The Impact of Implementing CCUS Cost on the Egyptian Cement Companies' Financial Position | Case Study, an Egyptian Cement Company

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Abstract

The greenhouse gases (GHGs) are behind the symptoms of climate change (Ahmed I. Osman, 2023). CO2 occupies the largest portion of the GHGs by around 81% of the total GHG (Hong, 2022) Although the cement industry is one of the most important industries for being the major contributor to the Egyptian gross domestic product (GDP) and the creator of direct and indirect jobs, as it is the most indispensable material consumed. However, it also contributes a huge amount of carbon dioxide (CO2) emissions to the environment for around 750 kg CO2 / ton of cement produced (ElGhamrawi, 2023). Despite the other measures that are commonly used for CO2 emissions reduction over the previous decades (Adina Bosoaga, 2009). The carbon capturing and storing CCS technologies are considered the most effective technology, regardless of the high cost of the technologies and the uncertainty of the cost estimation, which are still barriers to the technology distribution (Kasper Storrs, 2023).

Methodology: Multiple methodological and analytical approaches are used to gather both qualitative and quantitative data. The qualitative approach includes analysing secondary data, conducting a case study of a leading cement company in Egypt, and performing a semi-structured interview with one of the top managers of the case study company. For the quantitative approach, techno-economic assessment and cost-benefit analysis are employed to evaluate the impact of implementation costs on the company's financial position. Multiple scenarios are proposed, and sensitivity analyses of variables such as carbon pricing, government support, and changes in capital structure are examined. These efforts encourage investment in such technologies and support the goal of reaching net-zero emissions in the industry.

Findings: The high capital expenditure (CapEx) and operational expenditure (OpEx) of the technologies affect the companies' financial position negatively in terms of Internal Rate of Return (IRR), Net Present Value (NPV), Discounted PayBack Period (DPBP), and Real Option Approach (ROA). The moderating variable, the increase in the CO2 price, controls the relationship positively at a high carbon price of $70. This still needs the governmental support to raise the IRR above the weighted average cost of capital WACC. However, governmental support alone does not impact the relationship positively. But the change in the capital structure shows incrementally a positive impact on the financial position metrics.

The Keywords: Cement industry, carbon emissions, CCUS cost, governmental support, CO2 prices, change in capital structure, and financial position.

List of abbreviations:

CAPEX: Capital Expenditure.
CCU: Carbon Capture and Utilization.
CCUS: Carbon Capture, Utilization, and Storage.
CCS: Carbon Capture and Storage.
CO2: Carbon dioxide.
DPBP: Discounted Payback Period.
EGX: Egyptian Exchange.
EGEX: Egyptian Climate Exchange.
EOR: Enhanced Oil Recovery.
FCF: Free Cash Flow.
GDP: Gross Domestic Product.
GHG: Greenhouse Gas
IRR: Internal Rate of Return.
NPV: Net Present Value.
OPEX: Operation Expenditure.
ROA: Real Option Approach.
ROE: Return On Equity.
TRL: Technology Readiness Level.
WACC: Weighted Average Cost of Capital.

Introduction:

The overexploitation of fossil fuels due to the increase in global industrialization has led to an increase in the global temperature and many other environmental issues (Lin Chen, 2022). The industrial activities harm the environment by contributing a massive amount of greenhouse gases, particularly CO2, which affects both society and the natural world negatively (Raghad Adam, 2023).

Egypt and the MENA region are already experiencing the effects of climate change (ElGhamrawi, 2023). A large amount of carbon dioxide emissions in Egypt is released to the atmosphere, especially from building construction activities, which account for around 40% in 2020 (UN-Program, 2022). This is because Egypt depends on reinforced concrete as a structural system of modern construction, which consumes a large amount of cement and steel to erect this structural system (Xiaocun Zhang, 2021).

The main pollutants emitted by the cement manufacturing process typically include a huge amount of CO2, which is a major greenhouse gas (Yu Lei, 2011). Cement being the most material consumed with no substitute, the cement industry contributes to CO2 emissions to the environment for around 7% of the global emissions and 14% of the Egyptian emissions to which is equivalent to 750 kg CO2 / ton of cement produced (ElGhamrawi, 2023).

Most bodies of research generated to reduce the CO2 emission from the cement industry were focusing on different approaches in their reduction initiatives, like the reduction of energy consumption or switching to low-carbon fuels (Arshad Raza, 2019). However, the carbon capturing and storing CCS is unavoidable for effective emissions reduction in the cement industry (Juliana Monteiro, 2022).

