, mineral excavation, material transport, processing and production (Meng and Chi 2018), activities that are not exempt from environmental impacts. This situation has led to inequalities and to a path further and further away from sustainability (Kukyeva et al., 2014). As a result, an increasing number of governments, corporations, civil societies and international organizations have started alignment with the SDGs to improve human lives and protect the environment.

As noted by Gazzola, Campo, and Onyango (2019), a sustainable economy requires sustainable patterns of production and consumption that treat all parts of the economy equitably. In recent years, organisations have given much attention to corporate sustainability (Alshehhi, Nobanee, & Khare 2018), turning their focus to the environmental and social aspects in their practices rather than concentrating on merely boosting their financial performance (Alshehhi et al, 2018; Dixon-Fowler et al. 2013). However, becoming a sustainable business is not easy because it requires much consideration, including the cost of implementation that can affect the financial performance of the company (Ezani et al., 2018). The SDGs allows the balance between economic, social, and environmental development and aim to inspire the operationalization and integration of Sustainability into organizations worldwide (UN Global Compact, 2018).

3. SDGs and innovation in the Industrial Context

Although industrial development has clearly outlined the previous Millennium Development Goals, SDG 9 is the first autonomous development goal to incorporate industrialization into its objectives and covering some aspects of infrastructure development and technological development (UN, 2019). Nowadays, the industrial tendency towards automation and new technologies is referred as the Fourth Industrial Revolution (Industry 4.0) (Lorenzo, Antonio, Umberto, & Achille, 2017).

Industry 4.0 represents the approach of the Fourth Industrial Revolution, and it frames the current trend of automation technologies in the manufacturing industry. It mainly includes enabling technologies such as the cyber-physical systems (CPS), the Internet of Things (IoT) and cloud computing (Lu, 2017; Xu, Xu and Ling, 2018). According to GTAI (2014), Industry 4.0 represents the technological evolution from embedded systems to cyber-physical systems. In Industry 4.0, embedded systems, semantic machine-to-machine communication, IoT and CPS technologies are integrating the virtual space with the physical world, In addition, a new generation of industrial systems, such as smart factories, is emerging to deal with the complexity of production in cyber-physical environment (GTAI 2014).

The United Nations consider the industrial development as a key for both generating income and the improvement of life standards. In its turn, suited infrastructures deliver facilities for industry and society, and innovation increases technological capacities and leads to the development of new skills (Cheryl & Leurent, 2017).

The need to adopt a single framework for enforcing decisions with the SDGs and globalization background, have further complicated the competition between companies as traditional business models strive to achieve the right solution for survival. In this frame of reference, an alternative design of a sustainable business model can give companies a competitive advantage by improving traditional business models in order to achieve sustainable growth while preserving productivity and profitability (Small-Warner, 2018). Some authors emphasizes philosophical and epistemological aspects, highlighted ethical issues before economic, social and environmental issues, and adopted sustainable practices in the industrial sector to achieve the objectives related to SDG 7 (Affordable and Clean Energy), SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry Innovation and Infrastructure), SDG 12 (Responsible Production and Consumption), SDG 13 (Climate Action), SDG 15 (Life on Land) and SDG 17 (Partnerships for the Goals) (Ronzon and Sanjuán, 2020).

The SDG 7 seems to be a genuine multiplier for the other SDGs. Thus, some authors highlight the importance of an "energy access innovation centre" (Nathwani and Kammen, 2019) sponsored by the World Bank's Climate Innovation Centres (Artigo q li). In wealthy nations, SDG 7 is achieved by means of innovative elements of industry 4.0, such as digitization, real-time monitoring, big data collection and analysis (Beier, Ullrich, Niehoff, Reißig and Habich, 2020).

As the SDG 9, a few authors have demonstrated in the industrial sector (Beier et al, 2020; De Oliveira et al., 2019) a close relation between SDGs and innovation, either in patenting development (Wydra, 2020), open innovation approaches (von Geibler, Piwowar and Greven, 2020), open-source intelligence tools (Hayes and Cappa, 2018), and frugal (Khan, 2016) and reverse innovation [94]. Research suggests a positive linkage between sustainability and market (Shan and Khan, 2016), new products development and process innovation (Slowak and Regenfelder, 2017), and point to a tendency of growth of sustainability when the innovation concept is tied to each SDG. Literature analysis shows that innovation can be designed not just as a goal, but also as a condition for implementing the required changes in all sectors when targeting the sustainable development goals. In line with the need to embrace a cooperation strategy seeded in all sectors (SDG 17), some research work pinpoints the importance of open innovation as a fruitful form of collaboration in the industrial context. Examples, from the innovation process starting point (idea-generation stage, either participative or not (Cappa et al, 2016; Cappa, Oriani, Pinelli and De Massis, 2019), to the following start-up stage (Yun, Won and Park, 2018), development (Buhl et al., 2019) and the possibility of new products/processes patenting (Yun et al, 2018) reveals a change of paradigm, clashing with the model of capitalist (neoliberal) development that hold back the SDGs implementation (Dahlmann and Bullock, 2020; Kramer, Agarwal and Srinivas, 2019).

The prudent and not wastefully use of natural resources promotes the SDG 12 implementation (Brozovic, 2019) and the growing introduction of technological innovations in industry towards cleaner production practices is targeted for SDG 12, as also for SDG 15 (Fan et al., 2019). In addition, having employee well-being management guidelines which affects human reliability (Franciosi et al., 2019) as also environmental aspects, promote sustained, inclusive and sustainable economic growth, with productive employment and decent work for all as targeted by SDG 8. In addition, some authors believe that SDG 12 and SDG 13 will benefit, in a long-term perspective, through industry 4.0 innovative practices (Beier et al, 2020; ElMassah and Mohieldin, 2019), also with sustainable maintenance (Kanisuro, 2017).

Based on the content analysis of available public reports from 235 Portuguese organizations with Quality, Environmental, and Health and Safety certified management systems, Fonseca and Carvalho (2019) found that the top five reported SDGs are SDG 12 – Responsible consumption and production (23.8%); SDG 13 – Climate action (22.1%); SDG 09 – Industry, innovation, and infrastructure (21.3%); SDG 08 – Decent work and economic growth (20.0%); and SDG 17 – Partnerships for the goals (19.6%), which are in line with the above referred.

3.1. SDG’s and Innovation in the Stone Industry sector

Due to technological advances from artificial intelligence to robotics, new energy sources and storage, the stone Industry is undergoing rapid changes (Antunes da Silva, 2014). These changes are expected to occur quickly, and traditional manufacturing and service are likely to occur, leading to both difficulties and benefits. Technological innovations and ecosystemic industry networks are driving currents for industrialization trends and can, among other things, create a climate-friendly infrastructure and a basis for a climate-resilient development (Ramezani & Camarinha-matos, 2020). That is why implementation of SDG 9 in the stone Industry needs to take into consideration all the various stages of Industry 4.0 in order to remain competitive and sustainable in the coming years.

One of the greatest global challenges is to integrate environmental sustainability with economic development and well-being in order to reduce environmental degradation from economic growth and do more with less. The decoupling of resources and the decoupling of impacts are necessary to promote sustainable consumption and change production paradigms, facilitating the switchover to a circular economy (Neves, Godina, & Azevedo, 2019). A good example of this commitment is environmentally friendly products with low resource consumption and little social and ecological impact. SDG 12 calls for more comprehensive measures by companies, industry, policy makers, researchers and consumers to adapt to sustainable practices. It improves sustainable production and consumption based on advanced technological skills, efficient use of resources and general waste reduction.

Political cohesion is required in the stone industry to achieve SDG 12 (Sustainable Development Goals Report, 2019). Some authors argue that the dimension stone quarrying is relatively harmless from an environmental point of view. There is no other emission than the diesel earthmoving equipment with which it is extracted, and small amounts of dust spread in the atmosphere (UN, 2019). Pollution of water resources is only possible in the case of petrochemical leaks from storage facilities and equipment and can largely be avoided or cleaned. However, the main environmental impacts are visible and can have significant impacts: they greatly affect sensitive areas, leads to habitat elimination, loss of fertile topsoil and destruction of archaeological heritage (UGD, 2011).

