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Greening the Cement Industry in Egypt: Exploring Decarbonisation Policies for the Cement Industry

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Greening the Cement Industry in Egypt: Exploring Decarbonisation Policies for the Cement Industry

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List of Acronyms

2DS	2-degree Celsius Scenario
AFR	Alternative fuels and raw materials
B2DS	Beyond 2-degree Celsius Scenario
BAP	Best Available Practice
BAT	Best Available Technology
BTIA	Building Technical Inspection Agency
BTIA	Building Technical Inspection Agency
CACS	Carbonation of calcium silicates
CBE	Central bank of Egypt
CCS	Carbon capture and storage
CCU	Carbon capture and utilization
CO2	Carbon dioxide
COP	Conference of the parties
CSI	Cement Sustainability Initiative
DSS	Dried sewage sludge
EBRD	European Bank for Reconstruction and Development
ECA	Egyptian competition authority
EEAA	Egyptian Environmental Affairs Agency
EFCBC	Egyptian Federation for Construction and Building Contractors
EHR	Excess heat recovery
EOS	Egyptian Organization for Standardization and Quality
ESG	Environmental, social and governance
ETC	Energy Transition Committee
ETS	Emission Trading System
EU	European Union
FOB	Fee on board
GHG	Greenhouse gasses
GNR	Getting the numbers right
IDA	Industrial Development Authority
IEA	International Energy Agency
IFC	International Finance Corporation
IPCC	Intergovernmental panel on climate change
MRV	Measurement/Monitoring, reporting and verification

MSW	Municipal solid waste
NAMA	Nationally Appropriate Mitigation Actions
NDC	Nationally Determined Contribution
R&D	Research and development
RDF	Refuse Derived Fuels
RTS	Reference Technology Scenario
SRI	Sustainable Resource Initiative
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
USD	United states dollar
WBCSD	WBCSD World Business Council for Sustainable Development
WHR	Waste heat recovery
WMRA	Waste Management Regulatory Authority

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Abstract

The cement industry is a major contributor to global greenhouse gas emissions, accounting for approximately 7% of carbon dioxide (CO_2) emissions. Cement is the most consumed material on earth, second only to water, and its demand is fueled by continuous urbanization and the lack of alternative materials. In Egypt, the cement sector is responsible for 14% of CO_2 emissions, emitting over 800 kilograms of CO_2 per ton of cement, surpassing the global average of 600. In 2016, Egypt ratified the Paris agreement to address climate change and has committed in its National Determined Contributions (NDC) to reduce CO_2 emissions. However, progress towards reducing CO_2 emissions in the cement industry has been unguided and slow. This study thus investigates the potential for a green transition in Egypt's cement industry. The study aims to identify barriers to transition, explore opportunities, and propose policy changes to accelerate the reduction of carbon emissions in cement. Utilizing a qualitative approach, this research combines in-depth interviews with experts and senior executives along with content analysis of literature and industry reports to assess the current state of Egypt's cement industry and its current decarbonisation policies. Interviews with experts highlight the presence of significant challenges such as the absence of carbon policies that can provide appropriate incentives and penalties, in addition to financing difficulties. The study highlights several opportunities for reducing carbon emissions, including the utilization of alternative fuels and raw materials, the implementation of more efficient production processes and utilization of renewable energy sources. The research explores the potential for sizable CO_2 reductions in the cement industry while creating a market for waste management and utilization, as well as renewable energy sources. Finally, policy recommendations are provided for industry stakeholders to address needed carbon reforms and invites further research in the areas of cement demand and waste management value chains.

1. Chapter One: Introduction

1.1. Decarbonizing the Global Cement Industry

In 2015, the United Nations introduced their 2030 agenda for Sustainable Development, which emphasized in its 13th goal, the urgent action to combat climate change and its consequences. At the end of the same year, global leaders came together to sign the Paris Agreement in 2016, during the 21st session of the Conference of the Parties to the United Nations Framework Convention on Climate Change. This landmark agreement aimed to limit the rise in worldwide temperatures to below 2°C above pre-industrial levels (IEA, 2018).

Alongside these developments, many nations established their own Nationally Determined Contributions (NDCs), setting self-governed targets for greenhouse gas emissions reduction. Notable examples include the US, committing to reduce emissions by 50% to pre-2005 levels by 2030, the EU aiming for a 40% reduction in emissions below 1990 levels by 2030, and China pledging to reach peak emissions by 2030 and achieve carbon neutrality by 2060 (IEA, 2018).

These NDCs were shaped by two significant developments in recent years. First, an increase in the frequency and severity of extreme weather events, such as heatwaves, hurricanes, and wildfires, has been observed globally. Notable occurrences include the devastating wildfires in Australia during 2019-2020, the record-breaking heatwave in the Pacific Northwest in June 2021, and the deadly floods in Pakistan in 2022 (Clarke et al., 2022). Secondly, there has been increasing pressure from investors in heavy carbon companies for more reporting on environmental footprint, and roadmaps to lower emissions to ensure sustainability, although with limited efficacy so far (Baines & Hager, 2023).

Consequently, sustainable, and responsible investing has witnessed significant growth, incorporating environmental, social, and governance (ESG) factors into investment decisions. In 2020, the global market for sustainable investing reached an estimated $35.3 trillion, representing a 15% increase from the previous year. Moreover, investors are increasingly urging companies to address climate change and provide more information about their climate-related risks and opportunities, leading to a rising trend of companies setting their climate targets and disclosing their progress (Deloitte, 2023).

After the Paris agreement in 2016, the Intergovernmental Panel on Climate Change (IPCC), the foremost international authority on climate change, released several reports monitoring the progress towards achieving the NDCs. In 2021, the IPCC released a pivotal report indicating a global lag to

reach the NDCs, stressing the necessity for countries to accelerate their efforts to realize their carbon emissions' reduction target (IPCC, 2021.)

As cement production is responsible for 7-8 % of carbon emissions, several countries have started to explore ways of decarbonization for their cement industry. The global production and consumption of cement is not uniform, with China and other Asian countries producing more than 80% (IEA, 2018). It is important to highlight that cement is a decentralized industry because it relies on locally available raw materials, such as limestone, clay, and sand, which vary in quality and composition from one region to another. In addition, cement production also varies widely between regions based on infrastructure needs, urbanization levels, and availability of raw materials, among others. For example, in China the cement production per capita in China is 1818 kilograms of cement, compared to around 600 kg per capita globally. In the Middle East it is close to 827 kilograms of cement per capita (IEA, 2018). This indicates that policies to decarbonize cement industry will need to be tailored to region or country specific characteristics.

Lastly, cement is considered one of the hardest industries to decarbonize due to the fact that the biggest portion of CO_2 emissions from cement comes from chemical reactions in the production process that are not possible to change (IEA, 2018). Cement production is a three-stage process, the first stage is extracting the main ingredient, limestone from quarries (Busch et al., 2022). The next stage involves mixing limestone and other additives to form a material called clinker. This is done through a chemical reaction that results in decomposition of limestone $CaCO_3$ into Lime (CaO) and Carbon Dioxide CO_2. This material, clinker, which constitutes on average 80% of what cement is made of, is then mixed with other additives to form cement (ETC, 2020). This process is called calcination, and it is where most of the CO_2 emissions in the cement production comes from. This is because the chemical reaction in this process results in the releasing of CO_2, but also because to make this process happen, there is a lot of heat required. This heat comes from burning of fossil fuels to reach temperatures typically in the range of 1,400 to 1,500 degrees Celsius (Monteiro et al., 2017).

The other source of CO_2 in the production process of cement is usually referred to as "indirect emissions", and this includes the CO_2 emissions from the electricity used, the logistics and transportation, among others. Indirect emissions are responsible for about 10% of the CO_2 emissions in the cement industry, while the other 90% is released by the calcination process, and the burning of fuels (Monteiro et al., 2017). These figures are based on global averages, so it should be noted

that certain local factors can influence the ability of cement plants to reduce their carbon footprint including the availability of different raw materials, or other alternative fuels (Busch et al., 2022).

1.2. Sustained cement demand through 2050

Cement is the primary ingredient in concrete and holds the distinction of being the second most consumed material globally, behind water (McKinsey, 2020). Considering the ongoing trends of urbanization and the increasing need for infrastructure, the demand for cement is projected to rise significantly by approximately 12-20% until the year 2050 (IEA, 2018). However, the cement industry is a significant contributor to greenhouse gas emissions, accounting for approximately 7% of global carbon dioxide emissions. Each ton of cement production results in an equivalent of 600 kilograms of Co2 (IEA, 2018). There is a growing need for change in the cement industry as countries across the world are scrambling to reduce their carbon footprint while shifting their focus towards heavy industries that are heavy carbon emitters.

This in turn has put pressure on global leaders of heavy industry sectors as investors and shareholders are in turn pushing for corporates to transition to more sustainable practices considering increased carbon pricing policies (Rissman et al., 2020). For example, the CSI, Cement Sustainability Initiative, which was founded in 1999 and brings together 24 major cement producers in 100 different countries, have recently published a Low Carbon Roadmap in partnership with the International Energy Agency (IEA) with a plan to reduce carbon emissions in line with the 2 Degrees Scenario (2DS). The 2 Degrees Scenario was developed by the International Energy Agency (IEA) to describe a future pathway for the energy system that is consistent with limiting global warming to below 2 degrees Celsius above pre-industrial levels, as agreed upon in the Paris Agreement. The roadmap assumes ambitious deployment of carbon reduction technologies in the cement industry, but it also sets out an expectation for a high level of international cooperation and policy support towards encouraging low-carbon cement (IEA, 2018). Other heavy industries including iron & steel, chemicals, and plastics are also under the same pressures to decarbonize, with varying degrees of difference when it comes to availability of substitutes. However, the one of the shared factors is the sustained demand for cement and other heavy industry products, which makes policies and actions to reduce emissions even more critical (Rissman et al., 2020)

1.3. The Egyptian Cement Industry's Carbon Footprint

The cement industry is one of the oldest industries in Egypt, with the first plant established in 1927 in Cairo (Askar, 2010). Historically, the industry has been one of the drivers for economic development and urbanization, with the first cement plants built along the Nile River to transport cement across the country (Askar, 2010).

As per latest figures, the cement industry contributes to around 3.7% of GDP and is providing jobs for 50,000 directly, and an estimated 200,000 indirectly (Abdou, 2017). Cement is also a major contributor to the construction and real-estate sectors which represent close to 40% of Egypt's national economy. However, the cement industry also has a heavy environmental impact, with 5.3% consumption of total energy in Egypt, and approximately 14% share of Egypt's CO_2 emissions, which is double the global average (EBRD, 2016, p. 10)

In Egypt, the cement industry has recently received much criticism after cement companies lobbied to allow the importing and use of coal in Egypt after the natural gas shortage in 2016 (Global Cement, 2015). Critics argued this will only add to the already heavy carbon footprint of cement production. The Egyptian cement industry also compares unfavorably to other regions in terms of carbon emissions. For example, the average CO_2 emissions per tons of cement produced were 0.62 (620 kilograms) as of 2019, while in Egypt, the reported average was 0.75 (750 kilograms) tons of CO_2 per ton of cement produced (IEA, 2018). It is important to note the actual number for Egypt might be much higher as indicated by the 'Getting Numbers Right' (GNR) database (GNR, 2020).

The differences in cement footprint are due to variances in cement production capabilities and maturity of sustainable practices across different regions (Rissman et al., 2020). Accordingly, the transition to low-carbon cement production will vary based on the available infrastructure, technology, and raw materials, among others (Rissman et al., 2020). Therefore, the approach to reducing carbon emissions from cement production will need to be tailored to the specific context of each country and region.

In particular, Egypt is highly vulnerable to climate change impacts, due to its geographical location and socio-economic conditions. The whole region of the Middle East and North Africa (MENA) is already experiencing the effects of climate change, such as rising temperatures, water scarcity, and more frequent and severe weather events, including droughts and floods. Egypt's coastal areas are at risk from sea level rise, which could lead to flooding and erosion, damaging infrastructure, and displacing communities. In addition, current economic conditions and limited resources make it

challenging to adapt to impacts of climate change, which was highlighted in Egypt's latest update for its NDCs (UNFCCC, 2023). There has been ongoing discourse on reducing greenhouse emissions in the Egyptian economy ever since Egypt hosted COP27, the latest conference for the United Nations Framework Convention on Climate Change, at the end of 2022. In the months leading to and after COP27, Egypt has issued and updated its NDCs to include climate change mitigation.

In the recent June-2023 update, cement is listed at the top of the industry list that Egypt plans to decarbonize (UNFCCC, 2023). Even though there are no clear targets in terms of CO_2 emissions reduction, there is an approach to increase efficiency and reduce dependency on fossil fuels by incorporating more alternative fuels (refuse derived fuels). In March 2021, Egypt's Ministry of Environment published a mandatory decree for cement plants to substitute 10% of their energy usage by alternative fuels (EEAA, 2022). However, these efforts will seem insufficient if we consider the starting point: the cement industry's carbon footprint is higher than the global average. While cement production is responsible for around 7% of CO_2 emissions, in Egypt this number is closer to 14% (EBRD, 2016, p. 10). The higher percentage of CO_2 emissions for Egypt's cement industry mirrors those of other developing and middle east countries with high production capacity of cement. The global average for CO_2 produced as a byproduct of cement production is 620 kilograms of CO_2 per ton of cement, while in Egypt this number is much higher – sometimes reported at more than 800 kilograms of CO_2 per ton of cement (EBRD, 2016).

There are several explanations for the above figures that this study will present, but it is also important to note that the cement industry in Egypt is a major contributor to the construction sector, which represents 15% of GDP (Abdou, 2017), which means policy actions for reducing the cement industry's footprint in Egypt must consider its overall contribution to the economy. Cement plants by design are made to accommodate different types of fuel, and this means there is an opportunity to create a closed-loop system whereby waste is transformed into a valuable resource, driving the transition towards a more sustainable and circular economy (Busch et al., 2022). However, the cement industry in Egypt is facing many challenges including overcapacity, high energy costs, lack of access to financing, and lack of supporting regulator infrastructure for a true green transition (EBRD, 2022).

