Avenues To Reduce Carbon Emission In Cement Fabrication To Acquire Carbon Credit

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Abstract

The cement industry accounts for roughly 8% of global carbon dioxide emission, and for every tonne of cement procured, a ton of carbon dioxide is released into the air. Cement industry is the backbone of global infrastructure development with no sign of slowing down, as such, it provides the most promising testbed for a carbon credit market to start up. Carbon credit functions as a conversion of money as payment to offset carbon dioxide emission, and can be acquired by reducing carbon emission or its greenhouse equivalents. This carbon credit can then be sold on the carbon market which provides financial incentive for companies to reduce their carbon emission. Acquiring carbon credit can be a viable capital gain strategy in developing nations due to their relatively low labor and overhead costs. This study aims to provide avenues to reduce carbon dioxide emission in cement fabrication as a way to acquire carbon credit for capital gain purposes to developing nations worldwide. This study uses literature review with a descriptive qualitative methodology, with data from relevant books and journals of renowned and reputable publishers online as validity. This study identified three promising avenues to reduce carbon dioxide emission in cement fabrication: alternative cement aggregate material fly ash and bottom ash, carbon capture and storage technology, and alternative fuel in cement fabrication. Three avenues provide pathways for players in the cement industry to adopt according to their capabilities in order to effectively reduce their carbon dioxide emission for acquiring carbon credit.

Keyword: cement; carbon emission; reduce carbon emission; carbon credit; literature review

1. Introduction

Climate change refers to a gradual change in temperature as a result to changes in weather pattern as a direct consequence of human activity. Urgency on climate change began around the year 1750s, with the discovery of steam engine utilizing the burning of coal, fossil fuel, and natural gasses referred to the first industrial revolution, signals the steady climb of carbon dioxide concentration in the atmosphere, which plays the role of a greenhouse gas that can trap solar radiation coming into the earth. The scientific consensus of Intergovernmental Panel of Climate Change (IPCC) stated carbon dioxide emission as a result of uncontrolled fossil fuel burning will increase global temperature level by around 1.5 Celsius to 2.0 Celsius by the end of the century. As a consequence, carbon dioxide concentration counted from the pre-industrial level slated a record high never seen in 800,000 years.

United Nations playing the role of leader puts the action for other global organizations to press the urgency of climate action for the safety of future livability. Action were made by the European Union to lead by example by setting the goal for a Net Zero 2050 through neutral carbon emission across the EU by the year 2050, alongside the World Economic Forum that puts the pressure on developing nations in G20 to suppress their carbon emission with the help of developed nation by providing Carbon Credit incentive of 20 billion USD to be used by Indonesian government to kickstart decarbonization across the nation, known by the name Kemitraan Transisi Energi Indonesia yang Adil.

Following the sustainability theme set forth in G20 Bali, the Indonesian government puts a new law into order known as Pengembangan dan Penguatan Sektor Keuangan or in short (PS2K), which includes therein the mandate of authority towards Otoritas Jasa Keuangan (OJK) to authorate and regulate the trading of secondary instruments relating to the economic value of carbon in the carbon market. Thus, in September 26th 2023, the President Joko Widodo officially launched the country's first compliance-based carbon exchange operated by the Indonesia Stock Exchange, under the authority of OJK.

The opening of nation's first carbon market introduces a brand new avenue for corporations to acquire capital, whereas before a corporation's only directive to pursue investments towards green innovation were to increase their Good Corporate Governance score, with the carbon market, corporations now stand to profit from the sale of carbon credit, adding another stream of revenue and a potential competitive edge towards their competitors.

Indonesia, alongside other developing nations, consumes concrete as a backbone to national infrastructure development. This consumption of concrete rise in accordance to mega infrastructure development, as an example, the construction of Indonesia's Jalan Tol Trans-Sumatera consumes as much as half of the entire nation's use of concrete annually, and may increase substantially with the nation's plan to relocate their capital city from Java to Borneo in the foreseeable future.

Concrete is a mixture of cement and aggregate which comprise a viscous substance that hardens into a consistency of a rock when stilled and exposed to air. As such, concrete can be poured into a mould when liquid, and hardens into shape, which makes concrete a popular building material that places concrete as number two behind water for the most used substance in the whole world.

Problem began when a collaborative research by Material Economics as direct order from the European Union to achieve Net Zero 2050, which found the fabrication of concrete accounts for a total of 8% of global carbon dioxide emission, and that for every 1 kilogram of cement fabricated, 0.7 kilogram of carbon dioxide were released into the air (Material Economics, page 18, 2019). This implies the need for innovations that reduces carbon dioxide emission as a result of concrete fabrication and utilization.

