Lisbon School of Economics & Management
Universidade de Lisboa

MASTER'S IN MANAGEMENT (MIM)

MASTERS FINAL WORK

DISSERTATION

The Concrete Effect on Co2 Emissions

MIGUEL ESTEVES LOPES LOURENÇO

MARCH - 2023

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Glossary

Co2 – Carbone Dioxide.

COVID 19 – Coronavirus Disease 2019.

GHG – Greenhouse Gases

ISEG – Lisbon School of Economics and Management.

PIB – Gross Domestic Product

SDG – Sustainable Development Goals

VAB – Annual Gross Value

Abstract

This thesis explores the impact of the concrete industry on Co2 emissions and examines sustainable practices to reduce this impact. The concrete industry is a major contributor to global CO2 emissions, with the production of cement, one of the crucial ingredients in concrete production, being a significant source of greenhouse gases as global demand for concrete increases, so does the need for more sustainable production practices. The study examines the current state of the concrete industry globally and in Portugal, as well as regulatory frameworks for reducing carbon dioxide emissions.

Sustainable practices for concrete production, with a specific focus on some solutions from Solidia, CarbonCure, and Secil. The findings suggest that while the concrete industry remains a significant contributor to CO2 emissions, promising developments in low-carbon clinker production and carbon capture technologies indicate a potential path toward greater sustainability. However, there are many sustainable practices being developed and implemented to reduce the industry's environmental impact.

Overall, this work highlights the importance of continued research and regulation to ensure that the concrete industry can play a role in mitigating climate change. Finally, while the concrete industry remains a significant contributor to global CO2 emissions, we are making some progress toward achieving sustainability. The industry is increasingly adopting sustainable practices, and with continued research and development, it is expected to see even more progress in reducing the industry's environmental impact in the future.

Keywords: Concrete Production; Sustainability in the Concrete Industry; Concrete Alternatives; Cement Production; Co2 Emissions.

Resumo

Esta tese explora o impacto da indústria do betão nas emissões de dióxido de carbono na indústria do betão e analisa práticas sustentáveis para reduzir esse impacto. A indústria do betão é uma das principais contribuintes para as emissões globais de CO2, sendo a produção de cimento, um dos ingredientes mais importantes na produção de betão, uma fonte significativa de gases de efeito estufa e, à medida que a procura global por betão aumenta, também aumenta a necessidade de práticas de produção mais sustentáveis. O estudo analisa o estado atual da indústria do betão a nível mundial e em Portugal, bem como os quadros regulamentares para a redução das emissões de dióxido de carbono.

Foram exploradas práticas sustentáveis para o betão e o atual panorama da indústria em Portugal, com destaque para algumas soluções da Solidia, CarbonCure e Secil. As descobertas sugerem que, embora a indústria do betão continue contribuindo significativamente para as emissões de CO2, desenvolvimentos promissores na produção de clínquer com baixo teor de carbono e tecnologias de captura de carbono indicam um caminho potencial para uma maior sustentabilidade. No entanto, existem muitas práticas sustentáveis a ser desenvolvidas e implementadas para reduzir o impacto ambiental da indústria.

No geral, este trabalho destaca a importância da pesquisa e regulamentação contínuas para garantir que a indústria do betão possa desempenhar um papel na mitigação das mudanças climáticas. Por fim, embora a indústria do betão continue a contribuir significativamente para as emissões globais de CO2, estão a ser feitos alguns progressos no sentido de alcançar a sustentabilidade. A indústria está a adotar cada vez mais práticas sustentáveis e, com pesquisa e desenvolvimento contínuos, são esperados ainda mais progressos na redução do impacto ambiental da indústria no futuro.

Palavras-chave: Produção de betão; Sustentabilidade no setor da construção; Alternativas ao betão; Produção de cimento; Emissões de Co2.

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Chapter 1 - Introduction

Sustainability has become a highly topical issue in recent years, as the negative impact of human activity on the environment and society has become increasingly apparent. The importance of transitioning to more sustainable practices across various industries is being recognized by governments, organizations, and individuals worldwide. This study aims to contribute to the ongoing discourse on sustainability by analyzing the potential for sustainable practices in the concrete industry, which is currently facing significant challenges in this regard. The research had two questions present throughout its entirety: What is the current state of Co2 emissions in the concrete industry? and What are the most sustainable alternatives in terms of reducing Co2 emissions?

The research focuses on analyzing current methods and identifying areas for improvement in terms of reducing environmental impact and promoting social and economic well-being. This study's results will offer a crucial understanding for policymakers, industry leaders, and other key stakeholders in their efforts to promote sustainability in the Concrete Industry.

This work englobes mainly 4 SDGs: SDG 7 (Affordable and Clean Energy), is related to the concrete effect on Co2 emissions, as it emphasizes the need to reduce carbon emissions from energy production and consumption; SDG 9 (Industry, Innovation, and Infrastructure) aims to build resilient and sustainable infrastructure, promote inclusive and sustainable industrialization and foster innovation; SDG 11 (Sustainable Cities and Communities) is also related to this topic as the use of concrete in urban infrastructure and construction is prevalent; SDG 13 (Climate Action) emphasizes the need for urgent action to combat climate change and its impacts.

The methodology of the developed work is based on a literature review of three main pillars: Concrete Production, Sustainability in the Concrete Industry, and Concrete Alternatives. An empirical approach is implemented using when analyzing the solutions proposed by the Portuguese company Secil and the comparison of the 3 solutions presented in the fourth chapter. I opted to not conduct any interviews as the time constraints and the limited access to suitable and relevant participants would be challenging.

Out of all the most polluting construction materials, I have chosen concrete as the focus of my research and analysis. This is because concrete is one of the most widely used materials in construction, and its production and use have a significant impact on the environment. In terms of environmental impacts. I will only refer to greenhouse gas emissions and, within these, only to Co2 emissions as there are several GHGs, not only Co2.

This thesis is structured in the following way: The second chapter of this dissertation commences with a comprehensive description of the construction industry, serving as an introduction to the chosen topic. It then proceeds to discuss why the concrete industry was selected for study, among the various industries that constitute the construction sector. Subsequently, the production process of concrete is explicated, aiming to present the underlying problem. In addition, a correlation with John Elkington's theory is conducted to comprehend the impacts of concrete production on the economic, environmental, and social dimensions. The chapter concludes with an exploration of regulations in the concrete industry.

The third chapter of this dissertation focuses on analyzing the concrete industry in Portugal and highlights the economic and environmental impacts it has on society. This section seeks to provide insights into the industry's contribution to the country's economy and the adverse effects it has on the environment.

Finally, the fourth chapter of this dissertation showcases the innovative technologies employed by three different companies to reduce their carbon dioxide emissions during the production of concrete. This chapter aims to explore various sustainable technologies that can help reduce the negative impact of concrete production on the environment.

In terms of contributions, academically, this is the first approach to this topic that can be used as a baseline for future studies. A more practical contribution is given when analyzing the regulations in place for the solutions offered by the three chosen companies. I aim to raise awareness of the environmental impact of concrete and analyze already existing solutions for reducing pollution and promoting sustainability in the concrete industry.