Additionally, the waste reduction and management are utterly problematic for the stone industry, particularly in the aftermath of stone extraction, and companies have a social responsibility to protect the environment and ensure the sustainable use of natural resources (Girisken & Gu, 2013; Sivrikaya, Koray, & Zeki, 2014). For the countries with a developed stone industry, as Portugal (Carvalho, Lopes, Mateus, Martins, & Goulão, 2018), the waste generated in the natural stone processing plants pose environmental and economic problems if not appraised (Rebello, Zulcão, Calmon, & Gonçalves, 2019; Sivrikaya et al., 2014).

Through targeted sustainable management and efficient use of natural resources to ensure sustainable consumption and production patterns, and in accordance with the terms of the SDG 12 indicator, research on reducing, recycling, upcycling and reuse of waste from upcycling and stone processing has been intensified.

In this context, interest in the idea of the Circular Economy (CE) is growing fast. CE is an alternative to the traditional linear economy in which we keep resources in use for as long as possible, extract the maximum value from them whilst in use, then recover and regenerate products and materials at the end of each service life. The CE economic system aims to conciliate economic and environmental performance through the implementation of closed loops and regenerative and restorative physical and economic cycles and the combination of maintenance, repair, reusing, refurbishment, remanufacturing and recycling processes (Ellen MacArthur Foundation, 2017). This regenerative approach contrasts with the traditional linear economy, which has a 'take, make, dispose' model of production. The Circular Economy is all about business – economy has always been about how we manage scarcity and resources efficiently. In a circular economy, resources are handled in a more responsible way. The goal is to extend product lifetime and recirculate all materials without producing any waste. Success now in embedding circular principles in industrial growth and infrastructural development strategies can help to ensure that the needs of growing and urbanising populations are met without risking rises in resource use, emissions and environmental pollution.

Supported by a scientific literature review, Suarez-Eiroa et al. (2018) propose seven operational principles for CE implementation: i) adjusting inputs to the system to regeneration rates, ii) adjusting outputs from the system to absorption rates, iii) closing the system, iv) maintaining the value of resources within the system, v) reducing the system's size, vi) designing for CE, and vii) educating for CE.

In research with 99 Portuguese organizations, encompassing a wide range of sectors and sizes, Fonseca et al. (2019) posit that the results show that CE is regarded as a strategic and relevant issue for profitability and value creation. Furthermore, the perception is that it requires the adoption of new business models in addition to the classical "reduce, reuse and recycle".

3.2. A Portuguese Stone Industry approach

The most evident symbols of Portuguese Ornamental Stones are the numerous monuments in stone, built from the fifteenth century onward, using engineering, Portuguese stone and people whose know-how was transmitted from generation to generation (Antunes da Silva, 2014). Perhaps because it is part of the country's culture, in the 21st century Portugal is considered a world-class producer of stone products (Joana Frazao, 2018), with incorporation in the Construction Industry depending mainly on architects' will, knowledge and interest (Álvarez-Fernández, González-Nicieza, Álvarez-Vigil, & Alejano, 2012). Despite its small size, Portugal has a diverse and significant reserve of stones suitable for ornamental use (Siegesmund & Snethlage, 2017), and so, more than ever, the ability to co-create value with architectural technicians and investors, while still in the design phase, should be one of the core tasks of a stone product supplier (Breidbach & Maglio, 2016).

Once extracted, the different types of stone, according to the different transformation processes, originate a differentiated set of products, which are channelled to the most varied markets (Galetakis & Soultana, 2016).

In generic terms, we can list the following essential physical and mechanical characteristics of Portuguese Ornamental stones (Siegesmund et al., 2017): (i) Granites - show excellent physical-mechanical characteristics, making them usable in all types of applications, both indoors and outdoors (López, Martínez, Matías, Taboada, & Vilán, 2010); (ii) Marbles - in general, show values corresponding to stones of appreciable quality, whose use is generally extended to the whole range of applications, indoors and outdoors (Galetakis et al., 2016). (iii) Limestones - the vast majority have physical-mechanical characteristics compatible with their indoor and outdoor use, although in this case, some restrictions apply in the use of some typologies in situations of strong exposure to icing-thaw (Hycnar, 2015). Processing plants are essentially designed (layout) in size and structural organisation according not only to the type of stone worked, but also to the final products intended such as sawn slabs, finished slabs, tiles, customized work, among others (Siegesmund et al., 2017).

These definitions affect the distribution of undertakings in the Ornamental Stone sector, with significant variation resulting from the combination of the above aspects – the rock worked and the intended final product (Galetakis et al., 2016). Although in certain aspects, the type of stone processed will influence the definition of the dimensioning, this is not the main conditioning factor, considering the existence of equipment that enables the handling of a wide variety of materials. The main conditioning factor is, fundamentally, the type of final product intended (Silva & Almeida, 2016).

Recent studies show the approach to a mass balance, observing that to produce seventy tons of final product (e.g. tiles), it is necessary to extract 1.000 tons of blocs, which gives the existing process a yield of only 7% (Antunes da Silva, 2018). The remaining 930 tons represent either waste originating during the process or materials of poor quality (Antunes da Silva, Silva, & Almeida, 2016). It is estimated that the average amount of waste generated in Europe, in all stages of producing Ornamental Stones, can greatly exceed 80% of the total raw material produced (Galetakis et al., 2016).

One way to solve this problem is, or has been, the development of new technologies and different work organisation, which will lead to greater use by reducing waste at source (Womack, Jones, & Daniel, 2003), as well as an increase in the reuse of the waste created, thus increasing the total efficiency of the chain in not only economic but also environmental and social aspects (Melton, 2005).

Another point to consider in the area of effective product promotion is directly related to the figure of the prescriber, since the natural stone market (Antunes da Silva et al., 2016), although diversified, is closely associated with the civil construction sector (Costa & Madrazo, 2015). Here, it is important to consider that the prescriber may influence the client's choice in the process of selecting the stone for a given application (Oraskari & Törmä, 2015). This stakeholder is an element to be considered in the supply chain because, although almost invisible, here lies the effective choice of the material to be purchased (Galetakis et al., 2016). Thus, the development of actions to promote products becomes urgent, both in terms of information and training, in order to provide this stakeholder with the necessary knowledge on which to base opinions (Antunes da Silva et al., 2016).

In the Portuguese stone industry, sustainable management and efficient use of natural resources are a framework decision which aims at improving sustainable consumption and production patterns. This endeavour, which is manifested in R&D mobilization projects in companies consortium, has been looking for goals and challenges to grow in every way and build solid companies that are increasingly sustainable and sustainable in terms of health, safety as well as the environment.

4. R&D Mobilizing Projects

According to data provided by the Portuguese Marble and Granite Industry Federation (ASSIMAGRA[8]), in 2013, the Portuguese OS sector (i) exported to 116 countries; (ii) was in 9th position in the World International Stone Trade; (iii) was the 2nd country in International trade per capita; (iv) exports covered imports by 823%; (v) 45% of exports were to countries outside Europe and (vi) it was in 2nd position in the gross value added national ranking (after telecommunications) (Antunes da Silva, 2014). Consisting mainly of small and medium-sized enterprises (SMEs) (Ines Frazao, 2016), the OS Sector is considered relevant in the Portuguese economy, representing more than 16,000 jobs, and is one of the main generators of private employment in inland regions. It has a record of sustained growth in exports (Figure 1), placing Portugal as the eighth country in the International Trade of OS and the second country in the world in International Trade per capita[9] (Joana Frazao, 2016).