This study aims to assess Egypt's recent efforts in reducing the cement industry's carbon footprint, as well as provide insights for how the industry can move towards a more sustainable and efficient future.

1.4. Problem Statement

The cement industry in Egypt is a significant contributor to the country's economy, but it also has a substantial environmental impact, including high levels of greenhouse gas emissions and intensive energy usage (EBRD, 2016). To address these issues, there is a need for a green transition towards more sustainable and environmentally friendly practices within the industry. The cement industry in Egypt is responsible for close to 14% of the country's emissions, and is also a heavy user of energy, with low opportunities for exporting its products due to the logistical nature of the product. This reason- added to the complexity of the economic challenges currently faced by the industry and in Egypt in general such foreign currency shortage, decreasing local economic activity, among others- means that the question of green transition in the cement industry in Egypt is much more complex than the availability of technology for carbon reduction. Although there are several green transition models implemented in other countries, as well as a dedicated 2016 EBRD report with a low carbon road map for the cement industry in Egypt (EBRD, 2016); there has been slow uptake and lack of progress in moving toward sustainable practices. This is due, historically, to several factors including lack of regulations or policy actions promoting or mandating emissions reduction, low awareness levels of climate change mitigation imperatives, and economic conditions that limit investments in new technologies in addition to general heavy industry inertia. This study thus aims to understand industry perspectives on what a potential green transition grounded in the Egyptian context will look like, as well as the policy challenges and opportunities.

1.5. Research Aim & Questions

This study attempts to fill the literature gap in answering the complex questions about obstacles to green transition in the cement industry and aims to contribute to the discussion on how to move towards a cement industry with a lower environmental impact. This study also aims to explore the interconnectedness of the cement industry with other sectors in the economy, like solid waste management and disposal, and how these can be leveraged for the green transition.

The main research question is: **How is the cement industry in Egypt working to reduce its greenhouse gas emissions and what are the policy opportunities and challenges?**

To answer this question, this study will look at several sub-questions as follows:

- What are the factors influencing cement companies in taking steps toward reducing their environmental footprint? What are the available incentives or regulatory pressures?
- What are the available practices or technologies for cement companies in Egypt to reduce their carbon emissions? What are the challenges facing these practices, especially in terms of financing?
- What are the current oversight tools by regulatory agencies to monitor and support the cement industry in reducing their environmental footprint? What are the latest trends and challenges from a regulatory perspective?
- What policies can incentivize cement companies toward shifting to more sustainable practices?

1.6. Thesis Outline

To answer the above research questions, this thesis is organized into six chapters, as follows:

Chapter one provides an overview of the research problem and the complexity of green transition in the cement industry as well as the research question, and the research objectives.

Chapter two demonstrates the recent literature on green transition in the cement industry. The literature review covers three main themes: first, an overview of the latest publications from different international agencies and bodies that are active in pursuing sustainable practices for the cement industry. Second, the chapter discusses recent publications and experiences from the cement industry undergoing a green transition from comparable countries in the Global South. Finally, a review of recent literature on the cement industry in Egypt.

Chapter three discusses the conceptual framework designed for this study, and an explanation and reasoning for the adopted research design. The chapter details the research methods used, overview of data analysis, and ethical considerations as well as limitations to this research.

Chapter four provides the necessary contextual policy background to the cement industry in Egypt. The chapter first highlights the recent challenges and dynamics in wake of the economic challenges, as well as a simplified explanation of the cement production process to highlight how green transition technologies can help reduce carbon emissions. This chapter also presents the recent regulatory changes in the cement industry in Egypt.

Chapter five presents the findings from the interviews conducted with cement industry experts as well as insights from analyzing available secondary data like reports and publications. The chapter is divided into themes that discuss recent trends in the Egyptian industry, the carbon footprint of cement production in Egypt, current practices, and options to reduce Co2 emissions, and finally a discussion of the low carbon roadmap available for the cement industry in Egypt and its different challenges.

In closing, **chapter six** presents the conclusion and policy recommendations. This study calls for a pragmatic, but also practical and holistic approach to reducing the cement industry's carbon footprint in Egypt. The study advocates for the inclusion of cement companies as key stakeholders in circular economy solutions like recycling municipal waste. Finally, the study will highlight the low-hanging fruits for achieving considerable CO_2 reductions through specific policy recommendations for collaborative stakeholder actions.

2. Chapter Two: Literature Review

Even though climate change has been identified as an issue since the 1980s, it is only in this last decade that public discourse on climate change has made it into official agreements and policy documents that are now widely spread. Today, climate change is one of the most pressing global issues facing humanity. This is partially because Climate change is already having significant impacts on countries around the world. Many regions are experiencing more frequent and severe weather events, including droughts, floods, heatwaves, and storms (UNFCCC, 2022).

The leading international authority on climate change, the Intergovernmental Panel on Climate Change (IPCC) has identified two scenarios of potential global warming: one where temperatures rise by 1.5 degrees Celsius, and another where temperatures rise by 2 degrees Celsius above pre-industrial levels between 2030 and 2050 (IPCC, 2018). The 1.5-degree scenario is the more ambitious target of the Paris Agreement, signed by nearly 200 countries in 2015, which aims to limit global warming to well below 2 degrees Celsius and pursue efforts to limit it to 1.5 degrees Celsius. The difference between the two scenarios may seem small, but it has significant implications for the planet (IPCC, 2018).

This chapter presents the recent literature on reducing emissions in heavy industry, as well as an overview of the body of research on decarbonisation in the cement industry, including technical measures and policy actions. The first section demonstrates the high-profile publications by industry groups on roadmaps to reducing carbon emissions, including a review of the academic literature that reviews these plans. Section two reviews recent literature and best practices for reducing emissions in the cement industry, followed by a review of prominent literature and case studies from China and developing countries, while the final section reviews the literature from Egypt.

2.1. Climate change mitigation - reducing carbon emissions in heavy industries

There are two main approaches for addressing climate change, mitigation, and adaptation. Mitigation involves reducing greenhouse gas emissions to lower the pace of climate change impacts (UNFCCC, 2022). This is where different industries are expected to be modifying their energy efficiency or operations to reduce their emissions. These include practices such as electrification of industrial processes to reduce dependency on fossil fuels, use of hydrogen, energy efficiency, and carbon capture, among others (Rissman et al., 2020). On the other hand, adaptation involves preparing for and adapting to the impacts of climate change that are already happening or are expected to occur (UNFCCC, 2022). This can include measures such as building sea walls,

developing drought-resistant crops, and improving public health systems (Ray Biswas & Rahman, 2023). The goal of adaptation is to reduce the vulnerability of individuals, communities, and ecosystems to the impacts of climate change, and to help them cope with the changes that are already occurring.

In the context of cement production, and heavy industries in general, all proposed green transition options discussed usually fall under the mitigation approach, with the eventual goal of reducing the environmental impact of the industry. This is because the demand for cement is expected to rise until 2050, which means that, to a great extent, the discussion on decarbonisation for cement industry refers to ways to reduce the carbon emissions resulting from the production process, or offsetting it, but not on alternatives to cement as a building material or to explore ways to decrease the demand (Busch et al., 2022). This is fairly similar to other heavy industrial sectors, indicated in a McKinsey 2020 report on cement decarbonization potential, which highlights cement and steel industries for their share of 7% and 8% of carbon emissions, respectively (McKinsey 2020).

Cement is one of the leading six heavy industries, alongside iron and steel, chemicals, aviation, and shipping (Rissman et al., 2020). These industries are usually referred to as "hard-to-abate" in gray literature like reports by industry associations or consulting powerhouses like Mckinsey to describe industries that are particularly challenging to decarbonize. These industries often rely on fossil fuels as a primary source of energy and/or their processes involve high-temperature heat or chemical reactions that are difficult to electrify or replace with low-carbon alternatives. It is more complicated because these industries are essential industries with no viable environment friendly replacements so far (Deloitte, 2022).

The collective CO_2 emissions of heavy industries are significant, reaching about 30% of global CO_2 emissions, and cement production alone is responsible for 7% of this amount (Rissman et al., 2020). Addressing emissions from hard-to-abate industries is critical to achieving climate change mitigation targets. However, decarbonizing these sectors is challenging due to their reliance on fossil fuels and the technical difficulties of reducing emissions from high-temperature heat and chemical processes. For example, the production of cement inherently generates carbon emissions due to the chemical process of calcination, where limestone (calcium carbonate) is heated to produce lime (calcium oxide), releasing carbon dioxide as a byproduct. This accounts for a significant portion of carbon emissions in cement industry, in addition to the heat needed to make this process happen, which is achieved by fossil fuels (Rissman et al., 2020). Nevertheless, there is

growing recognition of the need to accelerate efforts to decarbonize these sectors to achieve a net-zero emissions target, usually set at 2070 in different industry roadmaps (Rissman et al., 2020).

Another important factor that is also often referenced as an indicator of the level of difficulty for the cement industry to reduce its carbon footprint, is the high percentage of emissions per dollar of revenue. This statement means that the cement industry, on average, generates more carbon dioxide emissions per unit of revenue than any other industry (McKinsey, 2020). This could mean that the cement industry will need more financial incentives for decarbonisation since there is less room on the balance sheets of cement companies to fund green transition solutions, when compared to other industries like iron or oil and gas (McKinsey, 2020) This is due to several factors but mainly the chemical reactions inherent in the production process and the energy used to facilitate the whole process (Li et al.,2015). This figure has been used to argue that decarbonizing the industry will be particularly challenging as reducing emissions from the cement industry will likely require significant changes to the fundamental processes and materials used in cement production, which could have significant economic and logistical implications (Deloitte, 2022).

In the past few years, there have been several high-profile publications that addressed the challenges of decarbonizing hard-to-abate industries including cement. Most notably, the Energy Transition Committee (ETC) published a comprehensive report in 2020 titled “Making Mission Possible: Delivering a Net-Zero Economy” which sets out a roadmap for achieving a net-zero emissions in the global economy by 2050, with a focus on decarbonizing hard-to-abate sectors like cement, steel, and shipping. The Energy Transition Committee (ETC) is a coalition which is composed of global leaders in the energy, industry, finance, and policy that was formed in 2015 to drive progress towards a low-carbon future. This is one example of several roadmaps or scenarios by industry associations or global consultants. Roadmaps to reducing carbon emissions in heavy industries outline the strategic pathways and actions required to achieve significant decarbonization within these sectors. These roadmaps serve as comprehensive plans that outline the necessary steps, technologies, policy changes, and investments needed to transition heavy industries towards lower-carbon and more sustainable practices. These roadmaps often prioritize a portfolio of measures that can be implemented in a phased manner, considering short-term, mid-term, and long-term goals. They may include strategies like energy efficiency improvements, fuel switching, adoption of low-carbon or carbon capture technologies, process optimization, and the integration of renewable

energy sources. In addition to the above example from ETC, there is also The Shell Sky Scenario (Shell, 2022), the 2-Degree Scenario (2DS) and Beyond 2-Degree Scenario (B2DS) from the International Energy Agency's (IEA) whereby different scenarios for industries to decarbonize are presented, in compatibility with holding global average temperature to below 2 °C, which the goal of the 2015 Paris Agreement (Rissman et al., 2020).

Within the scholarship on Energy transitions, several key studies have evaluated and provided complimentary recommendations to these different roadmaps. Most notably, one review article in the Applied Energy journal (2020) analyzed the different technologies and policies to decarbonize industry, to provide an assessment of these roadmaps (Rissman et al., 2020). Decarbonization or net-zero roadmaps is the term most often used for medium and long-term strategic plans to reduce greenhouse gas emissions in heavy industry. They mainly identify key areas of improvement across energy consumption, type of fuel, carbon capture potential, and other demand-factor areas. These roadmaps are usually funded by industry associations or international organizations, and in some cases by relevant regulatory authorities. The roadmaps are supposed to serve as an action plan on steps that need to be taken in order to reach reduction or net-zero carbon in the specific industry. There are several points of critique or challenges to these roadmaps, firstly, the effectiveness and feasibility of the proposed roadmap strategies need to be carefully assessed. The implementation of new technologies and operational improvements may face challenges in terms of scalability, cost-effectiveness, and compatibility with existing infrastructure. It is essential to thoroughly evaluate the technical and economic viability of the proposed measures to avoid unrealistic expectations or over-reliance on unproven solutions (Rissman et al., 2020). Additionally, roadmaps should not overlook the potential rebound effects or unintended consequences of emission reduction strategies. For instance, a shift to new technologies or processes may inadvertently lead to increased resource consumption or other environmental impacts. A comprehensive assessment of the life cycle implications and broader sustainability considerations is necessary to avoid shifting the burden or creating new environmental problems in the pursuit of emissions reductions (Rissman et al., 2020).

Reviews by the different scholars such as Rissman et al., (2020) and Davis et al. (2018), evaluate the decarbonisation pathways which outlines a range of strategies to reduce CO_2 emissions in different industrial sectors. These pathways can be summarized in three different phases, from 2020 to 2035: a focus on electrification, material and energy efficiency, and circular economy. In the following decades from 2035 to 2050, there is an expectation that carbon capture and utilization would be economically usable, and alternative materials would start being available for industries

like steel and cement (Dowel et al., 2017). From 2050 to 2070, there is an expectation for wide scale hydrogen use and zero-carbon hydrogen production (Bardow et al., 2017).

Several of these methods will be addressed in more detail in the next sections for their relevance to the cement industry.

An important note to the above framework is that these roadmaps are modeled using global averages. The actual implementation would most likely differ between developing countries and developed countries. This is why there are constant calls in recent literature to explore the discrepancies and the unique regional characteristics that would affect decarbonisation strategies (Rissman et al., 2020). The most common levers of decarbonisation mentioned in the literature can be summarized as follows. There are **supply side technological interventions** that would limit the carbon emissions during the industrial process itself, in addition to the carbon capture solutions that would remove the excess carbon (Fennell et al., 2021). Then there are **demand side interventions**, which improved product longevity, more intensive product use, material efficiency, material substitution, and demand changes driven by circular economy interventions (Napp et al., 2014). Lastly, both demand and supply interventions are supplemented by **policy actions** that would either limit or discourage emissions, increase demand for sustainably produced products through government green procurement policies, or promote research and development (Rissman et al., 2020).