Chapter 2 – Methodology

Firstly, desk research and a literature review were utilized as primary methods in this study. It involved gathering and analyzing existing data, reports, and information relevant to the research topic. This method facilitated a comprehensive understanding of the subject matter and served as a foundation for subsequent analysis and interpretation. The decision to employ desk research and a literature review was based on several reasons such as being able to get an holistic and in-depth understanding of the research topic. Examining a wide range of sources, it ensured a comprehensive exploration of existing knowledge, theories, and practices in the field. Through the literature review, it was possible to identify existing research gaps and areas where further investigation was needed. This facilitated the development of research questions that addressed these gaps, contributing to the advancement of knowledge in the field. The credibility and validity aspect was also of extreme relevance as the use of reputable sources and peer-reviewed literature ensured the credibility and validity of the findings, strengthening the overall rigor of the study.

The inclusion of ESG factors in your thesis on the concrete industry and its effects on CO2 emissions is justified by its direct relevance to the sector. ESG considerations play a crucial role in assessing the sustainability and long-term impact of concrete production on the environment, society, and governance practices.

Choosing to use the triple bottom line theory from John Elkington was also a major aspect on this thesis as it allowed to sustain some of the arguments used as well as giving useful perspectives on the social, economic and, environmental ideas.

Finally, the choice to focus on Solidia Tecnologies, CarbonCure and SECIl in this research can be justified due to their significant contributions to sustainable practices within the concrete industry. These companies have demonstrated innovative approaches and technologies that address the environmental impact of concrete production.

Chapter 3 – Literature Review

This chapter presents a literature review of previous research on sustainable practices in the concrete industry. Understanding the potential for sustainable practices in the concrete industry is crucial for promoting sustainable development. Firstly, a context of the construction industry, in general, is given to understand why this is a huge concern for our planet. The literature review in this chapter aims to provide an overview of the current state of knowledge on sustainable practices in the concrete industry. This will serve as a foundation for the remainder of the study, which will focus on analyzing the potential for sustainable practices in the concrete industry and proposing solutions for implementing sustainable practices.

3.1 Construction Industry

When discussing the topic of the construction industry and its potential to reduce CO2 emissions, it is important to first provide an overview of the materials that are used and the role they play in the overall emissions profile of the construction sector (Lozano et al., 2016) (Chang et al., 2017). Construction is a major contributor to global CO2 emissions, and the materials used in construction projects can have significant environmental impacts throughout their lifecycle, including during production, transportation, and disposal (Ekincioglu et al., 2013). Therefore, choosing low-carbon materials or using materials more efficiently can be an important way to reduce the carbon footprint of construction projects (Lima et al., 2021).

It is also useful to provide some context on the current state of the construction industry and its role in global emissions. It is estimated that the construction sector is responsible for approximately 40% of global CO2 emissions, making it a significant contributor to climate change (Benhelal et al., 2020) (Ekincioglu et al., 2013). This can be attributed to a variety of factors, but the main ones are the burning of fossil fuels such as coal, natural gas, and oil for energy and transportation that release carbon dioxide into the atmosphere. According to Rocha et al. (2022) 626 kg of produced cement per capita, is higher than the amount of food consumed by a person in a year. Additionally, the manufacturing of building materials such as cement, steel, and plastic also contributes to

CO_2 emissions. The energy consumption of buildings after construction also contributes to emissions.

Out of all the most polluting construction materials, I have chosen concrete as the focus of my research and analysis. This is because concrete is one of the most widely used materials in construction, and its production has a significant impact on the environment (Hanifa et al., 2022). Concrete is a widely used building material that contributes to greenhouse gas emissions, air pollution, and water pollution (Mishra et al, 2022). The exact percentage of global CO_2 emissions caused by concrete/cement production varies depending on the sources and methods used to calculate it (Ekincioglu et al., 2013). However, it is estimated that concrete/cement production is responsible for approximately 8%-10% of global CO_2 emissions (Rocha et al., 2022) (Hanifa et al., 2022). This is due to the fact that the production of cement, one of the key ingredients in concrete, is a major source of CO_2 emissions (Hoxha et al., 2016). The production of cement releases large amounts of CO_2 through the burning of fossil fuels and the chemical reactions that occur during the production process. This is also a raising problem as, in 1990, 576 million tons of Co_2 were emitted from the global cement industry, and in 2014 this number increased by almost 4 times to 2.083 billion tons (Benheal et al., 2020).

Concrete is a key component in the construction of buildings, roads, bridges, and other infrastructure, and the process of producing and transporting concrete contributes to greenhouse gas emissions, air pollution, and water pollution (De Brito & Kurda, 2020) (Assi et al., 2018). Other aspects, such as the destruction of natural habitats and the displacement of wildlife occur as a consequence of concrete production (Escamilla, 2016). Despite these challenges, concrete is also a versatile and durable material that can be produced using sustainable methods, such as using fly ash as a replacement for cement (Shen et al., 2016).

3.1.1 The Evolution of the Industry

In this part, it is going to be discussed how the industry has grown in recent decades and how this growth has contributed to increased emissions. Another important aspect is how the type and mix of materials used in construction projects can impact emissions, as well as how the efficiency of construction processes can affect emissions.

The construction industry is one of the largest and fastest-growing industries in the world, contributing significantly to global GDP and employment (Chiang et al., 2014). Over the past few decades, the construction industry has experienced significant growth, driven by a combination of factors such as urbanization, population growth, economic development, and technological advancements (Chan et al., 2017). The construction sector has experienced significant growth in recent decades, particularly in developing countries (Ahn & Pearce, 2007). This growth has been driven by a variety of factors, such as population growth, urbanization, and economic development (Banihashemi et al., 2017) (Bui et al., 2016). India is the world's second-largest cement manufacturer and user, only topped by China, with demand estimated to reach 550-660 million tons by 2050 (Mishra et al., 2017) (Xiao et al., 2012). However, as the construction industry has grown, so have CO2 emissions, as more materials have been produced and used in construction projects, and as more energy has been consumed in the construction process.

According to Mordor Intelligence, the global construction industry is projected to grow at a CAGR of 4.2% from 2021 to 2026, reaching a value of $8.9 trillion by 2026. This growth is expected to be driven by the demand for new infrastructure, housing, and commercial buildings, particularly in emerging economies.

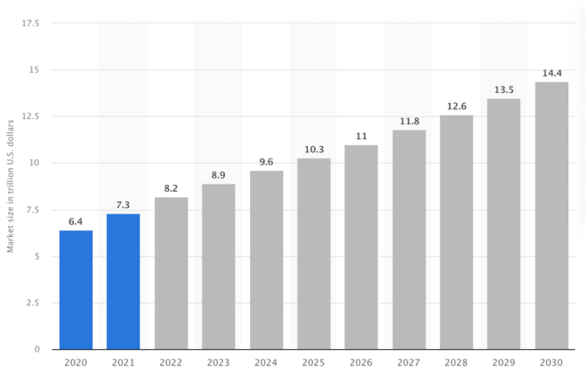
The COVID-19 pandemic has had a significant impact on the construction industry, with construction projects being delayed or canceled due to supply chain disruptions and reduced demand (Alsharef et al., 2021) (Ogunnusi et al., 2020). However, the construction industry is expected to recover, with the United States construction industry projected to grow by 4.2% in 2022 after declining by 2.5% in 2020, according to Dodge Data & Analytics (Lima et al., 2022).

One of the challenges facing the construction industry is the need to adopt more sustainable practices (Iribarren et al.,2014). The construction industry is responsible for a significant portion of global greenhouse gas emissions, and there is an increasing demand for green construction and sustainable design (De Brito & Kurda, 2020) (Assi et al., 2018). The global green construction market is projected to grow at a CAGR of 10.5% from 2021 to 2028, reaching a value of $483.2 billion by 2028, according to Fortune Business Insights. Another challenge facing the construction industry is the need to adapt to changing market conditions and technological advancements (Lima et al., 2022).