Despite the claim that the CCS is an efficient technologies that would decrease the amount of CO2 emitted to the environment, these technologies are still unique and immature; moreover, the uncertainty of the future price of the fuel and the high return on investment required by the investors made the cost estimation uncertain. (Hasan Muslemani, 2020).

There is a research gap in studying the cement industry decarbonisation using CCS in developing countries; most of the research that discussed these issues was concerned with developed countries. Although the carbon capturing and storing CCS are new technologies that can reduce the CO_2 emission significantly (ElGhamrawi, 2023). There is a limited identification of the viable business model of these technologies, especially in the industrial sector, except for some poor literature (Hasan Muslemani, 2020). Some studies were conducted for the power sector, but they are still limited as well ((Hasan Muslemani, 2020).

The research aims to examine the cost impact of implementing the CCUS technologies on the Egyptian cement company's financial position and examine also how the carbon pricing, the governmental support, and the capital structure changes might moderate the relation between them.

Literature review:

Although the cement industry is one of the most important industries for being the major contributor to the Egyptian GDP and the creator of direct and indirect jobs, as it is the most indispensable material consumed. However, it also contributes a huge amount of the CO_2 emissions to the environment by around 750 kg CO_2 / ton of cement produced (ElGhamrawi, 2023).

These carbon emissions of the cement production process are classified into direct and indirect emissions. The direct emissions, which account for around 90% of the total emissions of the industry, are related to the production processes and combustion processes, while the remaining 10% is the indirect emissions portion that occurs due to the electricity consumption (Keshk & E. E. Hekal, 2023). The energy efficiency, Fuel switching, and blended cement are three measures widely used to mitigate carbon dioxide over the past years (Adina Bosoaga, 2009). However, the carbon capture technology is essential when there is an intention to decarbonize or to reduce the climate impact of the cement production industry (Juliana Monteiro, 2022).

Moreover, the literature added that capturing carbon dioxide from the cement plants is considered a good option due to the similarity between the cement production and the CCS configuration, as the concentrated CO_2 stream in the cement industry is high compared to other industries (Tansu Galimova, 2022).

The technology of CCS relies on capturing carbon dioxide from a stationary source; this captured CO_2 is distributed to intermediate and/or final storage (John Frederick, 2018). Several capturing technologies are mentioned in the literature as available capturing technologies: the pre-combustion, post-combustion, oxy fuel combustion, the chemical looping, and direct air capturing (Hong Wan Yun, 2022).

The post-combustion technology is considered the most mature technology relying on capturing the carbon dioxide emitted from the point of source (Pawel Magejski, 2022). The latter is commercially preferred for its availability, its application to other dilute carbon dioxide streams, its compatibility with the operation process of the cement production, and the flexibility of adding the new equipment to existing cement plants (BCS Baliga, 2021). However, the significant challenge is the cost of the CCS implementation to reduce carbon emissions (M.M. Faruque Hasan, 2014).

Recently, the term CCS was changed to carbon capturing, utilization, and storage (CCUS) by the Carbon Sequestration Leadership Forum, which indicates the higher economic value of the CO_2, and the higher coverage for capturing, and storing costs (Xing Yao, 2018).

The revenues generated by selling the CO_2 emissions captured by the technology CCS are the benefit of combining the CCS and CCU (Arno Zimmermann, 2017). They can reduce the negative impact and create additional value from the economic and ecological viewpoints (Shuai Zhang, 2020).

The geological sequestration of carbon dioxide using the CCS technologies has become an effective method of CO_2 emission mitigation. Moreover, this geo-storage can help in utilizing the CO_2 in enhancing the oil recovery (EOR) (Mvomo N. Edouard, 2023). This indicates the higher economic value of the CO_2, the higher coverage for capturing, and storing costs (Xing Yao, 2018).

Although the economics of storing carbon dioxide captured are better than the economics of its utilization, recently, most of the operations are concerned with converting the CO2 to a byproduct rather than the injection into ground storage, as the utilization would generate a neutralization of the carbon cycle; accordingly, it could be a more sustainable option (Shuai Zhang, 2020).

For these reasons, around 133 projects worldwide were reported as commercial CCUS projects, while only 26% of these projects are considering permanent storage, and 74% are considering the benefits of EOR (Kenneth René Simonsen, 2024). Enhanced oil recovery (EOR) storage and Saline aquifer storage are fully commercial and widely used, especially in the United States (Ahmed M. Bukar, 2024).

For economic reasons, the pipeline is currently a proposed large-scale CO2 transport system due to the high technology readiness level (TRL) and the volume of CO2 transported per year. Alternatively, ships can be considered for the flexibility of the endpoint storage, while the trucks and the rails are excluded for the large scale (Hong Wan Yun, 2022).