2. Literature Review

2.1 Concrete

(Concrete Technology, page 2, 2010) Defined concrete in the broadest sense as any product or mass made by the use of a cementing medium. Generally, this medium is the product of reaction between hydraulic cement and water. Concrete is made with several types of cement containing pozzolan, fly ash, blast furnace slag, micro-silica, additives, and so on; these then be heated, steam-cured, autoclaved, vacuum-treated, hydraulically pressured, shock-vibrated, extruded, and poured. Simply put, concrete is no more than a mixture of cement, water, aggregate (fine and coarse) and admixtures.

2.2 Cement

Ancient Romans were probably the first to use cement to make concrete, which is a material that hardens under water. This property of not undergoing chemical change by water in later life are what contributed to the widespread use of concrete as a building material, until its disuse in 1824 by a replacement modern cement known as Portland cement. Inadvertently, when the noun cement is used, the correct context it referenced refers to what is known in modern times as Portland cement. Portland cement is the product obtained by pulverizing clinker consisting of hydraulic calcium silicates to which some calcium sulfate has usually been provided as an interground addition. In the broadest sense, cement is a chemical substance which functions as a binding agent to other materials that then hardens and bind them together. Cement that is mixed with fine aggregate will form mortar or plaster, whereas a cement that is mixed with coarse aggregate sand and gravel produces concrete (Concrete Technology, page 8, 2010).

2.3 Carbon Dioxide

The IPCC in their 2012 report of (Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation, page 556, 2012) defined carbon dioxide as a naturally occurring gas fixed by photosynthesis into organic matter. Given its climate change context, carbon dioxide is a byproduct of fossil fuel combustion and biomass burning, it is also emitted from land use changes and other industrial processes. It is the principal anthropogenic greenhouse gas that affects the Earth's radiative balance. It is the reference gas against which other greenhouse gases are measured.

2.4 Carbon Emission

The IPCC in their 2022 report of (Climate Change 2022: Mitigation of Climate Change, page 1795, 2022) defined carbon emission as emissions of greenhouse gases (GHG) in particular carbon dioxide, other trace gases, and aerosols resulting from the combustion of fuels from fossil carbon deposits such as oil, gas, and coal.

2.5 Carbon Credit

Carbon credit is a form of payment towards carbon offset introduced in the *Kyoto Protocol* initiated by the United Nations Framework Convention on Climate Change in 1997. Carbon credit was introduced to encourage firms to be more environmentally friendly in conducting their businesses. One carbon credit allows one tonne of carbon dioxide or a corresponding amount of other greenhouse gases to be discharged in the air. Businesses that are over their quotas must buy carbon credits for excess emissions, while those below can sell their remaining credits. In essence, the ones who are selling are companies that use clean technology, and those buying are the world's polluters. Carbon credits, just like any other monetary instrument, are traded in an open market, particularly in a carbon market or a carbon exchange (Gupta, 2011).

2.6 Carbon Market

The original term for what we contextualize now as the "carbon market" originates from the Kyoto Protocol in the report (Kyoto Protocol to the United Nations Framework Convention on Climate Change, 1997) under the umbrella term "emissions trading". The term emissions trading refers to a mechanism which allows countries that have emission units to spare – emissions permitted to them but not "used" – to sell this excess capacity to countries that are over their targets. The term evolves from the generalized "emissions trading" into "carbon market" due to the main driving principle of greenhouse gas being carbon dioxide, as such, people speak simply of trading in carbon, hence the evolution of phrase used into "carbon market".

The modern term of "carbon market" as defined in the (Emissions Gap Report 2021, page XI, 2021) by the United Nations Environment Programme, refers to carbon market as a term for a carbon trading system through which countries may buy or sell units of greenhouse gas emissions in an effort to meet their national limits on emissions, either under the Kyoto Protocol or other agreements. The term comes from the fact that carbon dioxide is the predominant greenhouse gas, and other gases are measured in units called carbon dioxide equivalent. Carbon market currently has two forms; "compliance-based" in which carbon credits were issued and has their value in the market backed by the government, and "voluntary" in which credit exchanges were done outside compliance market without any involvement or backing by the government.

3. Material and Method

This study aims to provide avenues to reduce carbon dioxide emission in cement fabrication as a way to acquire carbon credit for capital gain purposes to developing nations worldwide by identifying methods that are viable and applicable in order to reduce carbon dioxide emission in cement fabrication. The methodology used in this study is literary review which involves collecting and analyzing data from various journals books, proceedings, and documents and supplementary used by the Intergovernmental Panel on Climate Change as validity. Methodological approach used is descriptive qualitative due to the descriptive nature of data used in the form of prior research done by others. According to (Sugiyono, 2013), qualitative methodology is a research methodology under the basis of philosophy that is applied to a scientific condition, of which data is derived from the description which gives meaning. A qualitative method is best suited towards topics that are complex or not clearly defined, where the researcher plays a key role in obtaining meaning from data.