According to research by Global Market Insights, the construction market size is expected to reach $14.4 trillion in 2023 (M. S. Islam & E. J. G. Van der Sloot, 2019) (view Graphic I). This growth can be attributed to several factors:

- Increase in population and urbanization: The global population is projected to reach nearly 8.5 billion by 2030, and more than 66% of the population is expected to live in urban areas (G. McGranahan & D. Satterthwaite, 2014). This will drive the demand for housing, infrastructure, and commercial buildings, leading to an increase in construction activity.

Graphic I: Market size in trillion U.S. dollars

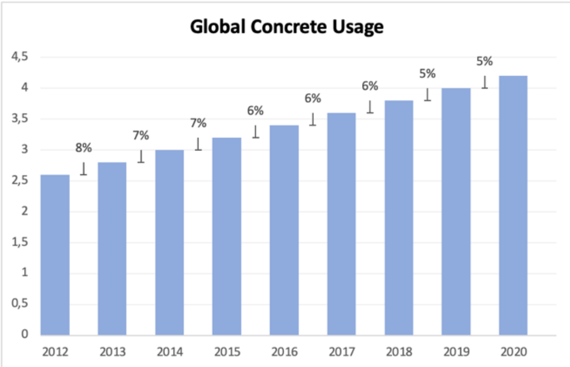


Source: Statista 2022 – Global Construction Market size

According to data from the Global Cement and Concrete Association (GCCA), between 2012 and 2020, the amount of concrete used globally increased by 1.600 billion tons.

According to the Global Cement and Concrete Association, in 2012, approximately 2.6 billion tons of concrete were used worldwide (view Graphic II). This number gradually increased over the years, reaching 3 billion tons in 2014, 3.2 billion tons in 2015, 3.4 billion tons in 2016, 3.6 billion tons in 2017, 3.8 billion tons in 2018, 4 billion tons in 2019, and reaching a peak of 4.2 billion tons in 2020 (It's worth noting that the exact amount of concrete used in these years may vary depending on the source and the method of calculation, but the Global Cement and Concrete Association is considered a reputable source in the field of cement and concrete industry).

Graphic II: Yearly global concrete usage in tons



Source: Own elaboration based on Global Cement and Concrete Association Data

In conclusion, the growth of the construction industry is expected to continue, driven by a combination of factors such as population growth, urbanization, infrastructure investments, and technological advancements. However, the industry needs to address challenges such as sustainability and technology adoption to remain competitive and meet the needs of customers and society. The construction industry is an important contributor to global GDP and employment, and it will continue to play a significant role in shaping the built environment in the years to come.

3.2 Concrete Production Method

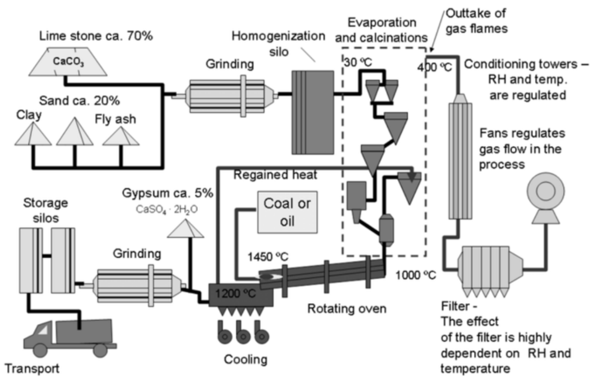
Sand, cement, gravel, and water. The most basic material that when combined create the literal foundation for so much of our modern world, is concrete. Roads, airports, houses, skyscrapers, dams the list is endless. Concrete has given rise to modern life, however, now there is increasing pressure to change the way we use and make concrete (Haneim et al., 2017). As cities warm and flood as biodiversity is reduced and as water becomes more scarce worldwide part of the blame is increasingly placed on concrete, the seemingly invisible foundation for our world (Lima et al., 2021).

The ancient Romans are believed to be the first people to use concrete in their structures. Yet the recipe was lost (Wesley et al, 1931). Attempts to recreate a version of what the Romans made were not successful until much later. While a man named Joseph Ashton Patton patented what was called Portland cement in 1824, it was his son William who had revolutionized the strength of that cement by adding clinker (burnt rocks of limestone and clay) to the process in 1843 (Shi et al., 2011) (Maltese et al., 2007). Cement which is often mistaken for the same thing as concrete, is the necessary ingredient that binds concrete together (Sutar et al., 2021). It is this cement that is binded the world's concrete for the last 200 years (Scrivener et al., 2015).

According to the United Nations, by 2050 about 68% of the world's population is expected to live in urban areas, and over 60% of the land projected to become urban by 2030 is yet to be built. As previously mentioned, concrete is basically just gravel, water, cement, and sand but the world is running out of sand. However, the world is just gobbling up more sand than the earth can create, and concrete is a major consumer (Damtoft, 2017). It is also using more water than the earth can provide. In 2012, 9% of the total global water distribution went towards the creation of concrete (Tomlinson et al., 2014).

The production of cement involves several steps (view Graphic III). Firstly, the raw materials used to make cement, such as limestone, clay, and iron ore, are mined and transported to the cement plant (Shen et al., 2016). Once at the plant, the raw materials are crushed and ground into a fine powder (Scrivener et al., 2015). This powder, called raw meal, is then blended, and heated in a kiln to a temperature of about 1400°C-1500°C, which causes chemical reactions that produce clinker (Ekincioglu et al., 2013) (Afkhami et al., 2015). According to Rocha et al. (2022) this process generates 842 kg of Co2 emissions per ton of clinker. This process causes the limestone to decompose and release CO2 as a byproduct (Liu et al., 2014). Another polluting aspect is the energy consumption required to heat the kiln, which typically uses fossil fuels such as coal, oil, or natural gas (Strunge et al., 2022). Additionally, the mining and transportation of raw materials, such as limestone and clay, can have environmental impacts such as soil erosion and deforestation (Liu et al., 2014). The use of additives and chemicals in the cement production process can also contribute to environmental pollution (Maltese et al., 2007) (Madlool et al., 2011).

Graphic III: Portland Cement line of production



<u>**Source**: Johanneson, 2012 – Portland Cement</u>

It is clear from the academic articles reviewed that concrete production is a significant contributor to global CO2 emissions, accounting for an estimated 8% of total emissions (Hanifa et al., 2022). This highlights the need for sustainable practices and innovative solutions within the concrete industry to reduce its environmental impact (Ortiz et al., 2008). One approach to achieving this is through the integration of recycled materials into the production process (Escamilla et al., 2016). Furthermore, sustainable building design and construction practices that minimize the energy consumption of buildings and promote the use of renewable energy sources can also contribute to reducing the carbon footprint of the construction industry. The construction industry has a critical role in the fight against climate change and it's important to consider the environmental impact of our built environment in every decision that we make.