Although transportation using trucks and rails is more viable, they are only convenient for small-scale and short distances. Accordingly, these transportation methods are not viable and scalable for large-scale and long distance, the cost of the transportation method varies depending on the scale and the distance (Hong, 2022).

COST-BENEFIT ANALYSIS:

Although CCS technologies would satisfy the aim of climate change by mitigating the resulting carbon emissions, the economic implications should be assessed to draw the technical feasibility aspects of the technologies (M.M. Faruque Hasan, 2014). The cost-benefit analysis and Techno-economic analysis TEA are comprehensive ways of assessing the economic implications of a project, especially for long-term projects, or over several generations, rather than the near-term projects, and helping in making certain economic choices (A. R. PREST, 1966).

Since the CCUS technologies are responsible for capturing carbon dioxide from emission sources to turn the CO2 wastes into valuable materials and products, reusing these materials and products would create an economic benefit; therefore, the net present value NPV, the internal rate of return IRR, and the Discounted Cash Flow are the tools of traditional investment decision-making (Weiwei Zhang, 2021).

Due to the uncertainty of the CCU technologies' revenues or the revenues are still unknown, this will require the cost-oriented indicators, the CAPEX, OPEX, and yield prices, which can help in evaluating the financial position by calculating the return on investment ROI, IRR, NPV, and Discounted Payback Period DPBP, according to the observations obtained from the literature review, a diverse set of indicators, such as the NPV, which is considered by one-third of the literature, IRR, total production cost, and discounted payback period DPBP, are repeatedly used to compare the feasibility of the technologies (Hanne Lamberts-Van Assche, 2021).

The literature also raised the importance of introducing ROA as a real option approach due to the irreversibility allowance, the uncertainty, and for enhancing the management flexibility to invest in CCUS (Hanne Lamberts-Van Assche, 2022). These reasons imposed the usage of the real option approach (ROA) in evaluating the CCUS investment value (Weiwei Zhang, 2021).

THE COST OF CCS:

Due to the high cost associated with the technologies, being a juvenile technology, all the advanced Egyptian proposals didn't exceed the phase of memoranda of understanding (MOUs) (Ahmed Elmezain, 2024). The cost is significantly affecting the feasibility of carbon capturing, utilizing, and storing technologies due to the major capital expenditure (CAPEX) needed to deploy full chain infrastructure, in addition to the operational expenditure OpEX related to the cost of the energy and the chemical feedstock (Kasper Storrs, 2023).

However, it is expected that the CCUS cost would be reduced over time due to the associated reduction of the uncertainty, tracking the performance, and recording positive cash flow (Eli Bashevkin, 2024). The literature highlighted a relationship between the cost of CCS implementation and the financial position of the cement companies due to this implementation (A.J. Simon, 2011).

The CapEX of CCUS investment includes the capturing equipment prices, carbon adsorption reagents, in addition to the cost of transportation based on different ways of transportation as CAPEX, while the OpEX includes the adsorption material cost, the maintenance fees, and the operational costs (Weiwei Zhang, 2021).

The fixed cost of OpEX should include the costs that would change with the operation of the organization, such as insurance costs, maintenance costs, labour costs, and overheads. In addition, the variable cost of OpEX is the cost that would be changed by the change in the operation of the company, such as the feedstock cost, utilities cost, energy consumption, and chemical consumption (Juanita Gallego Dávila, 2024). The increase in energy, such as steam and electricity, required for capture can significantly increase OPEX (BCS Baliga, 2021). The higher OpEX would affect the cash flow negatively, which in turn would affect the IRR, NPV, and DPBP negatively.

H1: The cost of implementation shows a significant negative relationship with the Financial Position.

THE NET PRESENT VALUE (NPV):

In the NPV calculation, the initial investment, such as capital costs, is considered as a cash outflow which is occurring at the beginning of the project. The subsequent cash flows, including revenues, operating costs, and salvage values, are discounted to their present values using an appropriate discount rate, which helps in assessing the overall viability of the investment.

However, the NPV can be applicable only if the investment is characterized by reversibility that enables the coverage of the initial cost or at least partially when the investment, for a certain reason, turns out to be unprofitable in a later stage, but it can recover its initial cost, which is not the case with the CCUS investment (Hanne Lamberts-Van Assche, 2022).

Due to the assumption of the NPV method being "now or never" and ignoring the management flexibility, accordingly, the consequences would be either to lose the benefit of the investment or to deal with the uncertainty, which might lead to the project's failure (Weiwei Zhang, 2021).