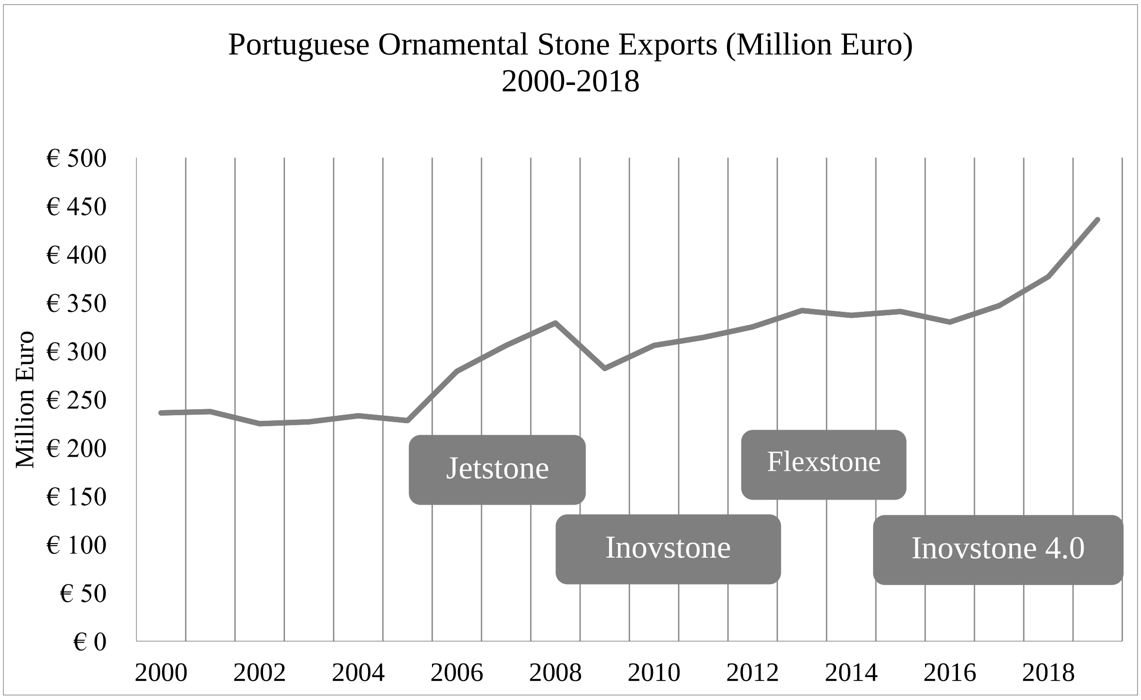

Figure 1: Evolution of Portuguese Ornamental Stone Exports. Source: European Commission (2019), Trade Export Helpdesk[10], [Online accessed 20 November 2019]

[8] www.assimagra.pt

[9] Gross Domestic Product per number of inhabitants

[10] http://exporthelp.europa.eu/thdapp/index.htm

The Prospective Strategic Study presented by Cluster Portugal Mineral Resources (CPMR[11]) in January 2004 (Antunes da Silva, 2014) resulted in the need to work on a lean [12] and flexible strategic path (Womack et al., 2003).

The first stage of this "path" was the creation of the Jetstone[13] Consortium, a partnership between ten business entities and several academic research centres, which resulted in the Mobilizing Project with the same acronym.

Figure 1 shows the "take-off" of OS exports from the creation of the Jetstone consortium in 2005. The OS sector, like the whole economy, was affected by the subprime crisis in 2008, but it rose again, in line with the Inovstone Mobilizing Project.

The most visible result of this project was 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.

This business partnership began by breaking down problems, building a distribution matrix of these same problems at a lower level (Antunes da Silva, 2014).

At the time of signing the Jetstone consortium contract, the goal was to have a positive impact on the industry's competitiveness, based on the following assumptions (Joana Frazao, 2018).

With the purpose of continuing to mobilize OS in the incorporation of leanstone concepts, the CPMR initiated the Inovstone[14] Project, based on new objectives, among them: (i) to involve more companies and entities; (ii) to attract critical mass to the sector; (iii) to continue the creation of new and modern production technologies that are environmentally friendly, energetically optimized, and which could add value and increase the quality and competitiveness of companies in the sector; (iv) to stimulate the export component of CPRM through both stone and technological products and through a change in mentality and attitude, based on companies that demonstrated considerable levels of success following adoption of the model in question.

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[11]https://www.clustermineralresources.pt/

[12] The lean concept utilized in the present work is the one related to Lean Production or Lean Thinking accordingly Womack et al. (1990) and Womack and Jones (1996). It is based on the concept of achieving improvements in most economical ways with an emphasis on waste elimination. Lean employs minimum resources for maximum output, and it is based on five well-known principles: value, value stream, flow, pull, and perfection.

[13]http://projetos.ani.pt/actions/project?id=C15/2002/0005&search=global&actionbean=actions/project

[14]https://www.inovstone.pt/pt/noticias/cei-na-mostra-de-inovacao-e-conhecimento-ani

The Flexstone[15] Project was followed with the main objectives of ensuring (i) continuation in traditional markets with growth potential, (ii) entry to new markets, (iii) increased differentiation and innovation of products with capacity to respond to more demanding markets, (iv) continued integration and technological evolution in companies, (v) an improved communication policy in the sector and companies, and (vi) boosting the Portuguese brand of Pedra Natural - Stone.PT.

Finally, the Inovstone4.0[16] Project, still under execution, is based on the relationship between companies and BIM platforms, including the participation of 24 companies, with their leadership. Its objective is to foster Inovstone 4.0 Collaborative Production in the context of BIM procurement in the construction industry (Ines Frazao, 2019).

This path of incorporating innovative technologies conceived according to flexible lean awareness, throughout the Ornamental Stone sector's supply chain, resulted in a primer, popularized in Portuguese OS by *leanstone hornbook*. A company that applies the principles of the *leanstone hornbook* makes its operations *leanstone*. Through lean principles, in *leanstone* operations, each small increment towards continuous improvement is supported in PDCA (Plan, Do, Check, Action) cycles, continuously repeated until perfection is reached (Chavez et al., 2015).

5. Research methodology and empirical framework

Guided by the pragmatist paradigm, the fundamental challenge of this research is to describe, provide the foundations for, and make a confirmative empirical test of an empirical framework (Tashakkori & Creswell, 2007). Conceptualization of the empirical framework must parameterize the KPI and the metrics to be used in data collection, according to the objectives (Maglio & Spohrer, 2008), making it possible to assess the evolution in efficiency and image resulting from OS companies' participation in R&D Mobilizing Projects, comparing the performance of two case studies, in terms of (i) energy efficiency, (ii) raw material efficiency, (iii) soft skills, and (iv) improved facilities.

The Ornamental Stone sector is one where asymmetry of information, power of influence and lack of a legislative framework do not provide a favourable context for in-depth

[15]https://www.ani.pt/pt/noticias/not%C3%ADcias-ani/apresenta%C3%A7%C3%A3o-dos-resultados-do-projeto-flexstone/
[16]https://www.inovstone.pt/#index

research. Moreover, the possibility of interviewing the main managers of the sample companies influenced the choice of companies (Crompton and Nicholls, 2019).

It was decided to analyse two case-studies. For each case study, companies were selected in an objective and convenient manner, as each case is intended to meet certain cumulative and previously specified criteria. The first case-study will involve a sample of companies that have voluntarily participated in all R&D Mobilizing Projects since 2004. The second case-study will involve a second sample of companies that have never participated in R&D Mobilizing Projects. The empirical data were obtained with the support of all the companies participating in this study.

In mixed methodology research, "no assumptions are made about relationships between variables, but multiple variables are exploited whose relationships can only be known after data is collected (Creswell, 2014). The empirical data was obtained mainly from written documents and interviews supported by an open questionnaire script. With this technique, always involving a face-to-face situation with the interviewee, a climate of relational approximation was created, which favoured the free expression of knowledge, attitudes and intentions by the interviewee, always recommended in Social Sciences (Tashakkori & Creswell, 2007). Thus, perception and common knowledge are the basis for elaborating a more formalized and general "version of reality" by social scientists (Akwei, Peppard, & Hughes, 2010).

All these companies were interviewed, following Morse's (1998) suggestions, namely meeting several criteria of a "good informer" (Akaka, Vargo, & Schau, 2015). For this author, these can generically serve as significant basic selection criteria (Emmer, Hofmann, Schmied, Stjepandić, & Strietzel, 2018). The names of these companies, at the request of those responsible, will not be disclosed in this work. However, by agreement with these same managing directors, there will be no limitations on academic use of data observations, as long as it is for the same purpose as this work.