3.3 John Elkington's Sustainability Theory

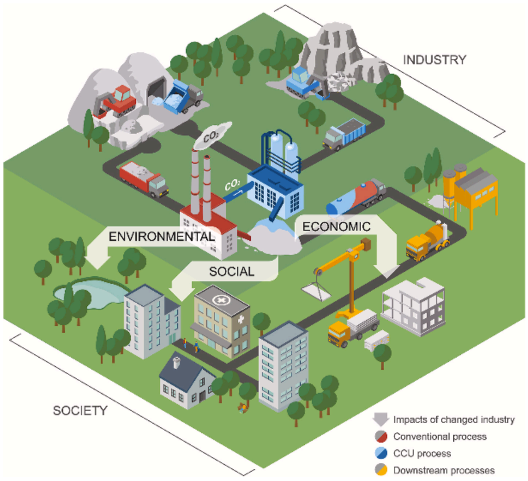
Sustainability is a term that has gained increasing attention in recent years as concerns about the environment and the future of our planet have grown. "Sustainability is the ability to meet the needs of the present without compromising the ability of future generations to meet their own needs" – Brundtland Comssion, "our Common Future" report, 1987. It is a holistic concept that encompasses economic, social, and environmental aspects (Dyllick & Rost, 2017). The construction industry has a critical role in the fight against climate change and it is important to consider the environmental impact of our built environment in every decision that we make (Lima et al., 2021). One of the most important theories to understand when it comes to sustainability is John Elkington's triple bottom line theory.

The concept of the triple bottom line, also known as the "three pillars" or "people, planet, profit," was popularized by John Elkington in 1994. Elkington, a British consultant, argued that businesses should be responsible not just for their financial performance, but also for their social and environmental impacts. The idea behind the triple bottom line is that businesses should strive to create a balance between economic, social, and environmental considerations to create a sustainable future (Russo et al., 1998). Elkington's work has had a significant influence on the business community and has helped to shape the way that companies think about sustainability and corporate responsibility.

3.3.1 Correlation between John Elkington's Sustainability Theory and Concrete Production

John Elkington's triple bottom line theory suggests that organizations should measure their performance not only in terms of financial success but also in terms of social and environmental impact (view Graphic IV). According to this theory, sustainability is not only about economic growth but also about balancing social and environmental well-being (Elkington et al, 1998). In the concrete industry, the triple bottom line theory can be applied by considering the economic, social, and environmental impacts of concrete production.

Graphic IV: Illustration of the Concrete impact of John Elkington's "three pillars" theory



Source: Till Strunge 2022: Priorities for supporting emission reduction technologies in the cement sector – A multi-criteria decision analysis of Co2 mineralization

The sustainability theory proposed by John Elkington, commonly known as the "triple bottom line," emphasizes the correlation of three pillars: environmental, social, and economic. The environmental pillar addresses the significant impact of concrete production on greenhouse gas emissions, particularly CO2, due to the high energy consumption and carbon-intensive nature of cement manufacturing. The social pillar encompasses the implications of CO2 emissions from the concrete industry on human health and well-being, considering factors such as air pollution and the potential contribution to climate change. The economic pillar considers the financial implications and economic viability of implementing sustainable practices and reducing CO2 emissions in the concrete sector. Examples such as employment can be given when analyzing both the economic and the social pillars.

3.3.1.1 Economic impact

The cost of production for the concrete industry includes the cost of raw materials, energy, and transportation (Banihashemi et al., 2017). The use of recycled materials in the production process can help to reduce the cost of production and increase the efficiency of the industry (Xiao et al., 2012). The income generated by the concrete industry includes the revenue generated by the sale of concrete products and the income generated by the industry in the form of taxes and other revenues. The concrete industry is a significant contributor to the economy, providing income and employment opportunities for a wide range of people (Poudyal & Adhikari, 2020). The job opportunities created by the concrete industry include both direct and indirect employment (Chiang et al., 2014). Direct employment includes the jobs created by the industry itself, such as those in production, transportation, and sales. Indirect employment includes jobs created by the industry in related sectors, such as those in construction and engineering.

In conclusion, the economic impact of the concrete industry is significant, as it contributes to the economy by providing income and employment opportunities. By reducing the cost of production and increasing the efficiency of the industry, the concrete industry can continue to contribute to the economy in a sustainable manner.

3.3.1.2 Social Impact

The social impact of the concrete industry refers to the impact of the industry on the health and safety of workers and the community, and the impact on the quality of life of the community.

The health and safety of workers in the concrete industry is a major concern, as the industry involves the handling of heavy equipment and exposure to hazardous materials. The industry must ensure that workers are provided with proper training, safety equipment, and a safe working environment to minimize the risk of accidents and injuries (Chiang et al., 2014). The impact of the concrete industry on the community includes the impact on air and water quality, the impact on biodiversity, and the impact on the quality of life of the community (Tomlinson et al., 2014). The industry should strive to minimize the environmental impact of its operations by using sustainable practices, such as reducing energy consumption, minimizing waste, and using recycled materials and cement (Assi et al., 2018). Additionally, the industry should engage with the local community by providing information about its operations and addressing the concerns of the community. By fostering good relationships with the local community, the industry can ensure that its operations are socially sustainable and contribute to the well-being of the community.

In conclusion, the social impact of the concrete industry is crucial, as it affects the health and safety of workers and the community. By ensuring the health and safety of workers and minimizing the environmental impact of their operations, the industry can contribute to social sustainability and improve the quality of life of the community.

3.3.1.3 Environmental impact

The environmental impact of the concrete industry refers to the impact of the industry on the natural environment, including air and water quality, biodiversity, and climate change (Damtoft et al., 2017).

The concrete industry is a major source of air pollution, as the production of cement, a key ingredient in concrete releases significant amounts of carbon dioxide (CO_2) into the atmosphere (Rocha et al., 2022). The industry can reduce its environmental impact by using alternative materials, such as fly ash or slag, which produce less CO_2 during production (Zhang et al., 2018). Additionally, the industry can also reduce its environmental impact by using renewable energy sources to power their operations. The industry also has an impact on water quality, as the production process requires large amounts of water, and the discharge of industrial waste can pollute local water sources (Tomlinson et al., 2014). The industry can reduce its environmental impact by recycling and reusing water, and by implementing proper waste management practices. The concrete industry also has an impact on biodiversity, as the extraction of raw materials and the construction of new infrastructure can result in the loss of natural habitats (Bandhavya et al., 2021). The industry can reduce its environmental impact by using sustainable materials, such as recycled concrete, and by minimizing the amount of land used for new infrastructure. Climate change is another major environmental concern that is related to the concrete industry, as the production of cement and concrete is responsible for a significant amount of CO_2 emissions (Damtoft et al., 2017). The industry can reduce its environmental impact by using sustainable materials, by using alternative energy sources, and by minimizing the use of cement and concrete.

In conclusion, the environmental impact of the concrete industry is extremely relevant, as it affects air and water quality, biodiversity, and climate change. By implementing sustainable practices, such as reducing energy consumption, minimizing waste, and using recycled materials, the industry can contribute to environmental sustainability and reduce its impact on the natural environment.

Applying the triple bottom line theory to the concrete industry can help to ensure that the industry operates in a sustainable manner by balancing economic, social, and environmental considerations.

By considering the environmental pillar of the triple bottom line, concrete companies could strive to reduce their CO_2 emissions through measures such as using alternative, low-carbon cement production methods or sourcing materials locally to minimize transportation emissions.

3.4 Regulation on the Concrete Industry

The concrete industry is a vital part of the global economy, providing income and employment opportunities for a wide range of people. However, as already stated in this study, as the industry continues to grow, it also has an increasing impact on the environment, including air and water quality, biodiversity, and climate change. To address these concerns, regulation is needed to ensure that the industry operates in a sustainable manner, balancing economic, social, and environmental considerations.