H1a: The cost of implementation shows a significant negative relationship with the NPV.

THE REAL OPTION APPROACH (ROA):

The real option approach is more suitable for CCS investment and widely used in such investments as it recognizes both the irreversibility and the investment flexibility that make its application potential to increase the feasibility of these investments, which the associated high cost, lack of incentives, and absence of viability decrease its deployment (Hanne Lamberts-Van Assche, 2022).

The real option approach allows the decision maker to invest now or later in response to the investment environment changes to avoid the expected future losses and increase the opportunities of gains from the investment, which differs from the traditional NPV (Hanne Lamberts-Van Assche, 2021).

The irreversibility allowance, the uncertainty, and enhancing the management flexibility to invest in CCUS impose wide usage of the real option approach (ROA) in evaluating the CCUS investment value on one hand, while, on the other hand the usage of two dimensional binomial tree model taking into consideration the

allowance price of the carbon emissions for CCS technology and the calculation of critical value (Weiwei Zhang, 2021).

THE INTERNAL RATE OF RETURN (IRR):

Investopedia defines the Internal Rate of Return (IRR) as "a metric used in financial analysis to estimate the profitability of potential investments. IRR is a discount rate that makes the net present value (NPV) of all cash flows equal to zero in a discounted cash flow analysis." (Jason Fernando, 2024).

"The IRR of incremental cash flow must be evaluated when comparing mutually exclusive projects." (Brown, 1994). The risks of high capital investment cost and uncertainty associated with carbon utilization and storage, and technical and financial failure, can have significant impacts on the calculation of the IRR for a CCUS project (Siyuan Chen, 2022). Some bodies of research claimed that the low or negative IRR are the characteristics of the CCUS projects, which make it unattractive for financing by bank loans and difficult to fulfill the debt requirement (Nan Wang, 2021).

H1b: The Cost of implementation shows a significant negative relationship with the IRR.

THE DISCOUNTED PAYBACK PERIOD (DPBP):

Discounted payback period is defined as "the length of time it takes for the discounted future net positive cash flows to equal the initial investment.", despite considering the time value of money but it ignores the cash flows after the payback period (Brown, 1994).

Some bodies of literature discuss that the Traditional Pay-Back period (PBP), in addition to the rate of return, can be alternatives to the Discount Cash Flow (DSF) method; however, these methods cannot calculate the time value of money (TVM), but all of them are essential for the DSF method (Kannapiran Arjunan, 2022).

The NPV is superior among the other metrics that are concerned with the assessment of the projects; it might ensure the profitability, but not the liquidity, while the discounted payback period rule can satisfy both concerns, liquidity and profitability, and it is preferred over the NPV and IRR (Bhandari, 2009). In case the useful life of any asset or investment is longer than the discounted payback period, then the investment is worthwhile, and it would be profitable (Will Kenton, 2024).

The increase in the initial cost of the implementation would be associated with a longer time for covering this initial cost until capturing enough amount of CO2 to generate revenue to cover this initial cost (OGL, 2022, p. 9).

H1c: The Cost of implementation shows a significant negative relationship with the DPBP.

DISCOUNT RATE:

Since the damages resulting from climate change are expected to increase in the future, and any action would require calculating the net present value of this future damage, which is highly dependent on the discount rate (EPA, 2016). The discount rate can help in making a decision regarding the CCUS investment and the opportunity cost compared to the different options of the alternative investments.

The discount rate significantly affects the financial viability of the Carbon capture, utilizing, and storage projects, as it has an impact on the NPV, IRR, and DPBP; moreover, it impacts the cost of capital and investors' attractiveness (Hanne Lamberts-Van Assche, 2021).

THE CARBON PRICES:

The theoretical argument highlighted that solving the climate change problems and meeting the climate change's complicated target would require a technological change; however, the economic incentives shaped by decreasing the cost and increasing the return would support the technological change's competitive advantage (Johan Lilliestam, 2021).

The cap and trading mechanism and carbon taxes are the two major instruments that support the carbon pricing policy, and the similarities between the two instruments are more than the differences between them. Eventually, both of them are working to place a carbon-pricing scheme (Stavins, 2020). The carbon credit framework, which will localize the revenues related to the Egyptian carbon pricing, is in continuous development (LYNX, 2023).

Since the literature suggested that the price of CO2 has a positive impact on the CCUS investment, and the price of CO2 is part of the cash inflow that would have a positive impact on IRR, NPV, and DPBP, the increase in the unit price would positively impact the feasibility (Hanne Lamberts-Van Assche, 2021).