The majority of literature on decarbonization of heavy industries place more emphasis on supply-side interventions, which include specific technological solutions that can reduce the carbon emissions while essentially producing the same products. More advanced technical solutions like carbon capture and storage go a step further and present potential options for producers to keep their operations largely unchanged while ensuring carbon capture solutions would cancel out their carbon emissions (Bardow et al., 2017). There is uncertainty in literature on the practicality of this approach as there are not enough evidence for its efficacy from an economical or technical perspective (Bardow et al., 2017).

The demand-side interventions that are referenced in literature usually refer to improving material efficiency, longevity, and the potential of re-use. This can apply to several industries including cement, steel, concrete, plastics, among others (Monteiro et al., 2017). While such actions might not necessarily need the same level of technological innovation as supply-side, they would need policy actions to accelerate implementation across different stakeholders and are usually given long-term

action plans in relevant industry roadmaps (Monteiro et al., 2017). This is due to the fact that demand for products such as cement and concrete, as an example of heavy industry, is expected to continue rising, and changes to the use of such products would involve the need to change regulations, behaviors and attitudes of numerous stakeholders in different regions (Miller & Moore, 2020).

The most referenced policy action is carbon pricing. It refers to a set of different policy tools that essentially assigns some economic price for carbon emissions (Rissman et al., 2020). By putting a price on carbon emissions, carbon pricing is expected to provide a market incentive for companies to invest in low-carbon technologies and practices and can help accelerate the transition to a more sustainable, low-carbon economy. Carbon pricing has been implemented in several countries and regions around the world, including the European Union, Canada, and some US states (Rissman et al., 2020). The most frequently mentioned concern of carbon pricing is “carbon leakage”, which refers to the increase of greenhouse gas emissions in one country or location as result of an emissions reduction policy action in another country (Harvey et al., 2018). This can understandably be difficult to assess, and recent research on how to estimate this risk have provided large variance in results (Fowlie & Reguant, 2018). However, it can point out to the importance of international cooperation in policy actions towards reducing emissions (Rissman et al., 2020). Other notable policy actions that are government procurement policies, data disclosure and ESG, and recycling incentives or requirements (Rissman et al., 2020).

The literature landscape on reducing emissions in heavy industries is still relatively new, as recent drives for decarbonisation have picked up after the 2015 Paris agreement (Rissman et al., 2020), but there is a clear need for more research from developing countries, as the rest of the chapter will explain. There are numerous sources for research on technological solutions for the top three emitting heavy industry sectors: cement, iron & steel, and chemicals and plastics. Research highlights there are historically a 30-year window between the development of new technologies and the time it takes for an implementation on an economically scalable way (Rissman et al., 2020), which indicates the importance of exploring how transitions will take place.

2.2. Literature on reducing emissions in the cement industry

The global demand for cement is expected to increase, especially in developing countries, fueled by urbanization trends, low cost of cement, abundance of raw materials needed for its production, and

absence of viable substitutes (Monteiro et al., 2017). There have been numerous technical solutions in recent literature for possible decarbonization options (Fennell et al., 2021; Habert et al., 2020; Miller et al., 2016; Pamenter and Myers, 2021), but adopting technologies needs policy actions to support implementation.

There are more than 35 recent studies on decarbonisation in the cement sector, and most of these studies provide an analysis of different measures to reduce emissions, while very few analyze policies or barriers (Busch et al., 2022). There are also several roadmaps or pathways that provide quantitative models and are mostly from industry associations, government, or international organizations (IEA, 2018), (GCCA, 2021), (Somers and Moya, 2020), and (McKinsey, 2020).

Though cement emissions are higher in developing countries (Rissman et al., 2020), the majority of literature on cement decarbonization comes from developed countries. This outlines a clear need for research on reducing emissions in cement in middle- and low-income countries (Busch et al., 2022). These studies typically provide or evaluate different technological measures for reducing emissions, A recent review in 2022 of the literature on reducing emissions in the cement sector summarizes the most common approaches and provides the foundation for the conceptual framework of this study. There are numerous measures for reducing carbon emissions in the cement industry, including energy efficiency, alternative fuels, carbon capture and storage, among others. Most notably, there are plenty of measures proposed for reducing emissions during the production process, but only handful of studies addressing lifecycle assessment (Rissman et al., 2020).

While the first measure in above table, which is **'improving energy efficiency of current cement production process',** is not the most frequently cited, it is one of the most implemented measures as it could be considered as a win-win situation for cement companies since such energy efficiency gains would be economically attractive as well. It is important to note that these efficiencies are expected to provide only 12% reduction CO2 emissions of global cement production (BEIS and MPA, 2017; Miller et al., 2016).

It is important to note that these improvements will be voluntary in nature in the absence of policy obligations, which essentially means that capital intensive improvements will most likely be only applied in markets where it is economically viable. This is especially true to Middle East and China markets where cement markets have an overcapacity.

Another commonly cited measure is **'switching to alternative fuels'**, which refers to switching to fuels that are less carbon intensive (Fennell et al.,2021) The second largest source of carbon emissions in the cement industry comes from fuel combustion that is required for production. This is why there are considerable carbon emissions reductions that can be gained with switching to alternative fuels. Alternative fuels include a variety of kinds that will differ in their availability in each region or location. The most common alternative fuels that can be used in the cement industry are biomass, which can contain agricultural waste, wood chips, and rice straw among others. Refuse-derived fuels or (RDF) is also one of the most common alternative fuels and it can include remains of municipal waste and sewage sludge. Used tires can also be used as well as other industrial by-products like fly ash, which is a by-product of the coal industry, and slag, which is a by-product of the steel industry.

Switching to alternative fuels is particularly attractive to policymakers and companies alike since these fuels are more cost effective than traditional fossil fuels and can also contribute to the creation of a circular economy and diverting waste from being buried in landfills. This is also considered a viable option since there are relatively lower capital costs needed to adjust the production process in the cement industry to use these different kinds of alternative fuels (Rissman et al., 2020).

However, it is important to note that this shift to alternative fuels could essentially require more energy consumption for processing of the different kinds of fuel. Also, there is no change in the cement production process itself, which is the largest source of the CO2 emissions in the industry. This is why the shift to alternative fuels is expected to help reduce carbon emissions of the cement industry by 9% only by 2050 (ETC, 2020).

There are of course several challenges to using alternative fuels in the cement industry, some of them are related to the production process, whereby pretreatment is mostly needed for handling different kinds of fuels, and certain adjustments in the cement plants as alternative fuels do not provide the same energy of fossil fuels (ETC, 2020). However, the bigger challenges to using alternative fuels comes from the degree of maturity of local infrastructure and regulatory frameworks that make it both possible and economically logical for the different stakeholders. The local infrastructure must support an effective and efficient waste collection network, and one that makes landfilling waste costlier than burning it in cement plants. There are also usually challenges with local governments, especially in developing countries where there are bureaucratic hurdles and low social acceptance (EBRD, 2016).

Another commonly cited reduction measure is **'reducing the clinker to cement ratio'**, which refers to reducing the percentage of limestone needed in the making of cement – which is the main source for the high emissions in the production process. This option promises the second largest reduction percentage of CO2 emissions compared to the alternatives in the green transition options in the cement industry. A recent IEA report estimated it could save almost 35% of CO2 emissions resulting from the cement industry by 2050 (IEA, 2018). There are numerous technical variations of methods to reduce the ratio of limestone needed in the production of cement (Fransen et al., 2021). These include **blended cements** which are new cement types are made by combining different materials in the cement production process that can be mixed with limestone and deliver the same quality but reduce CO2 emissions. Examples of these materials include fly ash, a by-product of burning coal, slag, which is a by-product of iron and steel production. There is also a potential for using **alternative raw materials,** of which calcined clay is the most common example, and it involves using naturally occurring clays to replace limestone, which helps in reducing CO2 emissions and needs much lower energy consumption to deliver the same results (Fransen et al., 2021).

There are several challenges to the above options including the fact that current regulatory standards for cement use are not unified across the world, and there have been several calls for adopting standards that are focused on the quality of cement and concrete, instead of raw material requirements. There has been notable progress in these regulations, with India being the leading country that adopted LCM3 followed by EU standards, but it has not yet been adopted in most of the developing countries (Deventer et al., 2011).

Also, the challenge with alternative raw materials like clay instead of limestone is since the material availability is not unified across the world which means adoption of this technology will vary regionally.

Another commonly referenced measure in the literature is the use of **'carbon capture, storage, and utilization' (CCSU)** (Rissman et al., 2020). Carbon capture is a technology that captures carbon dioxide (CO2) emissions from cement production process and stores them underground or reuses them in other applications in the chemical industry. According to the recent 2018 IEA low carbon roadmap, carbon capture has the potential of removing up to 35% of CO2 emissions by 2050 (IEA, 2018). There are more than four different technologies at varying phases of trials in the cement

industry, including calcium looping, direct separation, and chemical absorption. A 2017 study in Romania analyzed two different scenarios for carbon capture which indicated a massive potential of up to 90% capturing for CO_2 emissions from the cement production process using calcium looping, but at a staggering 120% of the actual cost of production (Cormos & Cormos, 2017).

It is important to note that the cost of capturing and storing CO_2 from cement production is estimated to range from around 70 USD to 160 USD per ton of CO_2 (Cormos & Cormos, 2017). This is higher than the current market price for carbon credits, which is around 40 USD to 80 USD per ton of CO_2, which can mean carbon capture is a long way for large scale deployment. This also must take into consideration that the average cost of producing one ton of cement is around 40 USD, which can clarify how carbon capture is not going to be economically viable for most cement plants as of today. The cost of carbon capture is expected to fall as policy interventions and R&D efforts into practical applications take place. There are also calls for cross-sectoral collaboration between industries that would be end users for the captured CO_2 so that there is a closed economy cycle instead of storing CO_2 in underground expensive storage with no economic benefits (Beddington et al., 2019)

On the other hand, excess heat recovery (EHR) refers to the recovery of excess or surplus heat that is generated during the cement production process and is not needed for other purposes. This excess heat can be used to generate additional electricity or to provide heat for other industrial processes or for district heating. Again, there are several technical variances depending on the cement plant type and available infrastructure but as of now, it is still not economically viable for cement companies to opt for this option in absence of further financial support or policy conditions (ETC, 2020)

Lastly, there are several initiatives that are currently in the technical evaluation phase for alternative cement binding materials. An example of these techniques is a method that uses carbonation of calcium silicates, which is a process that allows cement final product to absorb CO_2 during the process. However, it is still in early testing stages, and it would not be viable to use for all uses of cement due to technical specifications (Gartner and Sui, 2017). Another example is belite cement, which is a mineral compound of different composition that needs lower energy than in traditional cement process, but also in testing stages. These are only examples of alternative materials to traditional cement that can be used in the same manufacturing process, but all of these are currently under development and would require collaborative efforts and policy actions before they can be

commercially available (Gartner and Sui, 2017).

These measures have varying degrees of applicability, as well as being in different stages of maturity for the technology used. There are different barriers to implementing above measures as mentioned in the different studies. The barriers cited in studies include **economic** barriers, pertaining to high setup costs or other market dynamics like lack of demand. Technology barriers usually refer to technological immaturity of proposed solutions, or difficulty of retrofitting proposed measures to current production sites (Benhelal et al., 2021; Miller et al., 2021). A common theme across literature was that new technologies are estimated to take 15 to 30 years to move to maturity and achieve high levels of market penetration (Rissman et al., 2020).

Regulatory barriers include limitations on adoption of new technologies in cement production that could change the product specifications, which are commonly strict standards related to long-standing construction and building codes (IEA, 2018). This is also due to cement being an intermediary product to different end users changes to building or design standards are usually slow to take place due to the nature of the industry and the fact that the cost of failure is bigger than the cost of over-specification (Ida Karlsson et al., 2020). For example, there are certain changes that can be done to reduce the co2 emissions of cement by substituting some raw materials, but these changes mean a different way of using cement for construction; thus, posing a risk of enforcing and technical capacity questions (Ida Karlsson et al., 2020.

In addition to technology measures and their possible implementation, there are general policy actions that are common across literature to reduce carbon emissions in the cement industry. These policy actions can also be found in other literature on decarbonization in heavy industries as well (Rissman et al., 2020). Policy actions can include carbon pricing, public procurement and support to research and development (Busch et al., 2022).

In summary, the literature provided common technological recommended measures and policy actions for reducing carbon emissions in cement. Less focus has been on stakeholders and barriers to these measures (Busch et al., 2022). There is also a lack of actionable plans in the studies, which means that identification of the most suitable approaches for specific markets will be difficult (Busch et al., 2022). Most notably, there is a no common identified policy framework for decarbonizing heavy industries or cement as mentioned in particular by Nilsson et al., (2021).

Lastly, there were also studies that criticized the focus on developing new technologies and processes to keep producing cement while reducing carbon emissions since it overlooks the potential for demand-side interventions, and to tackle the bigger question of alternatives to cement or even to the need of it (Ahman, 2018). This means that the emphasis on finding less energy intensive ways of producing cement might mean the potential of reducing cement consumption or substituting it with alternative building materials could be overlooked (Ahman, 2018).

2.3. Literature from China and developing countries on reducing emissions

The literature review already highlighted that the majority of research on reducing emissions in the cement industry comes from developed countries in the global north. However, there has been extensive research from China in the past years, as efforts to decarbonize have swept through the industrial sector in China (Dinga and Wen, 2022). A recent review of literature on China's cement industry decarbonisation efforts highlighted that most studies were targeting emission reductions but not carbon neutrality, which can be understood considering demand for cement in China accounts for more than 50% of the world's cement industry (Dinga and Wen, 2022). However, the literature from China provides extensive quantitative modeling which can be helpful for replicating studies in other countries. Overall, there is a strong emphasis on emission reduction measures that can be identified as circular economy approaches, alternative fuel derived wastes as an example, since the expected co-benefits from such measures would make them more cost-effective to implement (Schneider, 2019). Identified co-benefits include recycled waste, less areas used as landfills, and safe disposal of hazardous waste (Schneider, 2019).