The regulation in the concrete industry is influenced by a combination of internal and external drivers. These drivers shape the development and implementation of regulatory frameworks, standards, and practices within the industry.

Some examples of the internal drivers can be: Environmental Concerns: In general, people are increasingly more concerned with sustainability; Operational Efficiency: Concrete companies may implement measures to enhance energy efficiency, waste management, and overall production processes, driven by the goal of maximizing profitability and competitiveness.

On the other hand, government regulations and stakeholder expectations can be given when discussing the external drivers. Government regulations at national, regional, and local levels are crucial external drivers that shape the concrete industry. These regulations may impose emission limits, environmental impact assessments, and waste management requirements, among others, to ensure environmental protection, public health, and adherence to sustainability standards. External stakeholders, including communities, environmental organizations, and investors, exert pressure on the concrete industry to adopt sustainable practices. Stakeholders increasingly demand transparency, accountability, and environmental responsibility, influencing the need for regulatory measures and industry practices that address their concerns and expectations.

These internal and external drivers collectively shape the regulatory landscape in the concrete industry. The interplay between these factors influences the development and implementation of regulations, standards, and practices to address environmental concerns, social responsibility, and economic viability within the sector.

Regulation in the concrete industry aims to ensure that the industry operates in an environmentally friendly and socially responsible manner, while also ensuring that the products and services provided by the industry meet the necessary quality standards. This includes setting limits on emissions, promoting the use of sustainable materials and production methods, and ensuring the health and safety of workers. Additionally, regulations also aim to ensure that the industry is transparent in its operations and that it engages with the local community. By fostering good relationships with the local community, the industry can ensure that its operations are socially sustainable and contribute to the well-being of the community.

In Europe, the concrete industry is regulated by several laws and regulations related to environmental protection, worker safety, and product quality.

One of the key regulations in Europe is the Industrial Emissions Directive (IED) 2010/75/EU. This directive sets limits on the emissions of pollutants from industrial activities, including cement and lime production. It aims to reduce the environmental impact of these activities and promote the use of the best available techniques (BATs) to minimize emissions. This includes encouraging the use of alternative materials, such as fly ash or slag, which produce less CO2 during production, and promoting the use of renewable energy sources to power the operations.

The Construction Products Regulation (CPR) 305/2011, which lays down the rules for the marketing of construction products in the European Union, including concrete products, ensures that construction products are safe, reliable, and perform as intended. This regulation promotes the use of sustainable construction materials, such as recycled concrete, in the production of concrete products and it aims to eliminate technical barriers to trade among the EU member states.

The European Union (EU) Workplace Exposure Limits (WELs): This regulation sets exposure limits for a range of substances that workers may be exposed to in the workplace, including substances found in cement and concrete. It aims to protect workers' health and safety by ensuring that exposure to these substances is kept to a minimum.

The EU Energy Efficiency Directive 2012/27/EU: This directive establishes a framework for the promotion of energy efficiency across the EU, with the aim of reducing energy consumption and greenhouse gas emissions. The concrete industry is required to implement energy-efficient measures and technologies to reduce their energy consumption.

The EU Environmental Impact Assessment Directive (EIA) 2011/92/EU: This directive requires that an environmental impact assessment is carried out for certain projects, including large-scale concrete and cement production plants. This aims to ensure that the environment.

The European Union (EU) Workplace Exposure Limits (WELs) regulation sets exposure limits for a range of substances that workers may be exposed to in the workplace, including substances found in cement and concrete. It aims to protect workers' health and safety by ensuring that exposure to these substances is kept to a minimum. This regulation is related to sustainable concrete as it promotes the use of safe and healthy production methods, which are considered to be sustainable.

In conclusion, regulation is an important aspect of the concrete industry to ensure that it operates in a sustainable manner, balancing economic, social, and environmental considerations. It helps to protect the environment and the health and safety of workers while also promoting transparency and engagement with the local community.

4. Portuguese Situation

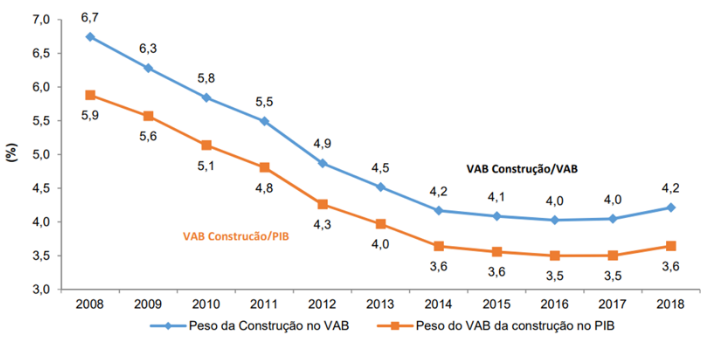
This chapter will delve into the current state of the concrete industry in Portugal, providing a comprehensive understanding of the key players, the environmental impact of the industry, and the sustainable practices being implemented. The study will give an overview of the regulations and laws in place to promote sustainable practices in the concrete industry. Additionally, it will be analyzed the current state of the construction sector in Portugal, and how its social, economic, and environmental impacts. By understanding the Portuguese situation, this chapter will provide valuable insights that will help to better understand the challenges and opportunities facing the concrete industry in Portugal, and it will also provide a framework for evaluating sustainable practices and regulations in other countries.

4.1 Portuguese Construction Industry Characterization

The construction sector in Portugal has been growing in recent years, driven by strong demand for housing and infrastructure. According to the National Institute of Statistics (INE), the construction sector in Portugal has grown by an average of 2.9% per year between 2014 and 2020, and it is expected to continue growing in the coming years. The country has experienced a large-scale housing construction boom and has been investing in infrastructure, such as transportation and energy. The construction of new housing, office buildings, and shopping centers, as well as the renovation of existing buildings, have been the main drivers of the construction sector in Portugal (Cruz et al., 2019). In addition to the traditional construction sector, there is also a growing interest in sustainable construction in Portugal (Horta & Camanho, 2014). The governments have set ambitious targets for the use of renewable energy and energy efficiency in the construction sector and have implemented policies to promote the use of sustainable materials and technologies in new buildings.

The construction sector in Portugal employs a large and diverse workforce, including skilled and unskilled workers, and it is considered as one of the main sources of employment in the country. According to the National Institute of Statistics (INE), in 2020, the construction sector employed around 300,000 people in Portugal, representing around 7% of the total workforce. The sector is characterized by a high proportion of small and medium-sized enterprises, which employ a significant number of workers. These companies are responsible for the majority of new construction projects in the country and are considered to be the backbone of the sector.

Graphic V: Weight of construction VAB on VAB's total and PIB/GDP



Source: Gabinete de estratégia e estudos: Eugénia Pereira da Costa, Catarina Leitão Afonso, Francisco Pereira & Paulo Inácio – 2020.

In conclusion, and as Graphic V shows, the concrete industry in Portugal is a vital part of the country's economy, providing income and employment opportunities for a wide range of people. When construction is at its high it can have as high as 10% contribution to Portugal's GDP. The industry plays an important role in the construction sector and is closely linked to the growth of the construction sector in the country. However, it is facing some challenges regarding environmental concerns, and it's important to implement sustainable practices to reduce its environmental impact.

4.1.1 Concrete Companies

The number of cement companies in Portugal has been growing over the years, driven by the strong demand for housing and infrastructure in the country. According to data from the National Association of Concrete Producers (ANICOP) and Empresite, the number of cement companies in Portugal has grown from around 8 in 2000 to around 430 in 2020.