According to some authors, a framework can be defined as a set of interrelated objectives and fundamentals, where the objectives identify the goals and the fundamentals are the underlying concepts that assist in achieving those same goals (Meynhardt, Chandler, & Strathoff, 2016). From the literature review, it was concluded that for new scientific disciplines such as Service Science (Demirkan & Spohrer, 2016; Demirkan and Spohrer, 2011; Spohrer, Maglio, Bailey, & Grughl, 2007), just as there is no separation between tangible and intangible goods, nor is there any "value creator" versus "value destroyer," since all social and economic actors are resource integrators as expressed by FP9[17] S-D Logic (R. F. Lusch & Vargo, 2008). Entities such as suppliers, customers, families or any other actors involved in economic activities are “exchange service entities” with the common purpose of co-creating value, as is reflected in the SDG 9. It is all B2B (S. L. Vargo & Lusch, 2010). In contrast to S-D Logic (Robert F. Lusch, Vargo, & Tanniru, 2010) but in line with Service Science, it will be assumed that there is a clear distinction between the four different types of main actors involved in co-creation interactions (Spohrer et al., 2007), also considering that all stakeholders will be value co-creators engaged in the service exchange along the service process (Maglio, Vargo, Caswell, & Spohrer, 2009; Storbacka, Brodie, Böhmann, Maglio, & Nenonen, 2016).

5.1. Case-study selection

The guiding research of this empirical study was based on comparison of the Innovation Outcomes from two case studies: (i) case study#1 | involving a group of Portuguese Ornamental Stone companies which have never participated in R&D Mobilizing Projects, and (ii) case study#2, involving a group of companies, which have participated in R&D Mobilizing Projects since 2004

5.2. Data Collection, KPIs and Innovation Outcomes

Very relevant data for the elaboration of this research were obtained from observations on the factory floor and the performance of the equipment developed in the scope of the Jetstone, Inovstone, Flexstone and Inovstone4.0 projects. In the case of computerized equipment, the production data are recorded from the machine servers.

Interviews were carried out, in an open manner, with managers of the sample companies, operators, section heads and company directors. As users, they have a clear perception of the limitations of the equipment, and of course, clear, well-conceived ideas on how to overcome those limitations - continuous improvement (Jaca, Santos, Errasti, & Viles, 2012). The waste of raw material is a double problem in this sector (Ines Frazao, 2016). Firstly, an increase in production costs, due to the lower yield of the raw materials themselves, and secondly, an increase in the costs of eliminating that waste, due to the greater amount of it (Thomas, 2011).

[17]Service Dominant Logic Ninth Fundamental Premise (S. Vargo & Lusch, 2016)

The two case-studies' performance will be assessed through KPIs measurements, indexed to the data collected. The Figure 2 resumes our approach.

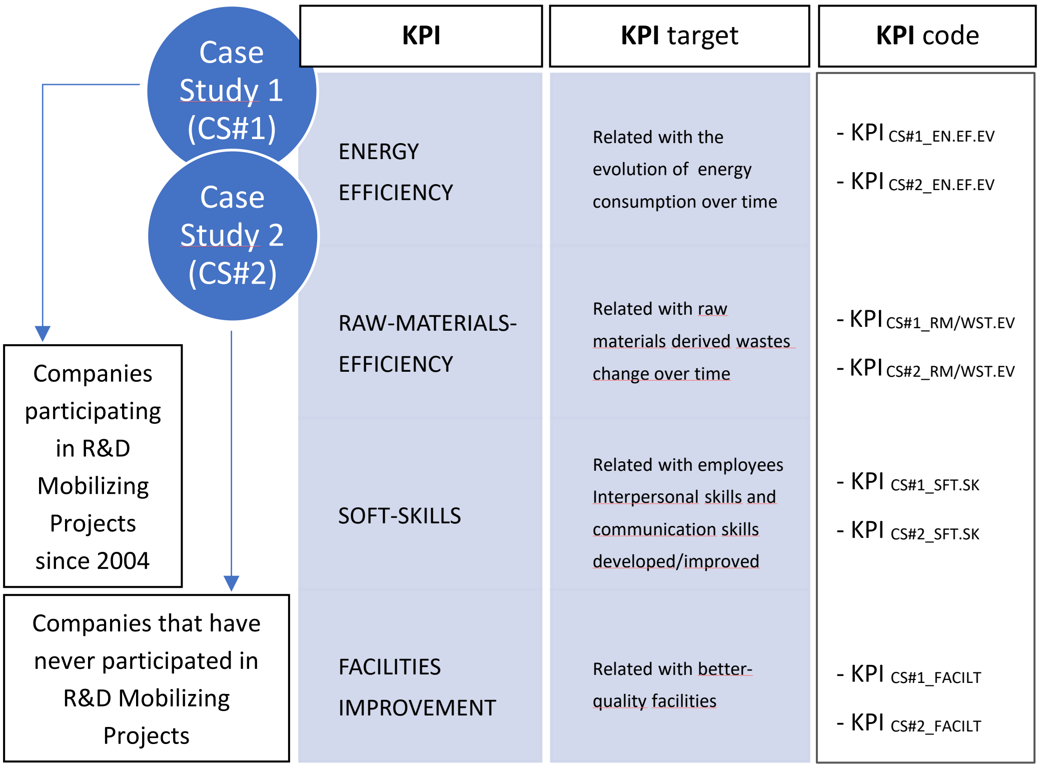

Figure 2: Case studies, addressed KPIs, respective targets and codes

Innovation Outcomes (IO) are the result of the evolution of KPIs, when companies change their mode of operation, i.e.: $KPI_{CS\#1} - KPI_{CS\#2} = IO$

Thus, it is through the IOs that the impact of participation in R&D Mobilizing Projects will be determined.

6. Confirmative study: Empirical test

By using the pragmatist worldview guidelines and the parallel convergent mixed methodology, the framework conceptualized will be applied to the case-studies related to the Portuguese Ornamental Stone sector.

6.1. Energy Efficiency

The rational use of energy, also simply called energy efficiency, consists of using energy efficiently to obtain a certain result. Energy efficiency consists of the relationship between the amount of energy used in an activity and that made available for its realization. Do more with less energy. This is energy efficiency and usually represents a value of specific consumption of primary energy, thermal or electrical relating to dimensional parameters (area, kWh/m^2/year or volume, kWh/m^3/year).

For the purpose of this study, the energy efficiency evolution (EN.EF.EV) indicator in both case studies (CS#1 and CS#2) is determined in relative terms, that is, considering the energy consumed over the value of the products sold (Equations 1 and 2).

Equation 1 | $KPI_{CS\#1\_EN.EF.EV\_2004\text{-}2018\ (\%)} = Avg\ (\frac{ENERGY\ USED}{PRODUCTS\ VALUE})$

Equation 2 | $KPI_{CS\#1\_EN.EF.EV\_2004\text{-}2018\ (\%)} = Avg\ (\frac{ENERGY\ USED}{PRODUCTS\ VALUE})$

The average annual evolution of energy efficiency (%) is presented (Figure 3) for each case-study it was considered as baseline value the energy consumed over the value of the products sold in the year 2004.

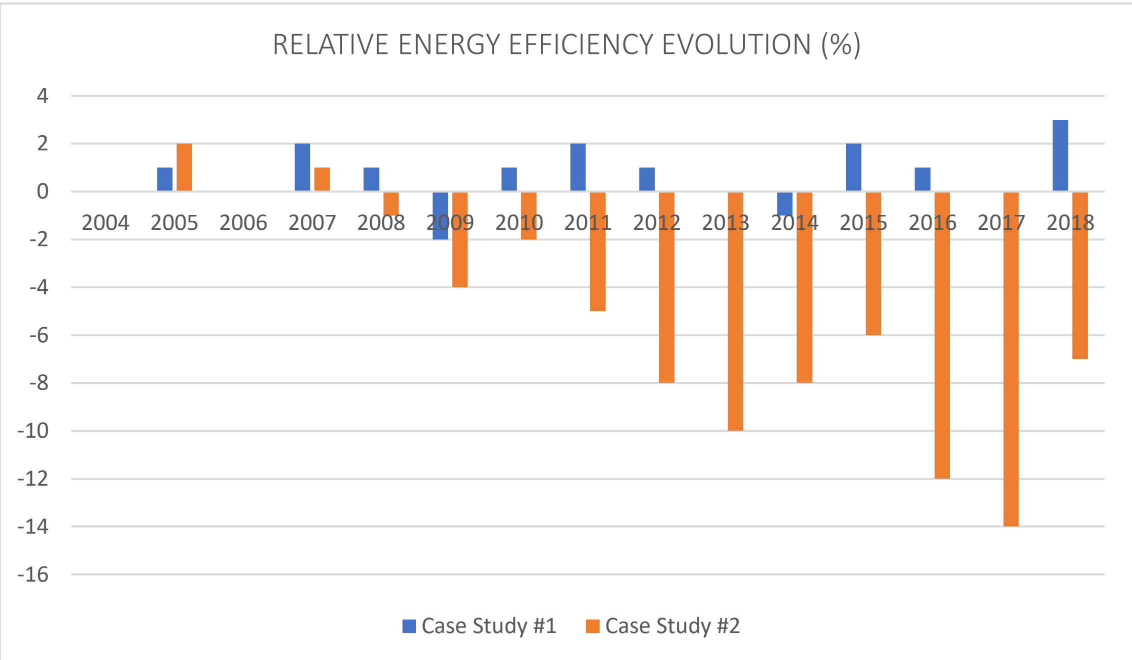

Figure 3: Average annual evolution of relative energy efficiency (%) in both case studies

Analysing the evolution of average energy-efficiency until 2018, based on the year 2004, it was found that $KPI_{CS\#1\_EN.EF.EV\_2004\text{-}2018(\%)}$ did not change significantly over the 15 years.