There is also recent literature from India, examining the different barriers to reducing emissions in India's cement industry (Balsara et al., 2021). The study highlighted the importance of analyzing barriers, citing 26 different barriers including economic and regulatory factors, technological and capacity gaps, among others. Most notably, Balsara et al. (2021) highlighted the need for developing countries to use analytical tools to rank policy actions that can be most effective in each country's specific case (Balsara et al., 2021).

Other research from developing countries included emission reduction measures that were not targeting carbon neutrality as well, but more towards the target of low-carbon cement. This means that no long-term research or roadmaps for net-zero cement production by 2050 were available for developing countries. However, literature from developing countries often focus on particular

emission reduction measures that can effectively work in the country's specific context. For example, a recent study in Philippines highlighted the co-benefits from using sugarcane ash, a waste byproduct of sugarcane, for use as biomass derived fuel in cement plants (Jamora et al., 2019). This is in line with Balsara et al. (2021) approach for focusing on specific measures that can be implemented in developing countries and will be relevant for the following discussion on Egypt.

2.4. Decarbonization of the cement industry in Egypt

Discussions on the decarbonization of cement production was not always on top of the agenda for publications on the cement industry in Egypt. Egypt was a late adopter of the regulatory standards that limit dust emissions and harmful pollutants from cement plants. It was only in 2010 that the Egyptian Environmental Affairs Agency (EEAA) implemented a stricter emissions guideline with online monitoring for cement plants (Askar, 2010). These guidelines were a long-awaited amendment to the 1994 Egyptian environment protection law which set the limits of dust emissions and other air pollutants for cement plants. It was only in 2010 that the EEAA updated the limits of air pollutants to match international standards. The guidelines and current regulations do not have any reference for CO2 emissions (Askar, 2010).

However, it should be noted that there were calls for using alternative fuels and using cement production process as a method of eliminating hazardous waste instead of landfilling, as several developing countries have started doing (Askar, 2010).

In 2015, there were several reports and official publications on the cement industry in Egypt and its environmental impact. This is due to the new regulations of the cement industry that allowed the importing and use of coal and petcoke (a high carbon by-product of oil refining) to be used as energy instead of subsidized natural gas that was either unavailable or economically not feasible. This change of fuel for the cement industry was expected to increase the CO2 emissions by up to 15% (EBRD, 2016). A study in 2016 conducted an environmental impact assessment for the cement industry after the new regulations using a life-cycle assessment (LCA) methodology to evaluate the environmental footprint of cement production in Egypt. The study found lacking monitoring and evaluation of greenhouse gas emissions, and only automated monitoring for carbon monoxide by the Egyptian Environmental Affairs Agency (EEAA) (Abdou, 2017).

The most notable publication on decarbonization of the cement industry came out at the end of 2016, one year after the Paris agreement and almost 2 years after Egypt allowed cement companies to start using coal and high carbon fuels in their operations. The "Low-Carbon Roadmap for the Egyptian Cement Industry" was published and funded by the European Bank for Reconstruction and Development (EBRD), in partnership with the relevant Egyptian authorities including the Egyptian Environmental Affairs Agency (EEAA), the Ministry of Trade and Industry (MTI) and the cement companies' association in Egypt with support from the World Business Council for Sustainable Development (WBCSD). The study provided a roadmap for the cement industry and the relevant stakeholders including government organizations to implement mitigation measures to reduce the CO2 emissions increase that will happen due using coal and heavy carbon fuels. The study estimates that without the mitigation measures, the cement industry in Egypt would be within the top 2% of carbon emitting cement industries in the world – with up to 820 kilograms of CO2 per ton of cement (EBRD, 2016).

It is important to note the study also provided a more ambitious roadmap, which would reduce CO2 emissions from the cement industry by 2% lower than the historical levels before switching to coal and heavy carbon fuels – the reference year is 2014 (EBRD, 2016). The following will present the most notable recommendations and insights of this report.

Establishing a monitoring, reporting and verification (MRV) system was one of the top recommendations of the 2016 EBRD report, which would provide accurate and up-to-date information on CO2 emissions in the cement industry, in line with relevant international standards (EBRD, 2016). It is worth noting that the last update of the NDCs by Egypt in 2023 included a commitment to establishing an MRV platform for greenhouse gas emissions but it did indicate that it was pending funding (UNFCCC, 2023).

Other recommendations generally followed the same approaches mentioned in the above section, including lowering the clinker ratio in cement, which essentially means using other raw materials with different qualities than limestone. The application of this in Egypt is expected to be more difficult as most of these materials, like fly-ash, a coal-byproduct, or pozzolana, a volcanic material, are close to non-existent in Egypt. However, the report does indicate that several other countries have allowed the import of such materials to reduce the environmental impact of the cement industry and that this is an economically viable measure for companies as well (EBRD, 2016). However, in the Egyptian context, there is another challenge to this approach, since lowering the

clinker content of cement means there will be different types of cement for different uses. To put it mildly, the application of this in Egypt suffers from long-term resistance from authorities responsible for construction codes, as well as from cement companies based on their historical experience with the end-users of the cement industry – leading to most of the cement sold in Egypt to be of the same, high clinker content type, for safety concerns in the absence of necessary training and lack of oversight (EBRD, 2016).

The EBRD report also calls for mandating the use of alternative fuels and raw materials (AFR) in the cement industry and providing a suitable legislative and market framework for the use of refuse and waste derived fuels. The report included a call for new solid waste management regulatory framework in Egypt, which did come out in 2022 (Enterprise, 2022).

Lastly, the EBRD report made recommendations to balance the licensing of new cement plants with long-term domestic market needs. This is because the cement market is operating at a 70% capacity, which is not sustainable economically in the long run, due to an influx in supply in the last 10 years that has been met with a decrease in demand. This is relevant from the green transition perspective since the cement companies will be less able to maneuver and take actions to reduce their CO2 emissions if they are in a negative economic condition. The report also made recommendations on financial and market-based incentives and capacity building and enhanced dialogue between stakeholders. It should be noted that no follow-up report or analysis was published (EBRD, 2016)

Based on the above, there is a clear need for more research on the potential pathways for green transition in the cement industry in Egypt, especially from a more holistic and less technical approach to reach a wider audience and garner relevant stakeholder engagement. The objective of this research is to move technical discussions on the decarbonisation of the cement industry conversation to a more holistic discussion on the available opportunities for a circular economy and sustainable development in Egypt. This study also attempts to reveal some of the consequences of the cement industry's low carbon roadmap after six years of implementation, to the extent possible within the scope of the study.

3. Chapter Three: Research Design

This chapter will present the research design of this thesis, starting with the conceptual framework, the rationale for the choice of research methodology, research design and sampling, and the ethical considerations and limitations.

3.1. Conceptual Framework

This section presents the conceptual framework used for this study and discuss the underlying assumptions behind it. The framework is prepared based on the main levers of reducing emissions in the cement industry, which were included in the previous literature review section (Busch et al., 2022) and (Zhang et al., 2021). It is important to customize these frameworks to local and regional contexts. This is because the challenges and opportunities of green transition can vary significantly depending on factors such as the local regulatory framework, the availability of resources and infrastructure, and the social and economic context. For example, the feasibility of using alternative raw materials or fuels in cement production may be influenced by factors such as their availability, cost, and quality in a particular region.

However, this study primarily utilizes the conceptual framework that was used in a recent comprehensive study for green transition pathways for the cement industry in China (Zhang et al., 2021), with adaptations to reflect the scope of this research and the local context in Egypt.

As previously discussed, the literature reviewed has presented several approaches to reducing the environmental impact of cement. In general, there are two main approaches, one is to explore ways to reduce the demand for cement in its current form, this could include a range of research from studying alternative building materials to evaluating ways to reduce the demand for building materials, for example through innovative building designs and public space sharing concepts. The other approach focuses on the cement production process and evaluates the technological available options to reduce the CO_2 emissions from cement plants.

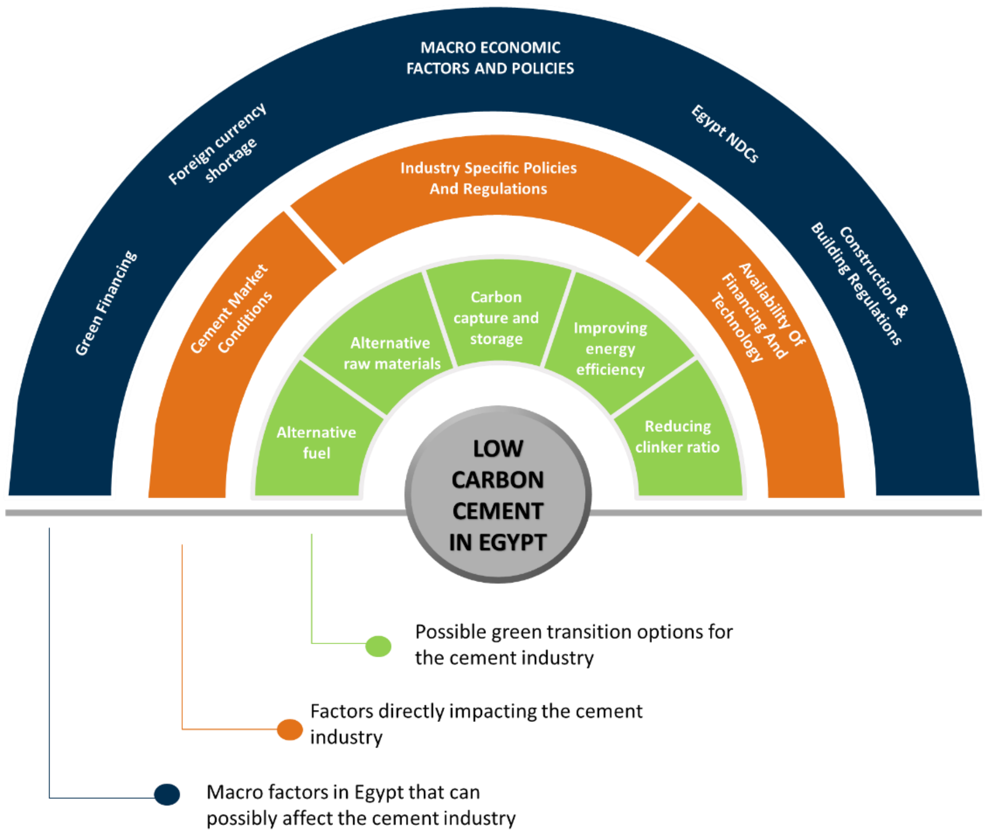

Figure 1 - Conceptual Framework, developed by author for this study

This study will use a modified version of the Net-Cement model in China (Zhang et al., 2021) to explore the potential of the different technologies that can reduce C02 emissions in cement. As illustrated in the diagram, the main dependent variable in this study is the production of low-carbon cement in Egypt, and the research will attempt to identify how it could be achieved.

The study will attempt to understand and clarify the recent market conditions and regulatory framework changes and how it affects the potential of low-carbon cement in Egypt. This will also be accompanied with exploring how other macro or overarching factors like general economic conditions or Egypt's NDCs have affected the viability of the above options for reducing cement's carbon footprint.

3.2. Research Methodology Rationale

This study uses a qualitative approach to provide insight into the possible green transition options for the cement industry in Egypt and its challenges. While there are several quantitative studies from different regions on the same topic, there is a lack of qualitative research that addresses the

perspectives of industry leaders, their current practices, and plans for the green transition (Busch et al., 2022). In addition, there is a lack of available data regarding several areas of interest in this topic of research including accurate numbers of CO_2 emissions in Egypt and the cement industry's share in it. Also, as presented in the literature review, there are few studies on reducing emission in the cement industry in developing countries, and this applies for Egypt for both qualitative and quantitative studies. For this study, a qualitative approach for understanding potential green transition options for the cement industry in Egypt is supplemented by conducting content analysis of relevant reports and publications to gain a comprehensive understanding. The content analysis was done prior and after conducting the expert interviews so that focus points can be identified and then later further explored. This approach allowed for a more in-depth exploration of the social, economic, and environmental factors that influence the adoption of sustainable practices.

3.3. Research Design and Sampling

This research used two main methods: in-depth interviews with relevant experts, and content analysis of relevant reports and official data. The following describes these methods used.

First, systematic content analysis addressed the gray literature available on the cement industry in Egypt. These included industry reports from international organizations like the International Energy Agency and the Energy Transitions Commission, and local relevant official publications including Egypt's NDCs, Ministry of Environment and EEAA publications, among others. A total of 40 documents were analyzed and the emerging themes helped inform the guiding questions for the interviews, as well as triangulation of the results of the interviews by including diverse backgrounds of participants and contrasting results with other interviews and data from content analysis. Some documents were also identified from the interviewees and were included in the content analysis.

Second, in-depth interviews were selected as the research tool that is most suitable to collect data from industry experts. The approach used for identifying the interviewees was non-random sampling. To get quality in-depth insights within the scope of this study, a purposive quota sampling technique was applied to identify potential participants. There were three different stakeholder categories identified for this research, first were cement producers, which included senior executives at cement companies in Egypt. The second category were either senior officials or consultants within the regulatory and financial sphere, which included the official regulatory agency in Egypt that supervises the cement industry, Egyptian Environment Affairs Egypt (EEAA) and the

European Bank for Reconstruction and Development (EBRD). The last category were senior experts in the technology provision sector, to understand the current offerings available to cement companies to support their green transition.

The interviews were conducted using a semi-structured interview guide with separate set of questions for each category, which can be seen in Annex 1. Interviews were recorded and transcribed and were conducted in both English and Arabic. Interview files were stored in an online 2-factor authentication drive. A total of 12 in-depth interviews conducted for this study, with the following breakdown, all using online calls of 40-50 minutes:

- **Cement producers:** a total of 7 interviews with senior executives in the cement industry in multinational and local cement companies. Local companies' interviewees included executives from private family-owned companies as well as EGX listed companies. This provided a good overview of cement companies in Egypt, but no interviews were conducted with representatives from state-owned cement companies – which represent 30% of the market.

- **Regulatory/Finance officials:** a total of 3 interviews were conducted with senior consultants in the EEAA and the EBRD.