There are several companies in Portugal that are in the lead for concrete production.

Cimpor: Cimpor is a Portuguese cement company founded in 1976. The company has operations in several countries, including Portugal, Brazil, Egypt, Mozambique, and South Africa. Cimpor produces a range of cement products, including ordinary Portland cement, Portland-limestone cement, and others. The company also produces aggregates, concrete, and mortars. In recent years, Cimpor has made efforts to reduce its environmental impact and has implemented sustainability initiatives, such as using alternative fuels in its production process and reducing CO_2 emissions. Cimpor has been part of the Brazilian group InterCement since 2012. This is a major player in the Portuguese cement and concrete industry, with a strong presence in the domestic market and a growing international presence. Cimpor is a subsidiary of the French company Vicat, one of the world's leading cement producers.

Secil: Is another major player in the Portuguese cement and concrete industry, with a strong presence in the domestic market and a growing international presence. Secil is a subsidiary of the German company Heidelberg Cement, one of the world's leading cement producers. SECIL (Secil - Companhia Geral de Cal e Cimento) is a Portuguese cement company based in Lisbon that was founded in 1940 and is one of the leading companies in the production and sale of cement, lime, and concrete in Portugal. SECIL is committed to sustainability and innovation, working to reduce its environmental impact, optimize its production processes, and improve the quality of its products and services. The company operates several cement and lime plants in Portugal and exports its products to several countries in Europe and Africa.

The leading cement and concrete companies in Portugal, such as Cimpor and Secil, have been implementing sustainable practices in their operations in order to reduce their environmental impact. Some of the sustainable practices that these companies have been implementing include:

Using alternative materials: Such as fly ash, slag, and recycled concrete, in their products to reduce the amount of cement and limestone used, which in turn reduces the CO2 emissions associated with the production of cement.

Investing in renewable energy: These companies have been investing in renewable energy sources, such as solar and wind power, to reduce their dependence on fossil fuels, which helps to reduce their CO2 emissions.

Implementing energy efficiency measures: These companies have been implementing energy efficiency measures, such as reducing the energy consumption of their plants and equipment, to reduce their energy costs and CO2 emissions.

Reducing water consumption: These companies have been implementing measures to reduce water consumption, such as recycling and reusing water, to reduce their water usage and help to conserve resources.

Promoting sustainable transportation: By using electric or hybrid vehicles, to reduce their transportation-related CO2 emissions.

In conclusion, these companies have been implementing a range of sustainable practices in their operations to reduce their environmental impact, such as using alternative materials, investing in renewable energy, implementing energy efficiency measures, reducing water consumption, and promoting sustainable transportation. These actions are in alignment with the regulations and laws in place in the country, aimed at promoting sustainable practices in the concrete industry.

4.2 The Concrete Footprint in Portugal

Around the world, rapid urbanization and infrastructure development have led to unprecedented increases in concrete production. Numerous regions have borne the brunt of these impacts and face significant environmental damage and problems. In this part of the work one of the most affected areas in Portugal, Arrábida, is described in order to understand the consequences resulting from raw material extraction, manufacturing processes, and subsequent ecological disruption. By examining these highly impacted regions, we can gain a deeper understanding of the urgent need for sustainable practices in the concrete industry and the importance of mitigating the environmental damage caused by concrete production.

The expansion of the concrete industry has led to negative impacts on the environment and on the local communities. There are several areas in Portugal affected by the industry, however, the one most affected is the Arrábida area (Branquinho et al., 2007). The Arrábida area in Portugal is a natural reserve that is known for its unique biodiversity, cultural heritage, and stunning landscapes (Schrittenlocher et al., 1997). However, the area has been facing significant environmental problems due to the expansion of the concrete industry in the region.

The dust generated by the quarries and the noise generated by the plants and the heavy vehicles used in the transportation of the materials are some of the major concerns for the residents and the visitors. The expansion of the concrete industry in the Arrábida area has also led to the destruction of natural habitats and the displacement of wildlife. According to Catarina Almeida Pereira (2016), the destruction of the natural habitats, along with the pollution of the water and air, has severely impacted the biodiversity of the area, putting at risk many species of plants and animals. Additionally, there are concerns that the expansion of the concrete industry in the Arrábida area is also damaging the cultural heritage of the region, which is home to several historical and architectural sites that are of great significance to the local community and the country.

In conclusion, the Arrábida area in Portugal is facing significant environmental problems due to the expansion of the concrete industry in the region. The industry has an impact on biodiversity, and it also threatens the natural habitats and the cultural heritage of the area.

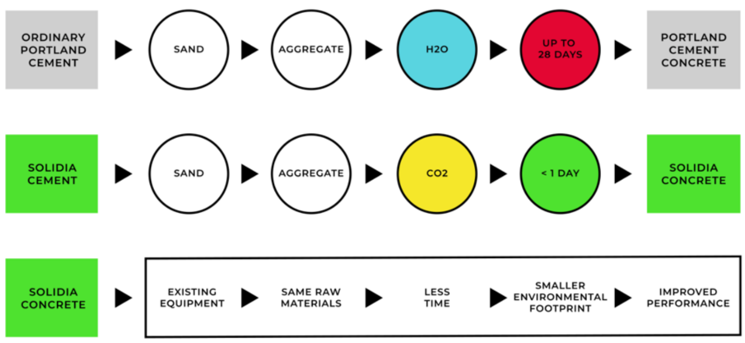
5. Solutions

As previously described, concrete is a critical building material that is used in construction projects around the world. However, the production of traditional concrete is a major source of greenhouse gas emissions, which contributes to global climate change. To address this challenge, several companies have developed innovative solutions that make concrete more sustainable, reducing its carbon footprint and helping to mitigate the impacts of climate change. This chapter looks at the technologies of three companies to make concrete greener. These solutions range from low-carbon cement to carbon-negative concrete, and they all share the goal of reducing the environmental impact of concrete production. Some of these solutions incorporate new technologies and processes, while others focus on reducing the energy consumption and emissions of existing concrete production methods. Regardless of the approach, these solutions offer a promising path forward for a more sustainable future for concrete and the built environment.

5.1 Solidia

One company working to reduce the carbon footprint of cement is New-Jersey based startup, Solidia technologies. Solidia is a company that specializes in sustainable concrete technology. They use a patented process to reduce the carbon footprint of cement production by up to 70% (Meyer et al., 2017). This is achieved by using CO2 captured from industrial sources, rather than the traditional method of using limestone. "Solidia takes exactly the same raw materials, but we change the recipe a little bit we mix it about 50%-50%, and that reaction happens at a much lower temperature about 1200 degrees Celsius" - Tom Schuler, President, and CEO of Solidia Technologies. What that means to the cement company is instead of emitting one ton of CO2 for every ton of cement they emit about 40% less. Solida uses 30% less energy to make that same amount of cement (Meyer et al., 2019). "This then means that Cement makers also get more cement with the same amount of raw materials." - Tom Schuler, President, and CEO of Solidia Technologies. The company also produces concrete that is stronger and more durable than traditional concrete and has a lower water and energy consumption (Sahu & Meininger, 2020). The process begins by mixing traditional cement ingredients, such as limestone and clay, with a small amount of water. The mixture is then heated to a high temperature to create a clinker, which is ground into a powder (Meyer et al., 2019). The powder is then mixed with a small amount of water and carbon dioxide, and the mixture is poured into a mold. The mold is then sealed and pressurized with carbon dioxide to cure the concrete (Meyer et al., 2019). Reacting with CO2 that the company injects into a drying chamber instead of water. This is another aspect Solidia helps with, water conservation (view Table VI). According to the International Cement Review, the production of 1 ton of cement requires approximately 130-150 liters of water.