This KPI evolved in a stable manner. On the other hand, $KPI_{CS\#2\_EN.EF.EV\_2004-2018(\%)}$ shows a gradual decrease over the same period, (Figure 4).

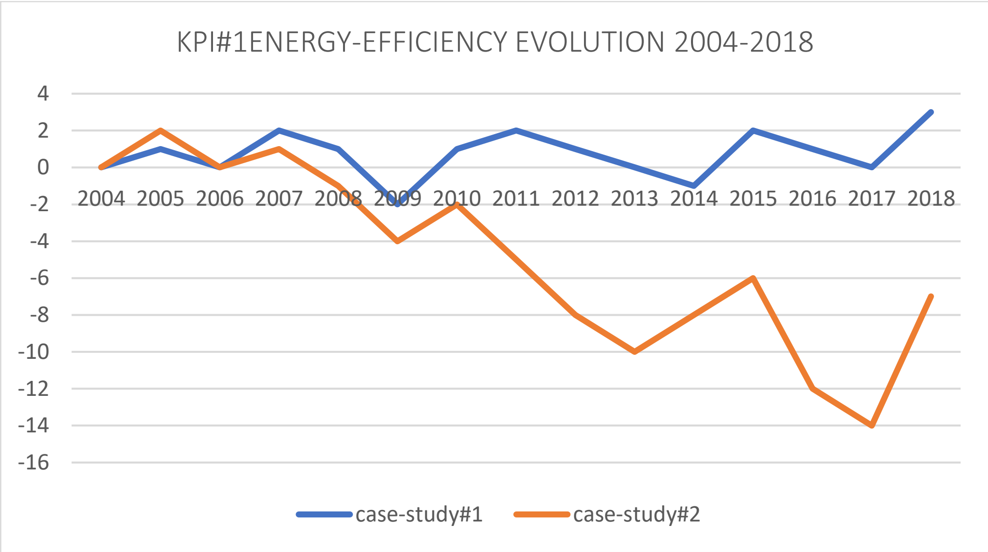

Figure 4: KPI Energy-Efficiency Evolution between 2004-2018

Based on these results, the linear evolution trend of the energy-efficiency KPI (Figure 5) was determined.

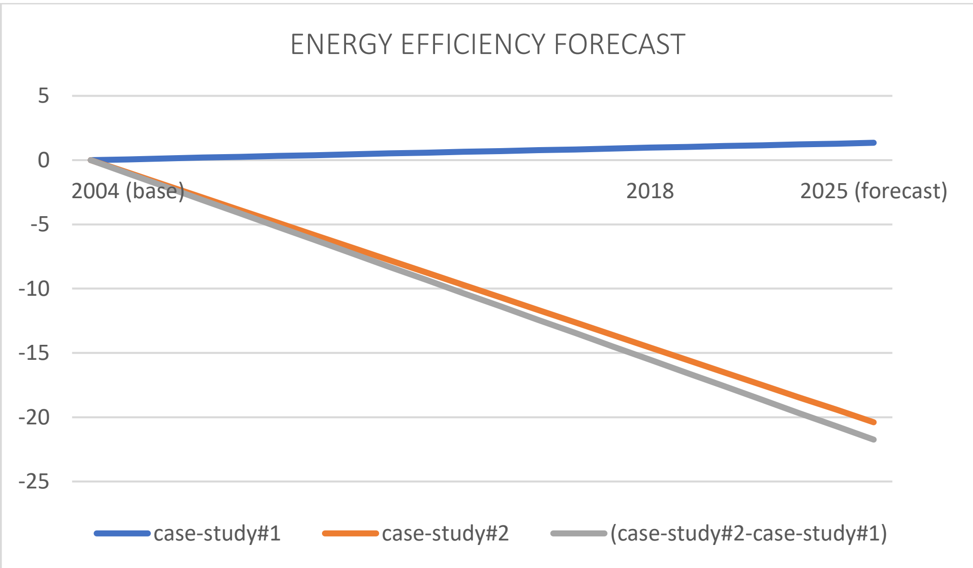

Figure 5: Energy Efficiency Forecast

Equation 3 | $IO_{ENERGY\text{-}EFFICIENCY\ FORECAST}$ = 0,0643x + 0,219) – (-0,9714x + 2,8381)

Through the respective IO, the gap between case-study#1 and case-study#2 was forecast till the year 2025, by using a linear correlation of the data collected from 2004 to 2018 (Equation 3).

6.2. Raw-Material Efficiency

Referred to as inefficient by some governments (HM Government, 2011), practitioners (Dankers, van Geel, & Segers, 2014) and academics (Babič, Podbreznik, & Rebolj, 2010), (Blanco & Chen, 2014), the current construction supply chain still generates avoidable waste, which is reflected in construction and maintenance costs, construction time and the ecological footprint, from the beginning of the building project up to the end of its life cycle.

The stone sector is part of the construction supply chain and waste in Ornamental Stone Industries plays a very important role in the sector’s competitiveness. Clearly finite raw stone must be transformed efficiently, resulting in the concept of raw material efficiency. In addition to energy efficiency, raw material efficiency also consists of using the minimum raw material to achieve the same result in terms of value. Thus, raw material efficiency is the ratio between the quantity of raw materials used and the quantity used in the final product. Do more with less raw material. However, for the purpose of this study, the raw material efficiency (RM/WST.EV) indicator in both case studies (CS#1 and CS#2) is determined in relative terms, that is, considering the stone consumed over the value of the products sold, over time (Equations 4 and 5).

Equation 4 | $KPI_{CS\#1\_RM/WST.EV\_2004\text{-}2018\ (\%)} = Avg\ (\frac{RAW\ MATERIALS\ USED}{PRODUCTS\ VALUE})$

Equation 5 | $KPI_{CS\#2\_RM/WST.EV\_2004\text{-}2018\ (\%)} = Avg\ (\frac{RAW\ MATERIALS\ USED}{PRODUCTS\ VALUE})$

The relative annual evolution of raw material efficiency, as a percentage, is shown for each case-study in Figure 6. It was considered as baseline value the ratio between the quantity of raw materials used and the quantity used in the final product in the year 2004.