- **Technology providers' representatives:** a total of 2 interviews were conducted with technical experts within companies offering green transition solutions to cement producers.

3.4. Data Analysis

This study used thematic analysis as the primary method to analyze the data collected through in-depth interviews and content analysis. Thematic analysis allowed for understanding the data gathered through the 12 interviews on a more abstract level. This approach allowed me to organize the findings into different themes including regulatory challenges, market and operational dynamics, financing concerns, among others.

3.5. Ethical Considerations and Limitations

Ethical considerations

The relevant procedures were followed while conducting the qualitative research for this thesis. The required IRB approval was acquired before conducting any interviews. Informed consent was obtained from all interviewees who acknowledged understanding that no potential harm or benefit will be gained from this research. For all interviewees, anonymity was agreed when quoting, and if a quote had to be referenced directly, it will be verified first with them.

In terms of positionality, I have worked in the cement and mining industries for more than 10 years, which allowed me to get high quality in-depth interviews with senior executives in the industry as well as consultants. I have conveyed to all my participants the academic nature of this study, and there was no competing financial interests or personal relationships that could have influenced the results of this research.

Research Limitations

There were several limitations faced while conducting this research. First, the fieldwork and in-depth interviews conducted with cement companies did not include state-owned companies due to time and bureaucratic concerns. It should be noted that interviews with cement experts in the private sector indicated that state-owned companies would be facing the same concerns and challenges in pursuing green transition options, but no further exploration was possible. This should be a future research topic for researchers interested in the field. **Second,** the focus of this thesis was the supply side of the cement industry, exploring the different pathways for cement production companies in Egypt. While the literature review and international experience indicates a growing emphasis on the demand side as well, such as reducing the amount of cement used in infrastructure and buildings by using enhanced structural engineering, 3D manufacturing or printing, or alternative building materials, these options were not explored within the context of this research. Further study is required to explore the potential of these options in Egypt.

4. Chapter Four: Contextual Background on the Cement Industry in Egypt

This section presents an overview of the cement industry in Egypt and the most relevant historical policy milestones, in addition to the environmental impact of the industry. This section also provides an understanding of the current economic and market conditions for cement, which would affect efforts to move toward more sustainable practices. The section ends with an overview of the current regulatory framework and policies relevant to environmental impact, and an introduction to the key stakeholders for the green transition of cement.

4.1. The cement industry in Egypt

Historically, the cement industry drew much attention in the 1990s with the state's privatization program that allowed multinational and private companies to buy state-owned cement plants or establish their own (Ghoneim, 2010). This allowed the cement industry to increase its production, and Egypt turned in a few years to be an exporter of cement, after being the second largest importer of cement in 1993 (Ghoneim, 2010). This privatization was able to attract several long-term foreign investments including Germany's HeidelbergCement, France's Vicat, Switzerland's LafargeHolcim, Greece's Titan Cement and Mexico's CEMEX, and Spain's Cementos La Union.

Today, the cement production landscape in Egypt is mixed, with 19 companies operating 24 cement plants. Of these 19 companies, there are five multinational companies, two state-owned, and the rest are national or regional private entities. It is worth noting that the cement industry plants in Egypt are fairly new, since more than 50% of the facilities have been built after 2000. This is relevant to the green transition question since newer facilities tend to be easier to retrofit or adjust to increase energy efficiency and solutions that reduce co2 emissions.

Another chronic issue that has plagued the Egyptian cement market is oversupply, where plants are running at 70% capacity, and there is a yearly production quota agreement sponsored by the Ministry of Trade as of 2021. The cement demand peaked in Egypt in 2015 at around 54 million tons, but has dropped to close to 45 tons, production capacity has increased to 87 million tons (Cemnet, 2021). This rise in production capacity is due to the inauguration of a state-owned 13 million ton-per-year plant in the recent years, which represents more than 20% additional supply to an already troubled market (Reuters, 2021).

It should be noted that the cement industry has been facing several economic challenges in the past 10 years. The following sections will give an overview of the challenges relevant in the context of the green transition.

Energy crisis: gas shortages and removal of fuel subsidies (2010-2015)

The challenges go back to the early 2010s when Egypt was faced with an extreme energy crisis that was caused by the lack of natural gas (Hafeez et al., 2015). This lack of natural gas in turn led to severe power shortages and blackouts across the country as the power generation plants were not getting enough energy. This resulted in the Egyptian government redirecting a huge share of the natural gas that was going to industrial factories, including cement, to power generation plants. This was also coupled with the phasing out of fuel subsidies that cement companies were benefiting from. This resulted in billions of lost revenues due to the lack of production during these early e years (ACC, 2016).

These energy challenges continued until 2015, when it was finally resolved by allowing cement companies to import high-intensity CO_2 fuels like coal and petcoke (EBRD, 2016). Before that, the Egyptian Environmental Affairs Agency (EEAA), one of the regulatory bodies for the cement industry, had not allowed the import of coal due to public health concerns. In fact, during the years prior to the decision, there were several local campaigns by environmental and human rights activists against the importing of coal (Zayed & Sowers, 2014). The new regulations did have a requirement for cement plants to have an action plan of how they would mitigate the increased CO_2 emissions resulting from the use of coal, but it did not have obligatory guidelines of how it will enforce these plans (EBRD, 2016). It should also be noted that this switch to using coal instead of natural gas required a high capital investment from the cement companies, estimated to be 600 million USD at the time (ACC, 2016). The huge capital investments by cement plants in Egypt to switch to coal in the past years can also explain the reluctance to invest in green transition technologies, especially during worsening economic conditions.

Economic challenges and Currency Devaluation (2016-2018)

At the end of 2016, the Central Bank of Egypt (CBE) implemented a significant currency devaluation as part of an overall economic reform plan (PWC, 2016). This resulted in the Egyptian pound losing around 50% of its value against the US dollar. This was part of economic reforms

aiming at addressing several challenges including a decreasing foreign currency reserve and a growing budget deficit, among others. Typically, this would have been good news for the cement industry, and other potential exporting industries, as it meant that Egyptian exports are now more competitive in the international market. However, the currency devaluation had a tremendous negative effect on the cement industry since the production process was now fully dependent on imported fuel like coal, which meant that their operating costs have suddenly exponentially risen. Also, cement plants are dependent, for the most part, on imported spare parts and service agreements with multinational companies, which means their operation fees have also doubled (Ramadan, 2020). It should be noted that the 2016 currency devaluation and economic conditions have also had their effect on cement demand in Egypt, as demand for cement started declining in the following years (Reuters, 2018). In summary, the currency devaluation increased the operating expenses of cement plants due to the dependency on imported fuel and spare parts, while the resulting economic downturn meant a decrease in demand for cement in the Egyptian market.

Oversupply due to economic conditions and new state-owned plants (2018-2020)

The economic challenges from the previous years continued, and it was worsened in 2018 as the Egyptian cement market started facing a new challenge: severe oversupply. In 2018 a new state-owned 1.1$ billion USD cement plant was inaugurated, which broke the records for the biggest cement plant in the world to be built at one time and one place, and the largest cement plant in Africa (Reuters, 2018). This added production capacity worsened the oversupply crisis and several companies made public calls claiming there are risks of closing plants or divesting, with few suspending operations and conducting major layoffs (Ramadan, 2020). In 2018, the Egyptian government did close off one of the historical state-owned cement plants (National Cement Company), but one that had been idle for several years already (Reuters, 2018). This did not change the chronic issue of oversupply but was seen as a token gesture for changing policies within the industry.

Yet, the situation continued to get worse for cement producers, several companies started reducing their manpower due to low utilization, and other companies shut down their plants temporarily. This was further exacerbated when the Egyptian government enacted a new building permits system that put a freeze on construction in Cairo and other capital cities in the governorates at the end of 2019. As Covid-19 hit, the cement industry continued to face increasing oversupply and lower demand

problems. The majority of cement consumption is mostly for individual usage, whereby 60% on average is domestic and only 40% is going to industrial uses like infrastructure projects including bridges and major constructions. Individual usage refers to apartment buildings and other small works by mid-size and individual contractors including home renovations, new buildings, among others (Ramadan, 2020). This means that even the massive infrastructure projects and new cities built by the public did not generate enough demand that would have compensated the decrease caused by the economic downturn (Ramadan, 2020).

Cement's lifeline: industry-wide production quota (2021-2023)

In the second half of 2022, and after years of calls and different media statements, mostly by multinational cement companies, cement producers reached a unanimous agreement with support from the Egyptian Competition Authority (ECA), in coordination with the Industrial Development Authority (IDA) to apply a production cut of 10% across all plants, with some variations depending on the cement plant's capacity, and other financial specifications (Reuters, 2021). The quota was welcomed by the industry as it provided needed assurance and stability. This production quota was requested by the majority private and international cement producers in Egypt, after oversupplying due to the inauguration of new state-owned plants, as well as dwindling demand due to building restrictions and economic downturn started to have severe effects. In the years prior to the production quota, there have been several plants that have halted operations, shutdown production lines, or laid off staff due to economic pressures (Enterprise, 2021). The quota allowed producers to reduce their losses and provided a degree of stability for companies to plan their operations. It should be noted that there were also criticisms to this regulation since it meant an increase in cement prices from an all-time low, which was justified by producers as a needed measure to remain economically viable. However, it is important to note that the quota was set for one year only, which limits the ability of cement companies in forecasting their sales and revenue, and thus their capacity to make long-term capital-intensive decisions like retrofitting or installing equipment that will support in reducing Co2 emissions.

The official reasoning for the quota system, as per official communication, was to control the oversupply in the market and stabilize prices, while maintaining that all companies can continue operating in an economically viable way. Companies that were able to export their excess product, were exempted from the quota. However, it should be noted that Egypt's cement fee on board (FOB), which is the price used to quote for exporting, is not competitive compared to other regional

players, due to factors including high shipping costs, the higher bill of fuel and other operating costs in Egypt, among others. Essentially, this means Egyptian cement companies do not have many opportunities for exporting, except for neighboring markets that are accessible by trucks (EBRD, 2016).

In 2022, the production quota system for cement industries was renewed for another year, and the move was again welcomed as there has been no major changes in demand, which is still 70% of total production capacity (Enterprise, 2022). As of July 2023, there are reports that the quota system will again be renewed for 2023-2024 as well, and cement companies are endorsing this renewal as they believe is the only way to navigate the dilemma of oversupply and decreased demand (Enterprise, 2023).

4.2. Carbon footprint of cement industry in Egypt

Historically, Egypt's cement plants were underperforming when it comes to control of air pollutants when compared to international standards. This was due to relaxed regulation that was eventually brought up to speed in 2010 when the Egyptian Environmental Affairs Authority (EEAA) amended the regulations for harmful emissions from cement plants and put in place a monitoring system (Askar et al., 2010).

According to the most recent available data, the cement industry in Egypt is estimated to be responsible for up to 14% of Egypt's CO_2 emissions, which is double the global average (EBRD, 2016). In terms of fuel, the cement industry in Egypt uses a fuel mix of almost 95% coal and petcoke, which are high carbon emitting fuels, and only 5% of waste and refuse derived fuels (RDFs). It should be noted that this increase in CO_2 emissions for the cement industry is largely attributed to the allowance of using coal in 2015.

The global average for the cement industry in using waste and refuse derived fuels (RDFs) as a source of energy is 15%, but the good available practice, which is an indication of moderate targets that can be reached by cement plants goes up to 30% (IEA, 2018). As for the direct CO_2 emissions per ton of cement, the Egyptian cement market also compares unfavorably to the global average: each ton of cement produced results in more than 800 kilograms of CO_2 emissions, which is far more than the global average of around 650 kilograms of C02 per ton of cement (EBRD, 2016t).

The cement industry in Egypt had a track record and reputation of contributing to air pollution since the 1980s, and the different Egyptian governments had tried to mitigate this by opening new plants in remote areas to reduce usage of plants in the middle of the cities like Cairo and Alexandria (Zayed & Sowers, 2014). More recently, the cement industry in Egypt began lobbying for introducing the use of coal as an alternative to natural gas that started to be scarce in supply in the years following 2012 (EBRD, 2016).

The move to use coal was not without opposition, as coal is linked with adverse health effects and increased pollution (Zayed & Sowers, 2014). In the years following 2012 and up to 2015, there was considerable debate on the use of coal from different civil society organizations, but eventually a regulation allowing the import of coal was enacted (Zayed & Sowers, 2014).

4.3. Regulatory framework and policies related to environmental impact of cement industry

The cement industry in Egypt is regulated by Egyptian Environmental Affairs Agency (EEAA) which was created in1994 to oversee companies working in the fields of cement, oil and gas, among others (IEA, 2022). The current guidelines for the cement industry by the EEAA mainly concern the dust emissions and air pollutants limitations and does not have mandates for CO2 emissions limits. These guidelines have remained the same from 1994 until an amendment in 2010 decreased the allowable limits of air pollutants from cement plants to match international standards (Askar, 2010).

In 2015, the EEAA allowed cement plants to import coal, which was previously banned, to use as fuel in the production process after a severe energy crisis. The next update came in March 2021, when the EEAA published new regulations for mandatory partial replacement of coal in cement plants (EEAA, 2021). The regulations set a new quota of 10% minimum use for alternative fuels (RDFs) as a requirement for cement plants to achieve every year to renew their licenses to import coal – which makes up 95% of the fuel used (EBRD, 2016). These regulations constitute the regulatory framework that governs the environmental impact of cement plants, which is still notably missing a clear mandate for carbon emissions.