Graphic VI: Difference example between Solida Cement and Ordinary Portland Cement



Source: Solidia 2023

As the cement hardens the CO_2 becomes trapped in the final concrete product (view Table VI). The use of carbon dioxide in the curing process has several benefits. First, it reduces the amount of water needed to cure the concrete, which in turn reduces the energy required to heat and pump the water (Sahu & Meininger, 2020). Second, it captures and sequesters the carbon dioxide used in the curing process, which helps to reduce greenhouse gas emissions. Third, it produces concrete that is stronger and more durable than traditional concrete. "When we make Solidia cement, we are cutting the CO_2 emissions at least by 30% and when we cure Solidia cement, to make the concrete, we add an additional 20-30% of CO_2 to be consumed during curing so this adds up to 50-60% and depending on the formulations our CO_2 savings can go up to 70% (Meyer et al., 2017)" – Tom Schuler, President and CEO of Solidia Technologies.

Solidia technologies also says its product makes financial sense. "We actually find that both on the cement side and the concrete side if you use our technology, you actually end up saving money." Most of the cost associated with manufacturing cement is in the energy used and Solidia claims they can reduce that by about 30%. Another differentiating factor, it's the ability to process it more rapidly, instead of curing it in two weeks, like normal concrete, it takes Solidia 24 hours so it's a lot easier to get it out in the market so in the end the industry can save significant amounts of money (Makul et al., 2020).

5.2 CarbonCure

CarbonCure Technologies is a Canadian company that developed a technology to reduce the carbon footprint of concrete production by injecting captured carbon dioxide (CO_2) into the concrete mixture (Bandhavya et al., 2021). The company's technology is based on an industrial process called carbon mineralization, which involves capturing CO_2 from industrial sources, such as power plants or natural gas processing facilities, and then injecting it into the concrete mix (Fennel et al., 2022) (Maries et al., 2019). The CO_2 reacts with calcium ions in the mix to form calcium carbonate, a mineral that is already present in many types of concrete (Wagner & Monkman 2021).

This process helps to improve the strength and durability of the concrete while also reducing the amount of CO_2 emissions released into the atmosphere (Fennel et al., 2022).

The Co2 emissions are lower this way due to the fact that less cement is needed to strength the concrete, which intern leads to less cost (Bandhavya et al., 2021). This also leads to the usage of less water (Fennel et al., 2022). The company claims that its technology can reduce the carbon footprint of concrete production by up to 500 kg (30%) of CO2 per cubic meter of concrete. Every cubic yard of concrete produced with the carbon cure technology saves an average of 25 pounds of CO2 emissions from entering the atmosphere. For example, an average high-rise building built with carbon cure would save approximately 1.5 million pounds of CO2 emissions which is equivalent to the carbon absorbed by 888 acres of forest in a year.

Additionally, CarbonCure Technologies has been recognized for its innovative approach to sustainability and has received numerous awards and accolades, including the prestigious Carbon Trust Standard for Carbon Reduction and also being named one of the World Economic Forum's Technology Pioneers in 2019.

The company also claims that the technology can reduce the cost of concrete production, making it more accessible for small and medium-sized companies. The cost of CarbonCure concrete compared to traditional concrete can vary depending on a few factors, such as the location of the project, the type of concrete being used, and the specific application. According to CarbonCure, the cost of their technology is about $15 to $30 per metric ton of concrete. The cost of CarbonCure concrete is expected to decrease over time as the technology becomes more widely adopted and economies of scale are achieved.

Finally, CarbonCure’s concrete may have a slightly higher price point than traditional concrete, it offers many benefits such as reducing the carbon footprint of concrete production and improving the strength and durability of the concrete. This can make it a more cost-effective option in the long run. Also, in some cases, CarbonCure's concrete can be cheaper than traditional concrete when the cost of carbon credits is included.

5.3 Secil

As there are several cement companies operating in Portugal, it is important to select a specific one to analyze in depth. Secil is one of the leading cement manufacturers in Portugal, and their commitment to reducing carbon emissions and promoting sustainable development aligns with the growing global demand for more environmentally friendly production methods. For this purpose, I have chosen to focus on Secil due to their approaches to sustainability and environmental responsibility in the production of cement. Another important reason I chose to focus on Secil was that, according to them, they have the first carbon-neutral concrete in Portugal.

Currently, Secil has a goal of being carbon neutral by 2050 and to get reach that goal they have developed 3 projects: Clean Cement Line, Low Carbon Clinker and Verdi Zero.

5.3.1 Secil – Verdi Zero

According to Secil (2023), "Verdi Zero is a sustainable concrete product developed by Secil that aims to reduce the environmental impact of traditional concrete". This is the first Carbon Neutral Concrete in Portugal, which was based on Secil innovation in terms of product development, complementing internal efficiency measures and the use of renewable energy, guaranteeing, right from the start, an important reduction in CO2 emissions. In its composition, raw materials were used that promote the circular economy, through the incorporation of recycled waste, assuming a lower use of natural resources.Verdi Zero, is certified as a CarbonNeutral® product by Climate Impact Partners, in accordance with the CarbonNeutral Protocol, which is the world's leading framework for carbon neutrality. This is achieved by compensating for remaining emissions through projects to reduce external emissions and ensuring that, for each ton of CO2 emitted by Concrete Verdi Zero, there is one ton less in the atmosphere.

"The "Verdi Zero" concrete contains 24% recycled waste in its composition." Additionally, it incorporates recycled materials such as fly ash, a by-product of coal-fired power plants, as well as industrial by-products such as slag, which are waste materials that would otherwise be discarded. Verde Concrete is also designed to have a longer lifespan, reducing the need for frequent replacements, and it can be recycled at the end of its useful life. This product is one of the initiatives developed by Secil to reduce the environmental impact of the concrete industry.

5.3.2 Secil – Low Carbon Clinker

Secil's Low Carbon Clinker Project aims to reduce the carbon footprint of cement production by replacing a portion of the traditional clinker, which is responsible for a significant amount of CO2 emissions, with a low-carbon alternative. The project involves using a type of clinker that contains industrial residues and by-products, which are generated by other industries and would otherwise go to waste. This alternative material has a lower carbon footprint compared to traditional clinker and can help reduce the overall carbon emissions associated with cement production. The Low Carbon Clinker Project is part of Secil's broader efforts to promote sustainability and reduce the environmental impact of its operations.

According to Secil (2023), "The low-carbon clinker is intended to develop a low-carbon clinker by changing its mineralogy and reducing CO2 emissions by about 15% compared to current emissions." For this purpose, it is necessary to develop a new grid cooler that modifies the current satellites of line 9 of Secil Outão. This new technology allows the co-processing of silicate materials, which can be natural or come from residues with latent hydraulics that have the potential for thermal activation. The improvement of the cooling conditions of the clinker, which occurs through a thermal exchange with the material at room temperature, increases production without additional consumption of fuel or a special material.
With the production of this new low-carbon clinker, a new range of cement is developed that minimizes the negative impact on product performance. The production of a new range of products with the lowest environmental footprint through the co-processing of clay-based materials or silicates silico-aluminous waste responds to the needs of a more circular economy.