H2: The carbon pricing shows a significant positive impact on the CCUS investment.

THE GOVERNMENTAL SUPPORT:

By realizing that the green economy is an effective tool of sustainability, the focus on waste management and reduction while promoting the economic resources raises the principles of the circular economy, this would lead to economic growth, and increase the governmental expenditure to protect the environment by the way that incentive the private sector (Amira Tohamy Mohammed Eltayb, 2021).

The financial support would moderate the relationship between the investment cost and the feasibility of CCUS by participating in the upfront cost (Kasper Storrs, 2023). The geological carbon storage using the existing oil & Gas wells not only serves the goals of sustainability, but it also has a positive impact from the financial perspective (Islam, Sohel, Redzuan, & Hasan, 2024).

Although (Ahmed Elmezain, 2024), highlighted that Egypt has no geological storage. It was claimed that Egypt has a lot of oil & gas, and abandoned wells throughout the country, especially in the western desert and in the Gulf of Suez. The usage of oil and gas wells that are abandoned and have no current economic value could positively impact the time and cost of drilling in the field of power generation, as the cost of drilling occupies a huge part of the CapEX (Ahmed M. Moustafa, 2022).

H3: Governmental support shows a significant positive impact on CCUS investment.

THE CAPITAL STRUCTURE CHANGE:

To build a successful CCUS business model, the revenue model is considered the most important element, followed by the capital structure, the different sources of funds, and the risk management (Hasan Muslemani, 2020).

The decision of selecting a specific capital structure, especially in the cement industry, would influence the companies' overall financial performance, as the increase in the debt share would affect the profitability negatively by increasing the debt expenses (Swati Negi, 2023).

However, according to Modigliani and Miller (1963) suggestion that maximizing the debt portion in the capital structure, would require higher interest payments, these tax deductible payments, helping in improving the companies' performance and contribute greater earning for the stakeholder, according to a study applied to a 217 Egyptian listed companies of different sectors in 2023 (Said, 2025).

H4: Capital structure change shows a significant positive impact on CCUS investment.

RESEARCH FRAMEWORK
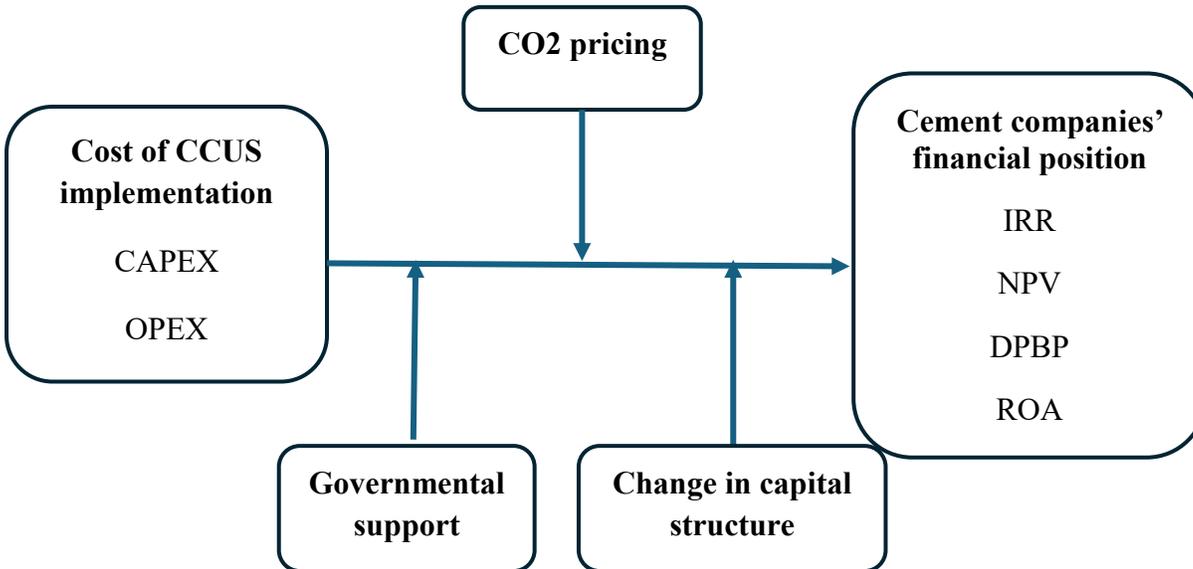
RESEARCH DESIGN:

The research methodology presented is a mixed approach that represents a pragmatic approach, which combines deductive and inductive approaches, offering a robust framework for exploring the complexity of the impact of the CCUS implementation cost on the cement company's financial position. Additionally, how the carbon prices and the governmental support would moderate this impact. The integration of quantitative and qualitative data collection techniques would provide a richer insight.