However, in the latest update of Egypt's Nationally Determined Commitments (NDCs), the Egyptian government issued a clear declaration to implement several measures to reduce carbon emissions for Egyptian industries as a whole. For the cement industry, the national commitment

meant lowering the clinker value in cement to 80% conditional on meeting relevant national standards, and implementing energy improvements (UNFCCC, 2023). In spite of these new commitments, there are still no clear carbon pricing approaches by regulatory authorities in Egypt, including the ones for cement. It is worth noting that recent studies have demonstrated potential positive impact for carbon taxes on economic activity in Egypt. (Elshennawy & Willenbockel, 2021)

The NDCs also included a commitment to increase the usage of waste-to-energy by utilizing waste in the cement industry as a fuel to replace coal, and to reach a 20% utilization rate of total collected waste (UNFCCC, 2023). The NDCs indicated there is also a plan to improve waste collection efficiency from 55% to 95% by 2025. This is relevant to the discussion on using alternative fuels such as solid waste in cement, but as the following section will discuss, there are challenges to procuring enough waste to use as fuel by the plants (UNFCCC, 2023). Lastly, it must be highlighted that while the latest NDCs published by Egypt have certain action items for the cement industry, there is no clear number or commitment for the percentage of reduction for CO2 emissions. The current share of CO2 emissions from cement production in Egypt is reported to be 14%, and the NDCs did not mention that number, and did not mention a target number (UNFCC, 2023).

There have also been recent policy developments for waste management. The executive regulations for the Waste Management act of 2021 finally came out in 2022, to set guidelines for the safe disposal of different kinds of waste and identify how it would be financed. The regulations stipulated that relevant administrative authorities would provide a range of incentives for companies working in the field of solid waste management and recycling including tax and financing incentives, in coordination with the newly established Waste Management Regulatory Authority (WMRA) (UNEP, 2020). Also, these new regulations established a timeline of two years from the date of issuance for the New Urban Communities Authority (NUCA) to finance municipal waste management in new cities. It is worth noting that cement plants would be the biggest buyers for municipal waste as it can be used as alternative fuel (EBRD, 2016). However, as these rules and regulations have just come into effect, it would be early to assess their effect.

4.4. Landscape of key stakeholders influencing a green transition

Implementation of sustainable development practices in the cement industry will require close collaboration of different stakeholders including cement producers, official regulatory authorities in Egypt, and relevant industry associations, among others. In addition, there are other key stakeholders who could influence the green transition in cement that industry players will have to collaborate with. It is thus important to understand these dynamic relationships between these players.

First, the construction sector is one of the most important stakeholders. The Ministry of Housing, Utilities and Urban Development, along with the relevant authorities that set and oversee the Egyptian construction code and practices, would be the main drivers of allowing the cement industry to reduce the clinker content in cement. This will involve capacity building and ensuring monitoring mechanisms are in place, as well as updated labeling and technical guidelines (EBRD, 2016). Organizations responsible for architectural and structural designs will also need to be involved, as well as construction and real-estate companies that are on the demand-side of cement and would also facilitate the reduction of CO2 emissions if they start to incorporate sustainable practices in design and building (EBRD, 2016).

Other important stakeholders include regional and international financing partners. There have been a few green financing programs available for cement companies in Egypt to apply for green financing, which would mean more favorable lending terms, and often a small percentage of grant (EBRD, 2016). Most notable initiatives have been the Egyptian pollution abatement program (EPAP), and the green economy financing facilities (GEFFS) by the EBRD. The range of offering can include financing, but also technical assistance and knowledge transfer of new technologies. This has provided few opportunities for cement companies to finance expensive upgrades that would increase their efficiency and lower their co2 emissions (JICA, 2018)

Lastly, the most notable stakeholders of government organizations, other than the obvious EEAA, would be the newly established Waste Management Regulatory Authority (WMRA). This authority is mandated to regulate and improve the waste management infrastructure and can have positive impacts if collaboration is improved with cement plants. There are several policy measures and action points that would need to be coordinated to allow the creation of a cyclical economy for Egypt's waste, and ensuring cement plants have access to waste that would be used as an alternative fuel to coal.

5. Chapter Five: Findings and Discussion

This chapter presents the main findings and results of the interviews with industry experts and content analysis of key documents in the industry. These findings include in-depth discussions with cement producers, green transition technology providers, and experts in the regulatory and financing policy spaces. This chapter is divided into five different themes. The first will present new insights from senior executives in the cement industry on the outlook of the market and the upcoming transition. The second will provide an important comparison in the different readiness levels for cement companies to embrace green practices. The third section will present the current practices that are in place to reduce CO2 emissions in the cement industry in Egypt, and future potential options. Finally, the fourth section will provide a summary of the major regulatory framework and financing challenges to reducing carbon emissions in the cement industry.

5.1. Insights on current outlook Egyptian cement market

The cement market in Egypt has been facing a chronic oversupply problem that was exacerbated when new state-owned plants also joined the market in2018 (Reuters, 2018). In 2021, the Egyptian Competition Authority (ECA) stepped in to resolve the chronic dilemma by establishing a year-long agreement with all cement producers to mandate a quota system of supply cuts in the range of 10% to 13% (Werr, 2021). This policy change tried to stabilize the market and protect cement producers that were on the brink of collapse. The quota system was applied in the summer of 2021, and was renewed for one more year in 2022 to the summer of 2023. Currently, there are news reports indicating there are requests from most cement producers to renew the production quota for two more years, to provide more short-term visibility to the market (Enterprise, 2023). This comes after a continuous decline in demand for cement, with 2023 in specific seeing further year-on-year 9% decrease in demand (Enterprise, 2023).

This uncertainty has been reflected in the comments by industry experts, as one senior executive highlighted as lack of short-term visibility of forecasted production capacity beyond one year, and consequently of sales and revenue, can limit their ability for effective planning and budgeting:

> *"Yes, the cement production quota since July 2021 has greatly helped stabilize the market, but the problem is it was a one-year agreement. Last year, the renewal of the quota was announced only a few days before the expiration of the previous*

agreement, and it was also for one-year. This year, we are in the same situation, it's less than one month and we have no confirmation, but we are optimistic of the renewal. You can imagine what this means if you are trying to make long-term or even medium-term budgeting." (Cement executive 1, local private sector, 20-June-2023)

As mentioned above, this uncertainty makes it harder for companies to plan short or medium-term projects. The quota agreement sponsored by the Egyptian competition authority (ECA) puts a cap on production capacity by the cement plants, and this in turn has consequences for how much sales they can budget for, and other operational needs. This means their revenue estimations are also affected, and hence any plans for large-scale projects related to sustainability or reducing emissions as well.

This has also been coupled with continued stricter regulations on building permits in Cairo and other governorate's capitals and main cities, which was cited by several cement executives as one of the main reasons for declining demand and was also referenced by the CEO of the biggest multinational cement company in Egypt in a recent public interview (Ramadan, 2020). Also, in early 2023, the Egyptian government announced it will reduce expenditures on construction and infrastructure projects, as part of the efforts to mitigate the foreign currency shortage, which will in turn cause further reduction in demand for cement (Abelmoneim, 2023). These reductions are expected to have effects on the cement industry as well. As for smaller consumers or individuals, the decrease in demand is also caused by stricter building codes in the main cities (Ramadan, 2020). As previously mentioned, most of the cement use is for domestic demand (60%) which means that all these components together directly affect the core business of the industry (Ramadan, 2020).

In addition, here are also certain industry specific challenges that have negatively impacted the market. One of these identified by my respondents are the increased operating costs coupled with lower export opportunities as a new executive from a local private Egyptian company further elaborates:

"There are more challenges for the cement industry, a couple of years ago there was a national company established for the management of quarries and mines, and it imposed significantly higher fees for the quarries we are using. Also, the current security situation in Sudan has meant that our export options have decreased even more." (Cement executive 2, local private sector, 3-July-2023)

In addition to these challenges, the current foreign currency shortage also adds to the long-existing woes of the industry, and this will be reflected in the below sections on green transition options and their feasibility. The majority of my respondents, especially from local Egyptian private companies, indicated that one of their biggest operating challenges is the importing of coal and other major spare parts as the foreign currency shortage and fluctuation in rates makes it more difficult to plan. Also, respondents indicated that the recent devaluation of the Egyptian pound has meant that installing or retrofitting equipment for reducing carbon emissions is even more expensive as most are imported technologies and parts. These macroeconomic challenges are one of the biggest hinderances to reducing GHG emissions in industry, as illustrated in recent literature from other developing countries. (Morrow et al., 2012)

5.2. Current practices to reduce Co2 emissions

Overall, the general market trend is that multinational companies have already started taking action to reduce their carbon emissions long before any regulations or policy pressures from authorities in Egypt. These actions or initiatives were implemented mostly due to ESG reporting requirements by the different multinational companies' global directives.

The interviews conducted with senior executives in different cement companies provided an understanding of the current practices by cement producers in Egypt to reduce their carbon emissions. A senior executive in one of the Egyptian private local cement companies provides an explanation for this trend:

> *"Of course, the multinational cement companies in Egypt have already started implementing actions towards environmental sustainability before local regulations came into effect. This is because they have their own global ESG mandates that they must follow. But you must also note they can finance such projects. Most local private companies do not have such mandates and will only do these sustainable projects when it economically makes sense and can provide either increased revenue or decrease cost but also it can be difficult if a big investment is needed in these market conditions." (Cement executive 1, local private sector, 20-June-2023)*

The above quote resonates with the other respondents from multinational companies, who have confirmed they have had environmental objectives from their global management to mandate energy efficiency and carbon emissions reduction upgrades for several years now.

However, it should be mentioned that most cement experts and consultants agree that there are at least certain potential green transition options that all cement producers will be looking to implement, like fuel substitution which promises savings on the import of coal if substituted by waste derived fuels. These would include the usage of solid waste and refuse derived fuels (RDF) to replace a portion of the imported coal that is currently the main fuel used in the industry in Egypt. One of the senior executives in a leading private Egyptian cement producer explained how sustainable practices can be good for business:

> *"To work in an environmentally sustainable way is good for two reasons, to reduce the environmental impact, but also it is good for business. We have set our own environmental sustainability plan for 2030 before the new regulations from the EEAA and with more ambitious targets, this is because the first step in the green transitions is to have operational excellence in production processes to reduce energy consumption. If you manage to reduce the fuel you need, you automatically reduce your CO_2 emissions, but also, you reduce the need to use imported coal – this means lower operational costs and most importantly less dependability on hard-to-find foreign currency for importing. On the same note, improving the reliability and performance of your equipment will mean less electricity used, which will also result in decreasing CO_2 emissions. These are win-win solutions where CO_2 emissions can be reduced without the need for capex investments."* (Cement executive 2, *local private sector,* 3-July-2023)

This sentiment shows that there are at least some actions that cement companies are already considering reducing their CO_2 emissions before or regardless of policy pressures. Another producer mentioned some of the steps they have also begun to consider in the past years to establish their own subsidiary for waste management to supply their cement plants with waste needed for waste derived fuels.

There is a multitude of new technologies that are featured in recent literature that promise a huge potential of reducing CO_2 emissions in cement production (Busch et al., 2022), but within the Egyptian context, the interviews with industry experts pointed to a few options only.

The most common practice that cement companies in Egypt are using to reduce their CO_2 emissions is the shift **to alternative fuels - fuels that are less carbon intensive than conventional fuels.** Alternative fuels are an expansive term that includes different kinds of waste from solid waste

to sludge and sewage waste. Even though the above quote mentions the push by the new EEAA regulations for cement companies to substitute 10% of their energy by alternative fuels, the next section will elaborate on why this might not be as effective as it is expected to be. However, the other current major driver for cement companies to use refuse derived fuels from waste instead of coal is indeed because of the foreign currency shortage, as supported by evidence from other interviews. This can be considered a beneficial consequence since supporting cement plants to use refuse derived fuels (RDFs) can deliver several benefits in addition to reducing CO2 emissions.

However, using refuse derived fuel (RFD) is not as simple as it can seem at the first instance. There are several challenges with procuring and sourcing waste for cement companies to as can be seen in below quote by one of the senior executives interviewed, who was also responsible for the cement company's subsidiary created for waste management:

> *"There is a huge market gap for alternative fuel in the cement industry, yes, a recent study just before COP27 indicated a need 2.5 million tons of alternative fuel is needed by cement plants, and to meet that target, 15 million tons of municipal waste must be collected. The problem is that collection is very expensive, we do have tons of garbage available, but the collection and handling is too expensive. The shredders, and other equipment needed for the recycling process are all imported, which means prices have skyrocketed. I was the general manager of our company's subsidiary for waste management, and we have been losing on an annual basis for five years, and barely broke even in the one year." (Cement executive 3, multinational private sector, 5-July-2023)*

The statement above provides insight into the challenges of the private sector waste management companies, which have been suffering due to several economic and structural challenges in past years. A recent report by Enterprise indicated that 15 waste management companies have closed since 2013 (Enterprise, 2022). The latest version of Egypt's NDCs have a dedicated section for waste management initiatives, and it includes a commitment to bring up collection percentages to 95% up from 55% by 2025 and to increase the recycling and waste to energy rates (UNFCCC, 2023).

However, it seems that cement plants also face other less obvious challenges in this regard, because in the absence of efficient solid waste management infrastructure, cement plants can find it difficult

to procure the needed waste to fulfil the quota, and it can get quite expensive as the below quote from a senior executive in a cement production company explains.

> *"I wonder if there was enough market study for the waste management sector before introducing the new EEAA regulations of mandating 10% refuse derived fuels (RDFs)? Did they consider the required tonnes of waste that will be needed by the 24 cement plants in Egypt? Now, it is probably 7-8 plants that are using refuse derived fuels, and if that number is expected to suddenly increase then there will be a shortage of waste to use, and I can tell you the vendors are aware of this. We already face price hikes when we are procuring the waste because the waste management companies are moving their prices with coal prices because they know this is the only other alternative in the market. This is not good for the market or the environment. The use of refuse derived fuels in cement plants is a cumbersome process that includes many technical challenges that must be overcome, including how to handle the different kinds of waste in a safe way, and so on. If the price of waste becomes close to the price of coal, the cement plants will just choose coal." (Cement executive 6, multinational private sector, 20-June-2023)*

While this sentiment was echoed by other interviewers, it must be noted that other cement executives indicated that the foreign currency shortage is a continuous problem so far, and one that has been as extreme as nearly causing some plants to stop their operations due to lack of foreign currency to import coal. Accordingly, while the challenges with using refuse derived fuels (RDFs) are acknowledged, it is still expected to be prioritized by cement companies as it can relieve a share, even if small, of the foreign currency shortage.