5.3.3 Secil – Clean Cement Line

According to Secil (2023), "The objective of the Clean Cement Line is to develop and demonstrate a new cement manufacturing technology. This project includes four R&D subprojects aimed at eliminating dependence on fossil fuels, increasing energy efficiency, self-generating electricity, integrating with the digitalization process, and reducing CO_2 emissions." These innovations will promote the development of low-carbon clinker production and consequently the production of a range of cements with a low environmental footprint.

This project has the following benefits: 20% reduction of Co2 emissions, 20% reduction of thermal energy consumption and 30% own production of electricity.
The project started on January 1st, 2019, and was approved on February 3rd, 2020, and had an initial investment of 86.339.791,77€. It is expected to be concluded by August 8, 2023. This project had a cost of 37.311.932,22€ of which 14.924.772,89€ was financed by the European Union through FEDER.

In Graphic VII, it is possible to understand the flow of Secil's Cement Clean Production Line, and their efforts to make every station, that their cement has to go through, sustainable, through renewable energies.

Graphic VII: Secil Clean Cement Production line

Source: Secil 2023

5.4 Solutions Comparison

While Secil, CarbonCure, and Solidia Technologies share a common goal of making concrete more sustainable, there are several factors that differentiate them from one another.

1. EcoCement vs Carbon Injection: Secil's EcoCement is a low-carbon cement that uses supplementary cementitious materials to reduce carbon emissions. In contrast, CarbonCure's technology injects carbon dioxide into the concrete mix during the mixing process to create stronger and more sustainable concrete.
2. Carbon Sequestration: CarbonCure and Solidia Technologies both have the ability to permanently sequester carbon in the concrete. CarbonCure injects CO2 into the concrete, which reacts with calcium ions to form calcium carbonate, while Solidia's carbonation curing process also forms calcium carbonate in the concrete.
3. Applications: While all three companies have developed sustainable solutions for concrete production, their focus and applications differ. Secil's EcoCement is primarily used for high-performance applications, while CarbonCure has been used in a variety of construction projects, including commercial buildings and infrastructure. Solidia's technology has been used for precast concrete, paving stones, and roof tiles.

In conclusion, while all three companies share a common goal of making concrete more sustainable, their technologies and applications differ, and each company has its own unique differentiating factors that set it apart from the others. In summary, the quicker way to reduce concrete Co2 emissions is to adopt product technologies like, CarbonCure's, Secil's, and Solidia's, as ready-mixed concrete products, have a broader utilization, therefore, are easier to be implemented. The Grapfic VIII clearly demonstrate the advantages and disadvantes of each company.

Graphic VIII: Solutions Evaluation

	Greener	Water Usage	Recycled Content	Cost - Efficiency	Durability	Scalability
SOLIDIA	++	++	O	++	++	+
CARBON CURE	++	++	O	++	++	O
SECIL	++	+	++	−	+	+

++ Very Strong
+ Strong
O Neutral
− Weak
−− Very Weak

Lastly, there is other solutions to help reduce Co2 emissions during concrete production. One of them would be the usage of recycled concrete. Recycled concrete is a sustainable alternative to traditional concrete made with virgin materials. It involves using crushed concrete as a replacement for traditional aggregates, reducing waste, and minimizing the need for new resources (Shi et al., 2016).
Recycled concrete can be used for a variety of construction projects, including roadways, building foundations, and drainage structures. It has several benefits, including reduced environmental impact, lower costs, and improved durability. According to Sousa et al. (2021), "in a conservative scenario, the estimated carbon dioxide emissions from recycled cement was as low. As 58%-74% of the clinker production".

In addition to using recycled concrete as an aggregate, it can also be used as a replacement for cement in the production of new concrete, further reducing the use of virgin materials.

6. Conclusion

It was stated in this dissertation that the production of concrete has an 8% yearly impact on Co2 emissions. With the growing awareness of the negative effects of carbon emissions on the environment, it is imperative that the construction industry takes proactive measures to reduce its carbon footprint.

The solutions proposed by Secil, CarbonCure, and Solidia Technologies offer promising and sustainable solutions for the concrete industry. These companies have found innovative ways to reduce the environmental impact of concrete production. Moreover, the solutions provided by these companies not only help to reduce carbon emissions but also offer additional benefits, such as increased strength and durability, water conservation, and reduced waste. As such, the concrete industry can benefit from incorporating these sustainable technologies into its production processes. From low-carbon cement to carbon injection technology and carbonation curing processes, these solutions offer promising benefits that go beyond just reducing carbon emissions. They also conserve resources, increase strength and durability, and reduce waste.

In addition to the efforts made by companies to reduce carbon emissions in the production of concrete, government regulations and policies can also play a significant role in promoting sustainability in the construction industry. Many countries around the world have already implemented regulations that require the use of low-carbon cement or mandate carbon reduction targets in the construction industry.

These regulations not only encourage companies to adopt sustainable practices but also create a level playing field where all companies are held accountable for their environmental impact. With continued efforts from both the private and public sectors, we can work towards a more sustainable future for the construction industry and reduce the negative impact of carbon emissions on our environment.

Overall, this work enabled to establish that people, in general, should be extremely concerned with the issue of sustainability in the Construction Industry, particularly in the

Concrete aspect. However, it is uncertain if constructors in general would be interested in making the changes to ensure the sustainability of the sector.

Another aspect worth mentioning is the inclusion of parameters such as climate neutrality, clean energy transition and protection of biodiversity and nature in the European Green Deal. The European Green Deal is a comprehensive and ambitious roadmap from the European Commission that aims to make Europe the world's first climate-neutral continent by 2050. Regarding climate neutrality: the main objective of the European Green Deal is to achieve climate neutrality by 2050, i.e., to offset greenhouse gas emissions through greenhouse gas removals or offsets. This goal includes reducing greenhouse gas emissions in all sectors, including energy, industry, transport, agriculture and buildings. Regarding the clean energy transition: the Green Deal aims to accelerate the transition to a clean energy system by increasing the share of renewable energy sources, improving energy efficiency, and promoting the use of innovative clean technologies. It includes initiatives to support renewable energy generation, enhance energy storage and interconnection, and promote sustainable and efficient use of energy. Lastly, in terms of biodiversity and nature protection: Protecting and restoring biodiversity is another crucial objective of the European Green Deal. It aims to halt the loss of biodiversity and ecosystem degradation through various measures, including the implementation of nature restoration plans, sustainable agriculture practices, and the development of protected areas.

The Concrete Industry will have to reduce CO2 emissions, while demand for concrete is predicted to rise. Despite the significant problems that the industry faces, the report clearly reveals that the required actions are being done to move the industry toward a low-carbon future. Without CO2 capture and accompanying infrastructure to transport and replace CO2, no meaningful reduction in CO2 emissions from cement manufacturing is achievable. As a result, the concrete industry has placed a significant emphasis on the development of technological applications.

For future research, it would be advisable to conduct studies that are both closer to the end consumer and to the concrete companies to understand the real demand that there is in the market for products like the ones mentioned. A life cycle assessment could also be an additional approach for future research as it would enable to acquire deeper knowledge on the full cycle impacts of concrete. This thesis provided insights into existing policies and regulations, however, future research can examine the effectiveness of these policies and explore potential policy interventions to further incentivize the adoption of sustainable concrete practices.

In conclusion, the development and implementation of sustainable concrete production technologies are crucial to reducing the environmental impact of the construction industry. As the construction industry continues to grow and develop, the use of these sustainable technologies will become increasingly important in reducing carbon emissions and mitigating the negative effects of climate change.

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