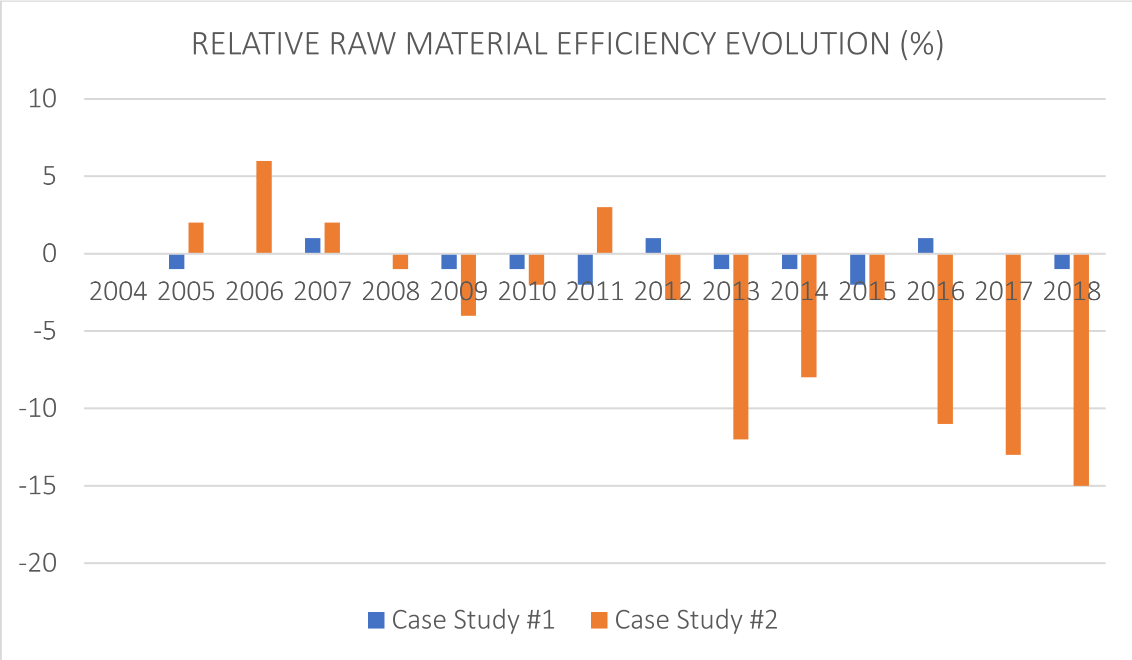

Figure 6. Average Annual Evolution of Raw Material Efficiency (%) in both case studies

Analysing the evolution of raw material efficiency on average until 2018 and based on 2004, it was found that $KPI_{CS\#1\_RM/WST.EV\_2004\text{-}2018\ (\%)}$ evolved steadily over the 15 years. On the other hand, $KPI_{CS\#2\_RM/WST.EV\_2004\text{-}2018\ (\%)}$ showed a gradual decrease over the same period, (Figure 7).

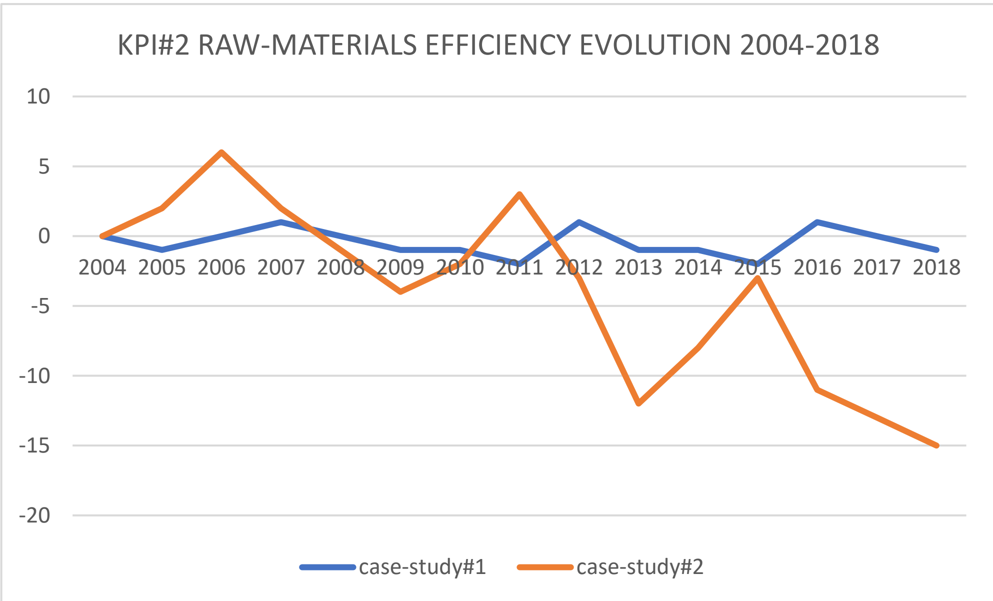

Figure 7: KPI Raw Material Efficiency Evolution 2004-2018

Based on these results, the linear evolution trend of the raw material efficiency KPI (Figure 8) was determined.

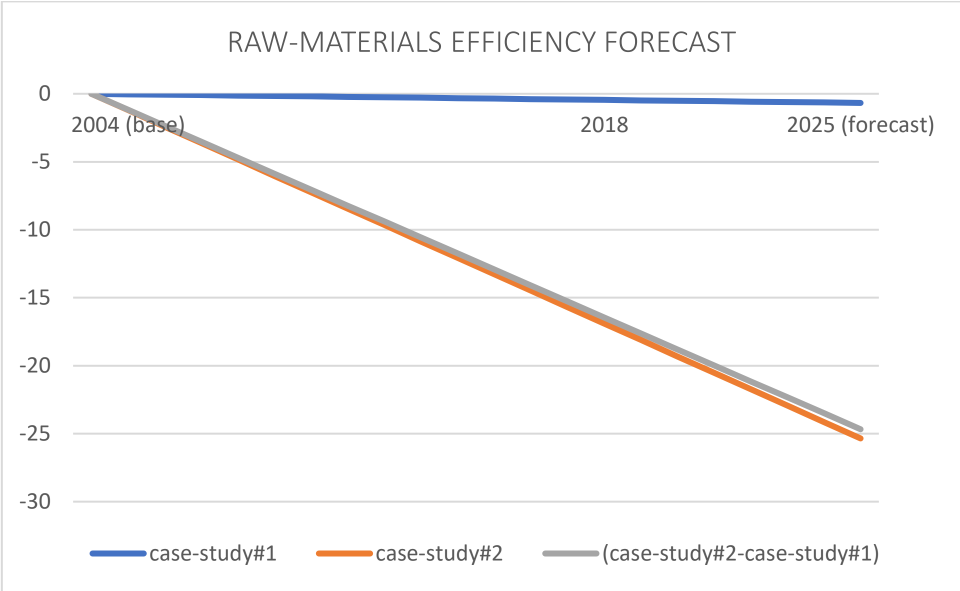

Figure 8: Raw Material Efficiency Forecast

Equation 6 | $IO_{\text{RAW-MATERIALS-EFFICIENCY FORECAST}} = (-0{,}0321x - 0{,}2095) - (-1{,}2071x + 5{,}72)$

Through the respective IO, the gap between case-study#1 and case-study#2 was forecast till the year 2025, by using a linear correlation of the data collected from 2004 to 2018 (Equation 6).

6.3. Soft Skills

The workforce's qualification, measured in terms of the capacity to attract and retain skilled employees, is increasingly an indicator of a company's evolution. The qualified employees in each year were chosen from the company's official documents in both case-studies and for the period from 2004 to 2018. Annual company's performance appraisal results regarding the employees' common sense, the ability to deal with people, as well positive flexible attitude (soft skills), besides technical skills, where considered.

For the purpose of this study, the "soft skills" indicator is determined by the ratio between the number of qualified employees that have been previously assessed as having soft skills and the total number of employees in each case-study (Equations 7 and 8).

Equation 7 | $KPI_{CS\#1\_SFT.SK.EV\_2004\text{-}2018\ (\%)} = Avg\ (\frac{TOTAL\ QUALIFIED\ EMPLOYEES}{TOTAL\ EMPLOYEES})$

Equation 8 | $KPI_{CS\#1\_SFT.SK.EV\_2004\text{-}2018\ (\%)} = Avg\ (\frac{TOTAL\ QUALIFIED\ EMPLOYEES}{TOTAL\ EMPLOYEEES})$

The average annual evolution of soft skills (%) (Table 1) is presented for each case-study, based on the year 2004.

Years	KPI#3 SOFT-SKILLS 2004-2018 (%)	
	case-study#1	case-study#2
2004	0	0
2005	0	0
2006	0	1
2007	1	1
2008	1	1
2009	1	2
2010	1	2
2011	1	2
2012	1	2
2013	1	2
2014	1	3
2015	1	4
2016	0	5
2017	2	4
2018	1	6

Table 1. Average annual evolution of soft skills in both case studies

Analysing the average evolution of the number of qualified employees in the companies of the two case-studies, based on the year 2004, it was found that $KPI_{CS\#1\_SFT.SK.EV\_2004\text{-}2018\ (\%)}$ evolved slightly over the last 15 years. In contrast, $KPI_{CS\#2\_SFT.SK.EV\_2004\text{-}2018\ (\%)}$ increased significantly over the same period, (Figure 9).