The inductive aspect adopts an exploratory lens, utilizing qualitative tools for data collection such as the analysis of secondary data, such as technical reports and conferences. As well as a case study of one of the leading companies in the field of cement production in Egypt, and a semi-structured in-depth interview with one of its top management to gain contextual nuances, patterns, and lived experiences regarding the cement industry and the current initiative toward the decarbonization of the cement industry. The inductive approach provides rich contextual insights into the characteristics and behaviors of the subject under study.

While the deductive approach would help in testing the hypotheses derived from existing theories, such as the techno-economic analysis and cost-benefit analysis, which help in quantifying the relationships and generalizing the results

Together, these complementary methods enhance the validity and comprehensiveness of research findings, enabling a more holistic understanding of the addressed research problem and the illustration of the proposed conceptual framework to fill the knowledge gap by answering the research questions and mitigating the limitations of singular paradigms. The independent and dependent variables and their dimensions, in addition to

the moderating variables, were operationalized to develop three main hypotheses and three secondary hypotheses.

According to the conceptual framework conducted by the literature review, the study used the real option approach by suggesting several scenarios to be able to monitor and track the impact of changes on the financial position of the cement company due to the implementation of the CCS technologies at each node of a decision tree using the NPV to give the management of the cement companies the flexibility in making the decision and at which circumstances the investment would be taken. Moreover, it provides the management with the requirements needed for making the decision.

METHODOLOGY:

In this study, several methodological and analytical approaches are employed, and both qualitative and quantitative research techniques are used to ensure the effective acquisition of the information required for each stage and the formulation of reliable findings.

DATA COLLECTION:

Due to the lack of available data regarding the accurate amount of carbon emissions and the CCUS Capex and OpEX, in Egypt generally and the cement industry in specifically the research would depend on the estimation shown in the secondary data such as technical data of the CCUS technologies and the technologies articles to obtain the budgetary offers and the technical specifications due to the inability of these data from the technology's providers.

The choice of having a case study as the research methodology would lead to a better answer to the research questions and the exploration of the new conceptual arguments that the case study would make possible, and stronger (Yin, 2018).
 A semi-structured interview is used as a qualitative method to gain a more in-depth and detailed picture from practitioners, experts, and industry leaders in the context of the study. The choice of semi-structured interview came from the points of strength of this type of interview, in addition to its suitability for the nature of the study, which requires a lot of information about new technology.
A questionnaire was prepared for a semi-structured interview to have insights into the cement industry in Egypt, the challenges that the industry faces, and the impact of the industry on the Environment. Moreover, the exploration of the decarbonization methods, the budget assigned for these methods, and its evaluation of these methods.

The discussion formulated through the semi-structured interview highlighted the actual impact of the current methods and the related impact on the emissions reduction and on the financial performance of the company, and whether the company is willing to apply the CCUS, and what is the expectation from this application.

The researcher collected historical data for the financial statements of the last 10 years to ensure the accuracy of the projection and to be able to exclude the years of unusual events that their impacts would have a negative effect on the projection of the financial statement if needed. Three years have had these events: 2016, 2022, the devaluation of the local currency, and 2020 due to COVID-19.

A financial model would be developed for the company by projection of the financial performance of the cement company in the future and setting some assumptions based on the historical data of the cement company and the qualitative data obtained through several tools. An integration of the CCUS technologies' financials in this projected financial model to be able to make the financial-economic decisions and to be able to test the hypotheses and answer the research questions.

A list of assumptions that is widely used in such cases, and as per the principles of the company, that estimates, and associated assumptions are based on historical experience and other factors that are relevant for the projection of the financial statements.

A techno-economic assessment (TEA) and cost-benefit analysis are used to assess the impact of the technologies' implementation on the company's financial performance. The researcher will conduct a comparative analysis by implementing the technologies in a cement company and measuring the difference in the company's forecasted financial performance in the presence of the control variables, and the sensitivity of these variables represents several scenarios for the period between 2026 – 2040.

CONSTRUCTION PLANNING ASSUMPTION:

According to the researcher's experiences, the schedule of 3 years and the capital cost allocation are reasonable and convenient, as 50% of the capital in the first year would be employed for the site preparation and the down payment of the long lead equipment, in addition to the permits and governmental expenses that would be demanded at the early beginning of the construction projects. While the equal capital for the second and third years is also convenient for finalizing the work, testing, and commissioning.