There are other practices that cement companies in Egypt have started implementing to reduce their carbon emissions and increase their operational efficiency. Most notably, **waste heat recovery (WHR)**, is one of these options. Waste heat recovery is a process by which excess heat and energy from the cement production process can be recaptured and turned into electricity that the plants can use (Busch et al., 2022). This can provide cement plants with considerable savings on energy consumption and subsequently provide a sizable reduction to carbon emissions. However, only a handful of cement companies in Egypt are considering or implementing this solution. This is because there is a huge capital investment required for the initial setup, and two different executives

have conveyed that they put their plans on hold after the most recent currency devaluation at the end of 2022.

The below quote by a senior technical expert at one the global leading providers for cement equipment provides contextual background for why this is the case:

> *"We have one of the best solutions in the market for substituting high carbon emitting fuels like coal with a wide variety of solid waste, from sludge to tyres, and this solution provides guaranteed cost reduction since there will be less dependance on high-cost fuels. However, we only have one installation in Egypt's 24 cement plants, and while of course there is competition, we can also observe the demand for green technology solutions in Egypt is driven only by economic viability of the solution itself. So, if there are no policy pressures, no price put on carbon emissions, no incentive for cutting it down either, then the cement companies will only pursue such options if it makes sense from an economic point of view only. And currently, the cement market in Egypt is in a dilemma due to the oversupply, the foreign currency, and other economic conditions. (Cement technology expert 1, multinational private sector, 20-June-2023)*

The above quote summarizes the overall status that cement companies would only act based on incentives or cost. This is consistent with other research findings that clearly indicate that for companies to invest in green transition technologies, there are certain policy assurances that need to be in place first (Busch et al., 2022).

5.3. Low carbon roadmap challenges: regulatory framework and financing options

The literature on reducing emissions in heavy industries, including cement, highlighted the importance of regulatory frameworks for guiding the transition to more sustainable practices (Rissman et al., 2020). There have been several updates to the regulatory framework that governs the cement industry. These changes have been briefly discussed in previous sections, but this section explains how these recent changes affect the efforts by cement companies to reduce their carbon emissions. This section will also provide insights into the available green financing options available to the cement companies, and the challenges that come with it.

While there has been an increase in policy pressures to the cement industry in some regions, like the emissions trading system (ETS) that the EU set for its industries, including cement plants

(CEMBUREAU, 2020), this does not yet exist in Egypt. Currently, Egypt does not have maximum limits for CO_2 emissions for the cement industry. While the EBRD did publish a low carbon roadmap for the Egyptian cement industry in 2016 (EBRD, 2016), this roadmap needs to be revisited now, as indicated by the below comments from one of my respondents, a senior EBRD regional economist who worked on the report in 2015:

> *Our whole baseline for the report has to be recalculated, because when we do these types of studies, cement, steel, whatever the industry is, at least 80% of the capacity of the market has to be represented in the modeling analysis, so considering that the new state-owned cement plant is about 25-30 of the overall production capacity, this means the baseline has to be redone basically. And that will change the business as usual, the accelerated and the fast accelerated scenario,*
>
> *Other thing: we did this study in 2015 with a view up to 2030, so a 15-year projection period, now it has to be done up until 2050 and with a view of net-zero commitment or 1.5 Paris alignment commitment. At that time the government of Egypt had not ratified the Paris agreement, they did that later in 2016 and ratified in 2017, which means that we did not include the long-term low carbon levers or technologies like CCUS or large-scale deployment of green hydrogen or large-scale deployment of wind or photovoltaic into the cement industry. (EBRD Regional Director, 1, 24-July-2023)*

The above quote speaks to the importance of new research efforts to create an updated version of a low carbon roadmap for cement industry in Egypt, which will reflect the new realities of oversupply, but also of increased government commitments to reducing emissions.

However, this government commitment is not yet reflected in the regulations of the EEAA, as confirmed by interviews. So far, carbon emissions are measured and governed by requiring cement companies to provide periodical performance reports that indicate their energy usage and updates on voluntary action plans to offset the increased CO_2 emissions due to the use of coal, compared to the base year of measuring CO_2 emissions, 2014 – which is the base year used by authorities to monitor cement companies. The below quote from a senior consultant with the EEAA explains how the periodical reporting works and the reasoning behind the voluntary approach:

> *"So far there is no mandatory CO2 emissions reduction target for cement plants, there is general guidance that pre-2014 levels, which is pre-using of coal is not surpassed but not yearly or periodical reduction target. The industry is already in very hard economic conditions and the demands must be realistic." (Cement consultant 1, 9-July-2023)*

While this approach can be justified by the challenging economic conditions, it can also make planning for a green transition more challenging. Without clear emission limits or regulations in place, it can be difficult for cement producers to prioritize reducing their emissions during challenging economic times. This lack of regulation may also discourage investment in cleaner technologies and processes, as companies may not see a financial incentive to make these changes. The current framework by the EEAA has additional flexibility for cement companies as it does not have an interactive or automated monitoring and verification (MRV) system for CO2 emissions, as confirmed by interviews. The initial step in greenhouse gas emissions reduction action plans typically start with collecting quality data in place to make informed decisions.

Evidently, the absence of data can make it harder for policymakers to set clear targets and track progress towards reducing emissions from the cement industry, which is a significant contributor to Egypt's overall greenhouse gas emissions. Nevertheless, the new EEAA regulations mandating cement companies to have at least 10% of their fuel mix as refuse derived fuels (RDF) has clearly put a financial obligation on these companies. To comply, cement plants will need to install or adjust certain equipment that would involve a huge capital investment. The regulations do not offer a grace period, but they do indicate a financial penalty that would be applied in case of noncompliance. A senior executive in one of the cement companies explains the process further:

> *"The way the regulation works is that a percentage of 10% from total fuel needs of the cement plant is supposed to be from RDF, but there is also a penalty that can be paid if this percentage cannot be met. The penalty is not substantial, so some local companies prefer to pay the penalty than to do the necessary capital investments and operational changes needed to use waste as an alternative fuel. What is even worse is that this approach is reportedly welcomed by the authorities as well because it means more revenue for them. While they should instead be putting more pressure to the plants to make an action plan to start using waste as an alternative fuel to meet the regulations. (Cement executive 3, multinational private sector, 5-July-2023)*

The above approach is counter-intuitive to practices that have been referenced in different literature that calls for holistic policy actions (Busch et al., 2022). However, there are cement companies that are increasing the percentage of alternative fuel from waste well before the regulations came into effect. As explained above, this is because despite the challenges associated with using waste as an alternative fuel, it still provides the companies with an opportunity to save some hard-to-find foreign currency which is used for importing coal. But this is not an approach that can be sustainable in the long run, and this has been proven more than once, as the example in the below quote.

> *"If there are no incentives to use waste as alternative fuels, then any company will only use it when it makes economical and operational sense. You must understand burning a ton of coal is not like burning a ton of waste. There are technical difficulties that must be overcome so it must be cost effective. For example, in the last years there was a couple of times when cement plants went back to using 100% coal when its prices dropped in 2015 and in 2022 – because then it made sense to just use coal, even if its imported, and not have to do the other operational and technical workarounds necessary to use waste as alternative fuel" (Cement executive 6, multinational private sector, 22-June-2023)*

Evidently, this is an example of the importance of a regulatory framework that would provide the right mix of incentives and limitations for the cement industry that would guide the companies in managing their carbon emissions. While the recent changes present an improvement, there are still calls for a more holistic approach, as the challenges of utilizing waste in cement plants go beyond regulations or mandates for the cement industry. Experts have stated that waste management in Egypt has a chronic problem with informality and financing, and cement companies have experienced this first-hand as confirmed by several participants. There are several companies that have started their own subsidiary companies of waste management to guarantee a continuous flow of waste to be used as alternative fuels in their sites, but this has been a challenging endeavor, as discussed with a senior EEAA consultant:

> *"It is very good that cement companies start waste management subsidiaries because they can increase the standard of the market, but it is not profitable. People are confused when they hear waste management companies here are losing money, while they are profitable business outside of Egypt. But you can easily observe this*

regardless of where you live in Egypt, look at any garbage disposal place and you will see the "scavengers" or informal garbage collectors and they take out the plastics, the paper, and the cans and metals. As a result, when this waste stream arrives to the waste management companies, it is devoid of any high value waste and it is mostly organic waste that must be composted at extra cost, cost that should be financed by the missing plastics, paper, and cans. There have been several trials to include the informal garbage collectors in the formal system through small and medium enterprises, but this is another topic. For now, the practical thing for cement companies is they try to source industrial waste from big corporations, but the municipal waste so far is challenging." (Cement executive 3, multinational *private sector, 5-July-2023)*

The above quote provides contextual understanding for the complex problems that face the green transition options, not just in the cement industry but in Egypt. There are currently new regulations that have yet to come into effect for waste management, which in principle promise better collaboration and incentives, but it would be too early to assess.

The other major opportunities for cement companies to reduce their carbon emissions and their electricity consumption- waste heat recovery (WHR) and renewable electricity generation- also face certain regulatory and financial constraints. While both technologies offer long-term savings and operational efficiencies, there are very few expected implementations. The below quote from a senior executive in a multinational cement company in Egypt provides more context.

"Yes, we had two major projects for installations of waste heat recovery and solar panels that would have provided more than 15% of the electricity needs of our operations by renewable energy. This would have of course reduced our CO2 emissions as well. But after the last devaluation we have stopped the project because now the payback period for the initial investment is going to be 12 years instead of 5. You also have to understand that getting financing from banks for the cement sector is increasingly challenging as they are aware the sector is in a tough situation." (Cement executive 3, multinational private sector, 5-July-2023)

Another executive shared similar remarks, adding that there are also problems in getting approvals for such projects and that authorities are less likely to provide approvals for projects providing renewable energy of more than 10% of industrial need for a factory because there is excess

electricity already. In the past years, Egypt has achieved a surplus in electricity production by adding several new power stations, and this surplus has continued to grow beyond global averages to reach approximately 30% (Al-Wali, 2022). This means logistical and operational difficulties for the government owned electricity supplier, since maintaining production and efficiency in a market riddled with over-supply is economically difficult. Essentially, several respondents indicated that projects to substitute portions of their electricity usage by renewable energy solutions like solar farms within their plants have faced difficulties in getting the required approvals. If this is added to the increasing cost of imported materials due to currency devaluations and long-term return nature of this products, it can be expected that few companies would opt for renewable electricity solutions unless clear incentives start to emerge. In summary, any attempts reduce carbon emissions caused by the high electrical energy consumption in the cement industry will currently face tough challenges that will most likely mean they will be put on hold for the time being.

Lastly, the option of lowering clinker ratio in cement has its own regulatory dilemma since there are various official authorities and organizations involved, with varying levels of willingness to change. The lowering of clinker ratio in cement means there will be different types of cement intended for different uses. The consensus is that this has not been a recommended practice in Egypt since most likely there is a lack of attention to these differences by the end-users. The result is that regulating authorities have been on the more conservative side and kept clinker ratios higher than global averages. There are many technical specifications of different options that can be used to lower the clinker ratio in cement, and thus lower the resulting the CO2 emissions, but the feedback from the interviews and content analysis pointed to the regulatory aspect to be the most challenging, which can be summarized in the below quote from one of the senior executives in a multinational cement company.

> *"To really achieve any improvement in this, the authorities responsible for construction code and Egyptian cement standards should have some flexibility and explore what other countries have done in Europe, India, and other countries. We cannot still be insisting on high clinker factor in cement. We have excellent research facilities if there are any tests that need to be done to do this, but the problem is it seems there is no willingness to take responsibility or make changes." (Cement executive 2, local private sector, 3-July-2023)*

It should also be noted that there are more barriers to the option of reducing clinker factor in cement in Egypt. In addition to the bureaucratic challenges in changing the construction code above, there are also challenges in availability of some of the materials that can substitute clinker, and some of it will have to be imported. Overall, this option will require extensive research and collaboration between different stakeholders before on-ground improvements can be observed.

The green transition in the cement industry is closely linked to questions of financing and regulatory framework. The transition to a more sustainable and low-carbon cement production requires significant investments in new technologies and infrastructure, and financing these investments is a key challenge. At the same time, regulatory frameworks play a crucial role in creating the incentives and requirements for the industry to transition to more sustainable practices. There is already sufficient literature and best practices from other countries to demonstrate that a combination of public and private financing, along with supportive policy frameworks and regulatory measures, can create the conditions for industries, including cement, to reduce their environmental footprint (Miller et al., 2016). The below was the closing remark by one of the senior executives in a leading multinational cement company in Egypt on this note:

> *"What incentives? We have no incentives. We seem to always insist on reinventing the wheel. We have said a million times before in different meetings that the use of waste in cement as fuel was successful in other countries because there is a gate-fee to finance it. In a previous meeting I had with a plant manager in a cement factory in Europe, my counterpart was astonished when I told him we pay to procure waste to use as fuel, because in his plant they get paid at least 40 euro per ton to burn it. You know, the lowest gate-fee in Europe is 28 Euro per ton, and it goes up to 90 euros in some countries which can be a considerable stream of revenue for the plants to finance green transition. But we have nothing like this here and even no hope for it. We have even got to the point where we are just asking to exempt the trucks that are carrying the waste to the cement plants from the road fees because this is a benefit to the country that this waste is going to be disposed in safe way instead of illegal landfilling and fires, but no success even for this simple request." (Cement executive 2, local private sector, 3-July-2023)*

While the above comments on incentives for companies to support moving to sustainable practices can be valid, it also points to more complex questions on financing, and the different levels of readiness across the word.