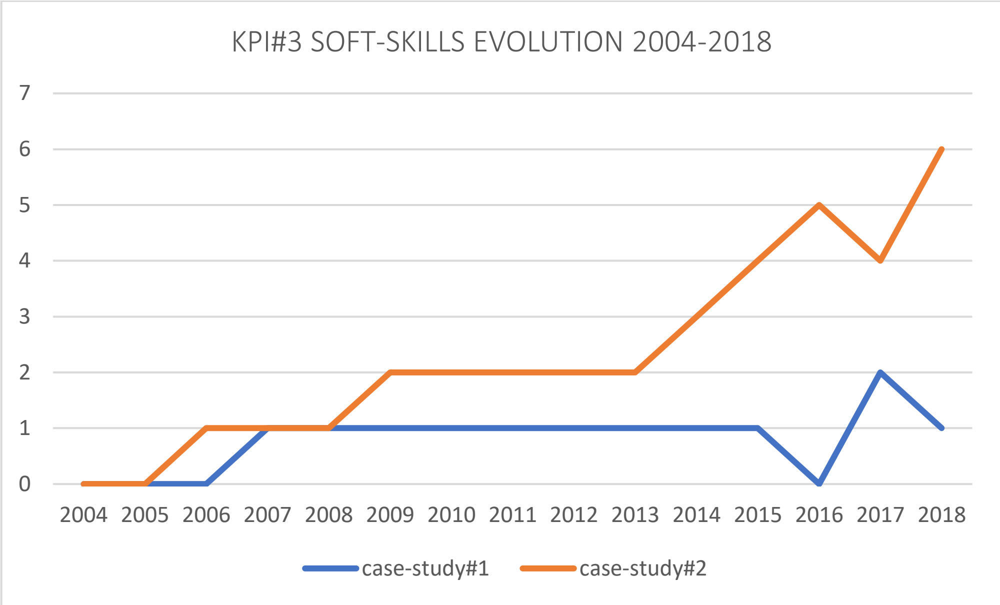

Figure 9: KPI Soft Skills Evolution 2004-2018

Based on these results, the linear evolution trend of the “soft skills” KPI (Figure 10) was determined.

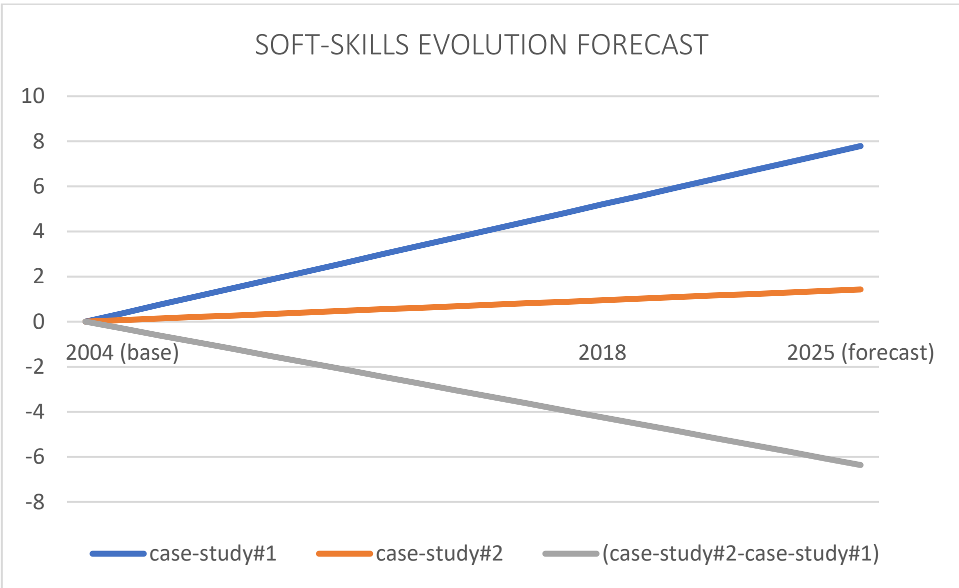

Figure 10: Soft Skills Evolution Forecast

Equation 9 | $IO_{SOFT\text{-}SKILLS\ FORECAST} = (0{,}3714x - 0{,}6381) - (0{,}0679x + 0{,}2571)$

Through the respective IO, the gap between case-study#1 and case-study#2 was forecast till the year 2025, by using a linear correlation of the data collected from 2004 to 2018 (Equation 9).

6.4. Improved Facilities

The care taken with the quality and functionality of company facilities is increasingly an indicator of the company's evolution. A modern, confident company is concerned with cleanliness, tidiness and image, both inside and outside its facilities. The data related to improving the company's premises were obtained from observations in the sampled companies and for the period 2004 to 2018. For the purpose of this research, KPI#4, concerning to facilities improvement ($KPI_{CS\#1/\#2\_RM/WST.EV}$) was evaluated according to the following levels of improvement, observed annually and described in each company's Annual Report:

(i) "great improvement" was assigned the value ($KPI\#4_{FACILITIES\ IMPROVEMENT} = 3$), (ii) "improvement" was assigned the value ($KPI\#4_{FACILITIES\ IMPROVEMENT} = 2$), (iii) " slight improvement" was assigned the value ($KPI\#4_{FACILITIES\ IMPROVEMENT} = 1$), (iv) "no improvement" was assigned the value ($KPI\#4_{FACILITIES\ IMPROVEMENT} = 0$) and (v) "disinvestment" was assigned the value ($KPI\#4_{FACILITIES\ IMPROVEMENT} = -1$), (Table 2).

Facilities Improvement	KPI#4 FACILITIES IMPROVEMENT
Great Improvement	3
Improvement	2
Slight Improvement	1
No Improvement	0
Disinvestment	-1

Table2: Facilities Improvement level

The average annual evolution of the "facilities improvement" KPI (Table 3) is presented for each case-study and based on the year 2004.

Years	KPI#4 FACILITIES IMPROVEMENT 2004-2018	
	case-study#1	case-study#2
2004	0	0
2005	0	0
2006	0	0
2007	1	0
2008	1	1
2009	1	1
2010	0	1
2011	0	2
2012	1	1
2013	2	2
2014	1	3
2015	1	2
2016	-1	3
2017	0	2
2018	-1	2

Table 3: Average Annual Evolution of the "Facilities Improvement" KPI

Analysing the average evolution of improvements to the company's facilities until 2018 and based on the year 2004, it was found that $KPI_{CASE\text{-}STUDY\#1\text{-}FACILITIES\ IMPROVEMENT\ EVOLUTION}$ from 2013 started to decrease. In contrast, $KPI_{CASE\text{-}STUDY\#2\text{-}FACILITIES\ IMPROVEMENT\ EVOLUTION}$ has continued to increase since 2004, (Figure 11).

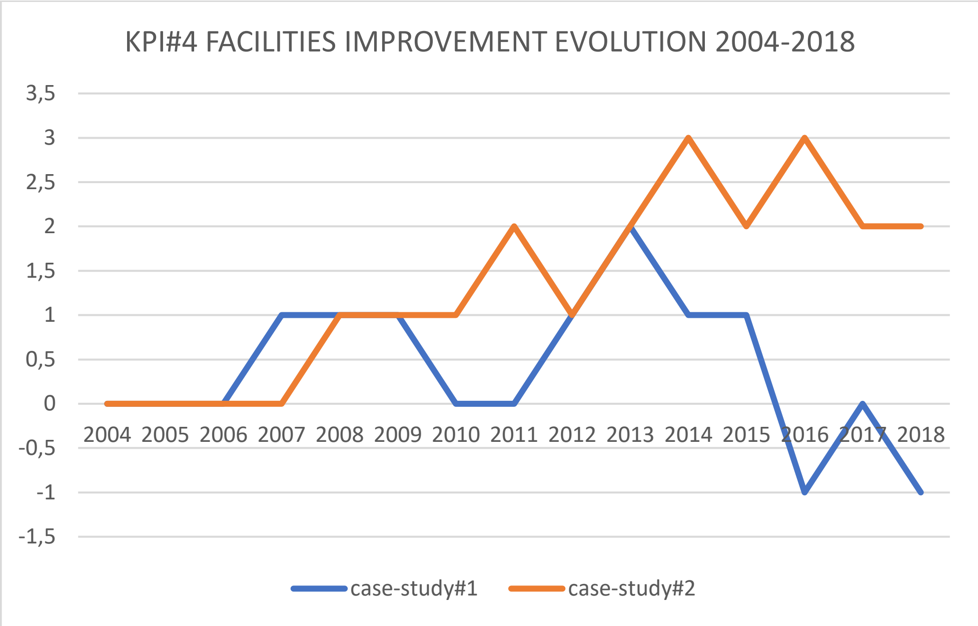

Figure 11: KPI Facilities Improvement Evolution 2004-2018

Based on these results, the linear evolution trend of the "facilities improvement" KPI (Figure 12) was determined.