CAPTURING CAPEX ESTIMATION

The researcher employed a conservative approach in all assumptions, especially in choosing the carbon capture capital cost by taking the average of the capital cost of Europe, which was also mentioned in the literature. The capital cost selected falls within the range of the global estimations as mentioned in the semi-structured interview. The higher range is convenient due to the limited experience with such green investments. The convenient carbon-capturing capital cost that would be used in the calculations would be \$120/tonCO2.

THE STORAGE & TRANSPORTATION CAPEX:

As a result of six case studies extracted from Skagestad et al for post-combustion carbon dioxide capture, and the pipeline or the ship to be used as a transportation method, the capturing consumed the highest portion of the expenses with 65% and the transportation consumed 25% while the storage consumed 10% (Kenneth René Simonsen, 2024).

OPEX DATA COLLECTION AND ASSUMPTION:

THE FIXED OPEX:

"The fixed OPEX is defined as 2.5% of the CAPEX plus labour cost." (Juanita Gallego Dávila, 2024).

The VARIABLE OPEX

The utilities: the energy required per year is one factor that indicates the cost of electricity; however, on average, the electricity needed for the operation is counted for around 90-150 KWH / ton of cement for the CCUS (CEMCAP, 2017). According to the Egyptian electrical utility and consumer protection, the cost of each KWH is EGP 1.60.

Labor: The amount of administrative labor in the OpEX is assumed to be 30% of the operation, while the maintenance labor is suggested to be 40% of the overall maintenance cost (CEMCAP, 2017).

The Energy: "A thorough evaluation of CO_2 capture and revealed that the lowest energy requirements were 1.88, 2.10, 3.64, and 5.20 GJ/tCO_2 for rectisol, DMC, CAP, and MEA, respectively." (Enobong Hanson, 2025, p. 4).

THE TRANSPORTATION AND STORAGE OPEX

The distance and the capacity of CO2 transported are the factors that affect the OpEX of the transportation. The literature claimed that the cost of the offshore pipeline for a facility of capacity of 2.5 Mt in Europe is around $11, and the transported distance is around 180 km, while this amount is decreased to $6.2 for the same capacity and same distance but for an onshore pipeline. However, the transportation cost of a ship with the same circumstances is around $9.4 (Hong Wan Yun, 2022).

THE CARBON PRICES:

In this study, three carbon prices were chosen to measure the sensitivity of the carbon prices: the carbon price of $20, which is used for trading in Egypt EGX (EGX, 2025), the carbon price of $40 mentioned in the semi-structured interview for international trading, and the carbon price of $70 mentioned in the literature, at which the technologies would be viable (BCS Baliga, 2021).

THE GOVERNMENTAL SUPPORT ASSUMPTIONS:

Since the Egyptian government usually supports green projects, the study assumes that the government would facilitate infrastructure such as pipelines and storage reservoirs by allowing the use of petroleum infrastructure, which would reduce the CapEX of the CCS, especially since the literature claims a similarity between the two infrastructures. Therefore, the CapEX for transportation and storage would be excluded from the overall CapEX.

THE CAPITAL STRUCTURE ASSUMPTIONS:

The change in the capital structure sensitivity is also considered in one case, the debt ratio is 70% to 30% due to the consideration of the available Equity shown in the financial statements, and in another Scenario, the capital structure was changed from 70% - 30% to 80$ - 20% as the maximum reasonable amount of debt can be obtained to track their impact accurately.

ANALYSIS:

The cost of CCS is introduced to the financial statements without any additional cash inflows; a significant failure in the company's net cash flows has been imposed. The net cash flows are associated with a negative sign; the high cost of implementing CCS has a significant negative impact on the company's net cash flows.

As revenues increased, due to the cash inflows from captured carbon trading and utilization, the net cash flows show a positive sign. The negative cash flows are shown at carbon prices of $20 and $40; this means that the company would not continue for long at those carbon prices, while at a carbon price of $70, positive net cash flows have occurred

The net cash flows of introducing government support separately are associated with a negative sign over the study period. The governmental support as a standalone control variable doesn't have a significant positive impact on the net cash flows. However, including revenues contributed from carbon trading with governmental support shows an improvement in the net cash flows at $70 carbon pricing.

The capital structure changed from 70% debt to 30% equity to 80% debt to 20% equity and has the same revenues as the previous scenarios at the same carbon prices; the net cash flows don't show any change.

The free cash flow represents the amount of cash that the company actually disposed. It is also an indication that the company is generating cash flow from its operations after subtracting the expenses, investments, and taxes. It also shows the financial metric that is essential to show the ability of the company to meet its obligations, and how healthy the financial position of the company (Adam Hayes, 2025). The Free cash flow is convenient to

consider the company's financial strength and show the impact of the CCUS investment on the overall company's financial position.