Finally, in the broader context of climate change and sustainability, it is important to note that the challenges faced by the cement industry are part of a larger global challenge of reducing greenhouse gas emissions and achieving climate justice. For example, Discussions of the Loss and Damage fund at COP27 were a clear example of how the issue of climate justice is at the forefront of global climate discussions. The below was the closing remark by one of the senior executives in a leading local private Egyptian cement company in Egypt in response to a question on the potential of using carbon capture and storage (CCS) for further reduction of CO2 emissions:

> *"Ok, let's say we have captured CO2 and stored it underground, and then? There isn't any realistic way to use this CO2 so who is going to pay for this super expensive technology? To be transparent, yes we are implementing environmental sustainable practices but ones that are also reducing the cost for us. But let me ask you this for the sake of argument, what is the CO2 emissions per capita for the US or China? It is 14.8 tons and 8 tons per capita. The number for Egypt is only 2 tons per capita. We contribute only to 0.73% of CO2 emissions globally. Why would we be expected to pay for these reductions then? But I am still saying we are doing the sustainable practices that do make economic sense." (Cement executive 2, local private sector, 3-July-2023)*

The quote highlights the significant disparities in CO2 emissions per capita between countries, with Egypt having a relatively low level of emissions compared to other developed countries like the US and China (Rissman et al., 2020). Moreover, the quote demonstrates that Egyptian industries may perceive themselves as less responsible for acting on climate change and may expect external financing and support to invest in low-carbon technologies and reduce their carbon footprint.

6. Chapter Six: Conclusions and Policy Recommendations

6.1. Concluding remarks

The research on carbon emissions reduction options for cement industry highlighted several options that are currently available (Busch et al., 2022). However, there is a clear need for research that focuses on Egypt as a developing country with its own specific characteristics, as the roadmap for reducing emissions will differ greatly based on country specific factors (Busch et al., 2022).

The results of this study indicate that the cement industry in Egypt is facing severe chronic challenges including oversupply, economic challenges due to foreign currency shortage, as well as decreasing demand due to economic conditions and increased regulatory pressure. These factors inevitably affect any potential for green transition by the cement companies. It can also be difficult for developing countries like Egypt to implement the same incentive schemes that have supported the green transition of industries in other countries. However, the research also implies that there are plenty of underlying advantages to supporting certain options that would secure a sizable reduction in Egypt's carbon emissions (EBRD, 2016). The research indicates that the waste management industry is an untapped potential for the green transition in Egypt, and if it is coupled with close collaboration with the cement industry, a continuous revenue stream can be secured for companies that operate in this sector which would add thousands of jobs to the Egyptian labor market, ensure a reduction in CO_2 emissions, and also reduce the dependability on coal which requires foreign currency for importing. This research also highlights the importance of Egypt's latest update to its NDCs and how it has already helped in providing clarity on Egypt's climate objectives. However, there is also the need for more clarity on the objectives for the cement industry, which can have a guidance instead of a mandating form, but this clarity will support in either securing green financing or providing multinational companies already working in Egypt with long-term vision to support in their investment decisions.

Lastly, mitigating the environmental impact of the cement industry in Egypt is an extremely complex topic that can be approached from various angles. It was not possible to explore the full potential of the green transition options within the scope of this thesis. For example, this study only touched upon the demand-side of the equation but did not explore the different policy options that can create the market for greener cement products from the side of construction or real-estate companies.

6.2. Policy recommendations to support green transition in cement

Based on the findings and the analysis conducted in this research, the below section will present a set of policy recommendations that are complimentary to the low carbon roadmap for cement industry in Egypt. These suggestions are based on discussions with the different stakeholders including senior executives in the cement industry, regulatory consultants, and technical experts.

1. **Revisit the low carbon roadmap for the Egyptian cement industry** that was prepared by the EBRD in 2015. This roadmap was prepared prior to the inauguration of several new cement production lines that added to the market capacity, and thus the baseline year of 2014 can no longer be a valid reference point as indicated by the expert interviews. Also, after Egypt signed the Paris agreement and published its NDCs, there are now public commitments that need to be translated into specific action plans, and cement is one of the industries targeted by Egypt to reduce emissions. Hence, an updated study needs to take place for a roadmap of the cement industry up to 2050, in accordance with the Egyptian national climate change strategy for 2050.
2. **Mandate a specific CO2 emissions reduction target for the cement industry.** This should be included as part of the country's national determined commitments (NDCs) by 2030. Mandating a specific emissions target for cement production would serve as a clear signal to the industry that reducing emissions is a priority for the government and would encourage cement producers to invest in cleaner technologies and processes. The target should be set at a level that is both ambitious and achievable, considering the technical and economic realities of the industry. This policy recommendation would demonstrate Egypt's commitment to transitioning to a low-carbon economy and meeting its climate goals under the Paris Agreement. Also, this policy recommendation would help in facilitating green financing options for both the cement companies as well as the official authorities that would need such financing for implementing green transition solutions, monitoring and verification systems, or technical capacity building programs.

3. **Provide more on-ground procedures to support and increase the usage of refuse derived fuels (RDFs)**. The recent EEAA regulations mandating the 10% minimum RDFs in the energy used by cement plants and the newly established solid waste management

regulations have provided the fundamental framework, and the below recommendations can provide immediate improvements:

- Revisit and possibly remove the road fees associated with the transportation of waste to cement plants to be used as alternative fuel. Imposing road fees on waste transport is counterintuitive to sustainability and circular economy objectives of Egypt's NDCs, as it disincentivizes the use of waste as a resource and encourages the landfilling of waste instead. By removing road fees for waste transport to cement plants, policymakers can incentivize the use of waste as an alternative fuel source, reduce greenhouse gas emissions from waste disposal, and promote a more circular economy. This would also help to reduce the cost of waste transport for waste management companies and other players in the waste value chain, making it more financially viable and reducing the cost for the end-users.

- Design and implement a collaboration framework between cement companies, the waste management regulatory authority (WMRA), and private sector companies that are operating across the waste value chain, from waste generators to companies working in disposal. Such a framework can help to address some of the regulatory and logistical challenges including sorting, separating, and can help in developing processes for handling and transporting waste to cement plants. Also, such a framework would promote a more circular economy by encouraging the reuse and recycling of waste materials. Lastly, this collaboration will eventually allow the WMRA and other relevant stakeholders to apply the "polluter pays principle" after enough data, experience and logistical setup is done. This would allow the introduction of gate-fees, which are fees the cement industry can collect from disposing of waste by using it as alternative fuels instead of landfilling.

4. **Expedite actions required to lower the clinker ratio in cement**. This will include utilizing partnerships and best practices in other countries that have already adopted such measures like India and other comparable countries to modify local construction codes and standards that are currently mandating higher clinker ratios that global requirements and causing higher CO_2 emissions as well as increased energy consumption, and in turn, higher cost of

foreign currency for the industry. While the latest NDCs did clearly state a reduction in clinker ratio is going to happen by 2030, there is still no indication of a timeline or actual progress yet. This will be a collaborative effort across different authorities and industries in addition to cement producers since it will include end-users like construction and real-estate companies, architects, and official monitoring organizations.

5. **Establish a system for monitoring, reporting and verification (MRV) for measuring carbon emissions.** This system will enable the availability and accuracy of data needed for decision making on CO2 emissions and energy usage and performance of cement plants. As it stands today, regulatory agencies are dependent on semi-voluntary performance reports submitted by the cement plants to measure their carbon emissions based on high-level calculations, which have been confirmed by experts to be inaccurate. It is also recommended to introduce a need for 3rd party verification of reported energy performance and CO2 emissions reporting by cement companies. This will ensure compliance with international standards and a level playing field. The establishment of such a platform will also allow the relevant authorities to explore different incentive schemes for cement companies that are exceeding their targets, as explained in below point.

6. **Implement an incentive scheme for reducing emissions** that can be added to the recent regulations that indicate a penalty for cement companies not meeting the 10% minimum usage of refuse derived fuels (RDFs). These incentives can be provided for companies that exceed the 10% on an upward scale up to the global average of 25%. It is recommended to explore what incentives can be provided in an equitable and practical way, and it can range from higher export subsidies or green public procurement agreements that favor cement with lower carbon emissions, or certain reductions in import or quarry fees.

7. **Revisit or remove current limitations of the maximum of renewable energy substitution threshold for cement plants**. The use of renewable electrical energy in the cement industry can support CO2 reduction efforts in a cost-effective way for cement plants. While these limits might be based on on-ground facts like excess electricity production at the national grid level, it should be highlighted that its contradictory to Egypt's NDCs vision of achieving 42% of electricity to be generated from renewable sources by 2030. Along the

same lines, revisit and possibly remove the EEAA regulations stipulating that cement plants that reach 40% thermal substation rate (which means plants reduced usage of fossil fuels by 40%) would be subject to stricter emissions guidelines.

8. **Finally, the Egyptian Competition Authority (ECA) should revisit the production quota in the cement industry in Egypt to consider extending for at least two or three years,** with the option of periodical revisions in case of market changes instead of the 1-year renewals that have been ongoing for the past two years. The current gap between the production capacity of cement plants in Egypt and the demand for cement is 30-35% and there are no realistic expectations that this would be resolved within a year. This policy change would provide better long-term planning for cement producers, allowing them to make more informed investment decisions and protect the market from disturbances or shortages. By providing greater stability and predictability in the industry, cement companies would be able to plan with better visibility and implement more sustainable practices. Additionally, the option for periodical revisions would allow for adjustments to be made based on changing market conditions or other factors, while still maintaining a level of stability in the industry. Lastly, when cement companies have better revenue and overall business forecasting, it will improve their ability to secure long-term green financing for capital investments needed for technical solutions that would reduce their carbon footprint (Miller et al., 2016).

6.3. Implications for future research

While this research aimed to assess the decarbonization policies for the cement industry in Egypt there are several pathways for future research that have been identified. First, the findings presented above suggest the need to conduct technical research for the advanced methods that could reduce CO2 emissions from cement. New technologies like carbon capture and utilization can be useful for other industries like oil and gas but these technologies are still in early stages and would require extensive research.

Second, this thesis explored the potential of green transition in the cement industry from a cement production perspective and did not evaluate the potential options for reductions in cement's environmental footprint by changes on the end-user's side like the construction or concrete

companies. Further research is required to understand factors that drive demand such as urbanization, and infrastructure development, to identify opportunities to reduce the overall demand for cement.

Also, the findings of this study indicate an urgent need to understand the landscape of waste management in Egypt and how it can contribute to sustainable development practices in other industries and the application of circular economy principles. Given the recent updates in both the regulatory landscape for the waste management industry in Egypt, and the growing demand that will be created from heavy industries like cement, it is imperative that further research is conducted to explore the challenges and possible solutions for sustainable waste management.

In summary, this study identifies that reducing the carbon footprint of the cement industry in Egypt is a long-term goal, and one that can only be achieved in phases with close collaboration of multiple stakeholders including cement producers, regulatory agencies, construction companies, waste management companies, among others. This collaboration will require further inter-disciplinary research that can guide the policymakers to better informed regulations for the industry.

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Appendix 1: Interview guide for participants

Questions for cement producers

1. Market Outlook & Environmental Impact of Cement Industry		15 MIN
Covid-202 & Economic Crisis *Environmental Impact*	1.1 What are the current market trends in the cement industry in Egypt? 1.2 What are the biggest challenges for your company now? 1.3 What are the possible opportunities for your company now? 1.4 Where does your plant stand in environmental reporting & thresholds? 1.5 What is the current energy mix used in your cement plant?	
2. Green transition options for cement industry		***20 MIN***
Plans for reduction. *Carbon capture & carbon credits*	2.1 What are the options available to your company for green transition? 2.2 Do you have a current plan to reduce the environmental impact of cement production? 2.3 If yes, what is your main approach in reducing environmental impact? 2.4 What are the factors affecting your plans for reducing environmental impact? 2.5 What is the potential of using carbon capture or carbon credits to reduce your environmental impact?	
3. Financing & Regulatory Framework		***20 MIN***

2021 Ministry of Environment Decree *Financing options*	3.1 How has your company been affected by the recent ministry of environment decree in 2021 on using RDF "refuse-derived fuel" in cement plants? 3.2 If capex investments are needed, what are the financing options available to your company? 3.3 What are the current incentives available to your company for reducing environmental impact? 3.4 What are the current risks to your company if environmental targets are not met? 3.5 In closing, what are the policies that you believe will incentivize companies towards green transition in cement?

Questions for Cement Consultants (Regulatory - Financing)

1. Market Outlook & Environmental Impact of Cement Industry		5 MIN
Gas Shortage *Coal Importing* *(AFR) Alternative Fuel & Raw Materials in Cement*	1.1 What are the current top priorities for the EEAA (Egyptian Environmental Affairs Agency) now in monitoring the cement industry? 1.2 What are the latest figures of the cement industry's environmental impact? 1.3 What are the current targets or thresholds for emissions or energy usage?	
2. Current Monitoring System		***15 MIN***
Automated (MRV), Monitoring, Reporting & Verification	2.1 What are the latest trends in the monitoring tools for tracking energy usage and emissions? 2.2 What are you most concerned about now? Is it energy usage mix or emissions? 2.3 What are the top challenges for effective monitoring of cement plants? 2.4 What is the potential of using carbon capture or carbon credits to reduce your environmental impact?	
3. Roadmap for Green Transition		***20 MIN***

2021 Ministry of Environment Decree *Financing options*	3.1 In an ideal scenario, what would be the regulations you would enact? (Not limited to cement: probe for construction & waste management sectors) 3.2 What are the biggest challenges in enforcing new regulations on cement plants? 3.3 What policies do you believe will incentivize or create a market for green transition in the cement industry?

Questions for Cement Tech-Providers

1. Market Outlook & Effect of Environmental Regulations	5 MIN
Environmental Regulations *European Green Deal* *2021 Egyptian Ministry of Environment Decree*	1.1 What are the current market trends you are seeing as a technology & capex provider? 1.2 How are your customers adapting to increasing environmental regulations? (Probe for differences across regions, probe for Egypt) 1.3 How is your offering changing due to above mentioned environmental regulations?
2. Green Transition Technologies	***15 MIN***

Green Cement *Water usage*	2.1 What are current alternatives available to cement producers to reduce their environmental impact? (Probe for specific emissions, water usage, etc.) 2.2 Could cement production ever become environmentally neutral? Is green cement possible? 2.3 What are the biggest challenges and/or limitations for green transition technologies?
3. Roadmap for Green Transition	***20 MIN***
Geographical Limitations *Financing options*	3.1 Can you share recent examples of cement plants that used green transition technologies to reduce their environmental impact? 3.2 What variations can you see between different locations in adoption of green transition technologies? 3.3 What policies do you believe will incentivize or create a market for green transition in the cement industry? (Probe for financing)