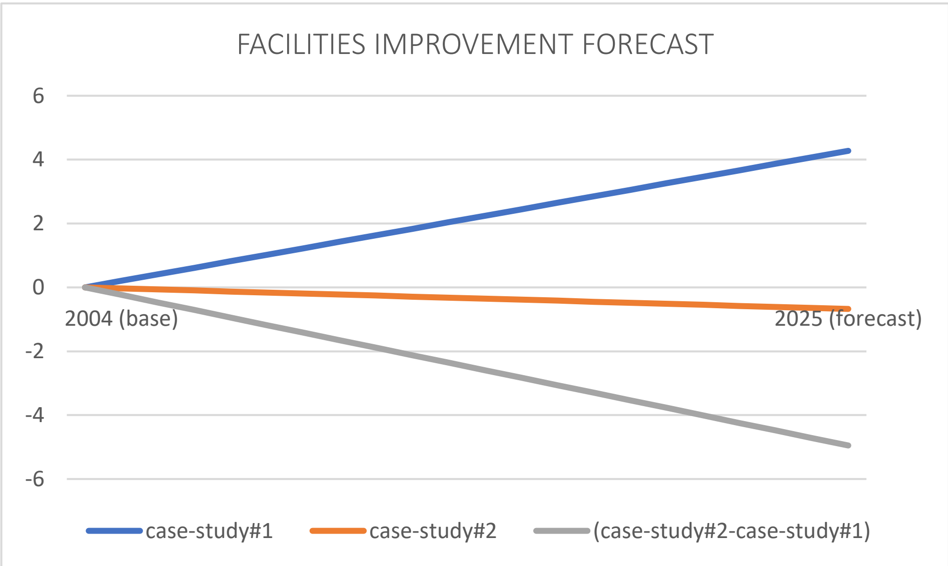

Figure 12: Facilities Improvement Evolution Forecast

Equation 10 | IO $_{\text{FACILITIES IMPROVEMENT FORECAST}}$ = (0,2036x - 0,2952) - (-0,0321x + 0,6571)

Through the respective IO, the gap between Case Study #1 and Case Study #2 was forecast till the year 2025, by using a linear correlation of the data collected from 2004 to 2018 (Equation 10).

7. Cross analysis of the Case Studies

From the Innovation outcomes for 2018, we obtain the following results:

$IO_{\text{ENERGY EFFICIENCY (2018)}}$ = Abs [(0,0643 x (2018-2004) + 0,219) - (-0,9714 x (2018-2004) + 2,8381)] = 11,88%

$IO_{\text{RAW-MATERIALS EFFICIENCY (2018)}}$ =Abs [(-0,0321 x (2018-2014) - 0,21) - (-1,2071 (2018-2014) + 5,7238)] = 10,51%

$IO_{\text{SOFT-SKILLS (2018)}}$ = Abs [(0,3714x (2018-2004) - 0,6381)- (0,0679x (2018-2004) + 0,2571)] = 3,35%

$IO_{\text{FACILITIES IMPROVEMENT (2018)}}$ = Abs [(0,2036 x (2018-2004) - 0,2952) - (-0,0321 x (2018-2004) + 0,6571)] = 2,35%

From the $IO_{\text{INDUSTRIAL EFFICIENCY AND IMAGE IMPACT}}$ = Avg ($IO_{(2018)}$) it was found that the Impact of R&D Mobilizing Projects on the company's efficiency and image of the Portuguese Ornamental Stone sector in Portugal is 7,03%

8. Conclusions

The research carried out in the sector in recent years leads to the conclusion that the positive response of Portuguese OS companies appears to be related to incorporating modern practices and technologies in their production, allowing them to offer the market custom-made products (Ines Frazao, 2016; Joana Frazao, 2016).

In this context, the following research question arose: What is the impact of R&D Mobilizing Projects on the efficiency and image of Portuguese Ornamental stone companies? The answer to this research problem was found through an empirical model and its application to case-studies: (i) case study#1 - involving a group of Portuguese Ornamental Stone companies which have participated in these projects since 2004, and (ii) case study#2, involving a group of Portuguese Ornamental Stone companies which have never participated in R&D Mobilizing Projects. The guiding research of this empirical study was based on the comparison of KPIs and Innovation Outcomes in these case-studies and in terms of (i) energy efficiency, (ii) raw material efficiency, (iii) soft skills, and (iv) improved facilities.

a) Analysing the evolution of “energy efficiency”, $KPI_{\text{CASE-STUDY\#1-ENERGY EFFICIENCY EVOLUTION 2004-2018 (\%)}}$ revealed a continuous decrease since 2004, meaning less energy consumed per product sold. This positive trend in terms of energy-efficiency found in case-stuty#1, contrasts with the stable trend in energy consumption per product sold, since $KPI_{\text{CASE-STUDY\#2-ENERGY EFFICIENCY EVOLUTION 2004-2018 (\%)}}$ has been stable since 2004. These results are in line with the forecasts resulting from the $IO_{\text{ENERGY-EFFICIENCY FORECAST.}}$ This Innovation Outcome reveals a clear gap between the forecast evolution of the case-studies, in favour of case-study#1 companies.
b) Analysing the evolution of “raw-material efficiency”, $KPI_{\text{CASE-STUDY\#1-RAW-MATERIALS-EFFICIENCY EVOLUTION 2004-2018 (\%)}}$ showed a clear annual decrease since 2004, meaning less raw-material consumed per product sold. This positive trend found in case-study#1 contrast with a stable trend found in raw material-efficiency through $KPI_{\text{CASE-STUDY\#1-RAW-MATERIALS-EFFICIENCY EVOLUTION 2004-2018 (\%).}}$ No reduction was found in the raw material consumed per product sold in case-study#1. These results are in line with the forecasts resulting from the $IO_{\text{RAW-MATERIALS-EFFICIENCY FORECAST.}}$ This Innovation Outcome shows a clear gap between the forecast evolution of the case-studies, in favour of case-study#1 companies.
c) Analysing the evolution of “Soft Skills”, $KPI_{\text{CASE-STUDY\#1-SOFT-SKILLS-EFFICIENCY EVOLUTION}}$ showed a significant increase in Soft Skills since 2004, meaning these companies have a clear notion their operations are increasingly complex, and they have greater confidence in the future. This positive trend found in case-study#1 contrasts with the negative trend of case-study#2, since the $KPI_{\text{CASE-STUDY\#1-SOFT-SKILLS-EFFICIENCY EVOLUTION}}$ indicator shows a stable trend in the same period. These results are in line with the forecasts resulting from the $IO_{\text{SOFT-SKILLS FORECAST.}}$ This Innovation Outcome shows a clear gap between the forecast evolution of the case-studies, in favour of case-study#1 companies.
d) Analysing the evolution of the KPI indexed to "facility improvement", case-study#1 has shown a significant improvement in facilities since 2004, meaning that companies have concerns about their image, reputation and employees’ working conditions, thus showing great confidence in the future. This positive trend found in case-study#1 contrasts with the negative trend in "facility improvement" in case-study#2 during the

same period. This Innovation Outcome shows a clear gap between the forecast evolution of the case-studies in favour of case-study#1 companies.

In overall, the $IO_{\text{INDUSTRIAL EFFICIENCY AND IMAGE IMPACT}}$ revealed that the impact of R&D Mobilizing Projects on company efficiency and the image of the Portuguese Ornamental Stone sector in Portugal is 9.6%.

9. Limitations and suggestions for future investigations

Although the proposed objectives have been broadly achieved, there were several difficulties to overcome during this research, which led to some limitations. In the context of this research problem, we may consider as possible future developments, dynamic analysis of the cost-benefit relationship and interpretation of the frontier conditions, related to the investment required to become a member of R&D Mobilizing Projects.

Moreover, the authors recognize the potential problems related to the use of KPIs based on the arithmetic mean and intend to make the replication of this investigation with more powerful statistical techniques.

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