The free cash flows have improved from one scenario to another, imposing a positive impact on the company's free cash flow; however, this positive impact of each scenario separately does not improve the financial position. The higher carbon prices supported by the governmental support and capital structure change have imposed a positive impact on free cash flows.

The free cash flow improvements compared to the net cash flows indicate that the company has strong operating cash flows. This situation typically occurs due to significantly large cash outflows from investing in CCS technologies that reduce the net cash flow below the level of free cash flow. In other words, the strong operation of the cement company and the generation of new revenues allowed the investment in the CCS to a certain level.

THE FINDINGS

The result of the analysis shows that the cost of implementing the CCS technologies would affect the IRR and the NPV negatively, as the IRR after investing in the technologies is not applicable due to the negative IRR, and the NPV is affected negatively by the cost of implementation of CCS technologies. Moreover, the high implementation costs have a negative impact on the discounted payback period and make the initial investment coverage period very long.

The carbon prices have a significant positive impact on the relationship between the cost of implementation and the financial position. However, the low carbon prices of $20 and $40 improve the IRR to be positive, but with NPV remaining negative. The higher carbon price of $70 shows a higher IRR and positive NPV, but the IRR is still smaller than the weighted average cost of capital (WACC) of the project, which is not potentially promoted.

The governmental support for around 33% of the CapEX, in addition to high carbon prices, shows an improvement in the IRR to be positive, to exceed the WACC rate, and the NPV becomes positive. While the change in the capital structure incrementally with carbon prices and governmental support doesn't show an improvement in the IRR compared to the scenario of the high carbon price with the governmental support; however, it shows a significant positive impact on the NPV.

The high investment cost affects both the payback period and the discounted payback period negatively, as the results show a very long payback period, except only at the high carbon price.

DISCUSSION:

The findings are consistent, supporting that the construct of cost of implementation of CCUS with its dimensions of Capex and OpEX, has a direct effect on the financial position of the Cement company. This is similar to the technical assistance consultants' report conducted in India which has different economic parameters such as the low and several market risks, confirming that the cost of implementing CCS with its two dimensions would affect the financial position in terms of IRR, NPV and MIRR and it also confirmed that the change in the utilization price and increase in the carbon credit in addition to the governmental support would moderate this relationship (BCS Baliga, 2021).

This study showed that high investment cost affects both the payback period and the discounted payback period negatively. This finding is supported by (OGL,2022, p.9), which highlighted that if the CapEX payment has not been paid within a certain period, the CapEX payment rate will continue until the fixed quantum of return is fully paid.

This study showed that governmental subsidy as a single variable had a negative NPV and negative IRR, which answers the research question of the impact of governmental support on the relationship between dependent and independent variables. These findings are concurrent with the findings of a study conducted in a different region of China, using a case study methodology of coal-fired power plants, conducted by (Weiwei Zhang, 2021), which showed that the governmental subsidy would never alone promote the investment in CCUS even at the highest limit of 33%.

Moreover, this study also supports the findings of a study conducted in a different sector, as steel industry, conducted by (Hasan Muslemani, 2020), which highlighted that structuring the funding source and capital and ownership structure, in addition to the risk management, is important for the revenue of the successful implementation of the CCS; however, the findings of this study raised the importance of occurring at higher carbon prices.

CONCLUSION:

By the utilization of the real option approach and exploring the embedded scenarios to give the decision-making unit the flexibility of making a decision, the results highlighted that the different moderating variables influence the relationship between the dependent and independent variables positively. However, the impact of the high cost made the results still negative in all scenarios proposed, except at a higher CO2 price of $70 and with the help of governmental support. While the change in the capital structure improves the financial position metrics' results, such as the NPV and PBP.

Although the positive impact of each moderating variable on cash flows and the financial position, each moderating variable as a single variable cannot mitigate the effect of the high cost of CCS implementation. The moderating variables together improved the IRR, NPV, and payback period and could reach the viability of the CCS technologies implementation to the Egyptian.

In Egypt, the high cost of capital represents a high discount rate that the stakeholder would require as a minimum return. This required a high carbon price of $70 and support of the government by availing the idle oil and gas wells to reach an IRR exceeding the WACC, higher NPV, and shorter PBP. Accordingly, the Egyptian cement industry would not be able to invest in CCS before the carbon price increases from the current price of $20 to $70, and the usage of the idle oil and gas wells by the Egyptian government is granted.

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