This study has the objective to identify avenues to reduce carbon dioxide emission in cement fabrication as a way to acquire carbon credit for capital gain purposes.

This study has the scope of literature review to identify, explain, and cost/benefit analysis if applicable, to methods identified to be capable to reduce carbon dioxide emission in cement fabrication.

4. Result

This study has identified three possible solutions to reduce carbon emission as a result of cement fabrication, that being the use of alternative aggregate material of fly ash and bottom ash (FABA) courtesy of (Siriruang et al, 2016), carbon capture and storage of carbon dioxide emission in clinker fabrication courtesy of (Barker et al, 2009), and the use of alternative combustion fuel in cement fabrication courtesy of (Hasanbeigi & Bhadbhade, 2023).

Conclusions and explanations of each method obtained from respective authors are as followed in the Discussion segment.

5. Discussion

5.1 Alternative Aggregate Material – Fly Ash and Bottom Ash (FABA)

One avenue to reduce carbon emission is through the utilization of fly ash and bottom ash (FABA) material as a main aggregate in a concrete mix. Fly ash is the byproduct waste of coal power plants, that has a particular molecular characteristic as calcium oxide (CaO), which reacts with carbon dioxide ($CO2$) in the atmosphere that absorbs it and entraps it within its structure. This carbon absorption significantly reduces expansion characteristics of concrete when exposed to heat, as such prevents the forming of cracks in structural integrity (Siriruang et al, 2016).

Research done by Kementerian Lingkungan Hidup dan Kehutanan (Ministry of Life Ecosystem and Forestry) alongside Kementerian Energi dan Sumber Daya Mineral (Ministry of Energy and Mineral Resources) to FABA waste management in a Pembangkit Listrik Tenaga Uap (Steam Power Plant) in Indonesia, concluded the classification of FABA as a “waste nonB3” with a specific source code of “B409 Bahan Tidak Berbahaya dan Beracun” (B409 Material Not Dangerous Nor Toxic). This research was supported by other independent source done by a research led by the Toxicity Characteristic Leaching Procedure towards FABA waste of 19 different steam power plants in Indonesia, with all toxicity parameter results of below the threshold in accordance to the Toxicity Reference Value set by the Peraturan Menteri Tenaga Kerja No. 5 Tahun 2018 (Ministry Rule of Labour Number 5 Year 2018). In addition, Indonesia’s largest coal exporting destinations China, India, South Korea, United States of America, Australia, Canada, Continental Europe, Japan, Russia, and South Africa has not categorized FABA as a “waste B3” equivalents, but rather as “solid waste”. FABA has also found wide use as a supporting substance used in mineshaft reclamation to prevent collapse, stabilization of landslide-prone landscape, and carbon dioxide soil enrichment in the form of fertilizer in agriculture (Kementrian Lingkungan Hidup dan Kehutanan & Kementerian Energi dan Sumber Daya Mineral, 2021).

However, the usage of FABA as an alternative aggregate material to reduce carbon emission may be limited in its availability in the future. As the cement industry become aware of the benefit of FABA to reduce carbon emission, so does the demand towards it become high. Coal power plants produces FABA as a waste byproduct of its operation, as such it is not in their business to produce FABA. As such, its availability highly depends on vicinity to a nearby coal plant, limiting its feasibility as distance increases due to raising cost to transport. In conclusion, this avenue has a wildly varying feasibility dependent to access of a nearby coal power plant, and would only work short-term as further demand may increase which limits the availability of this material.

5.2 Carbon Capture and Storage – Carbon Dioxide Emission in Clinker Fabrication

Concrete is comprised in two main constituents—that is cement and aggregate. In cement fabrication, it has been identified which step in its fabrication process that contributes to the majority of carbon dioxide emission, and that is the ignition of limestone in order to produce clinker. Clinker is an additive substance for cement that whenever mixed with water and aggregate, will function as adhesion which gives concrete its capability to be molded when liquid, and stand firm as a unit when solid. Clinker is obtained through the ignition of limestone which comprises of calcium carbonate (CaCO3), which contain inside the fossilized sea shells in the form of silica, that which then evaporates into the atmosphere as carbon dioxide through burning. In this process, 83% of carbon dioxide mass trapped in its chemical structure evaporates into the atmosphere, accounting for 60% of total carbon dioxide emission in cement fabrication. As such, this fabrication step cannot be avoided, and has a high potentiality for the carbon capture and storage technology to be practiced (Ishak & Hashim, 2014).

Prior study done by author (Barker et al, 2009) conducted the efficacy of carbon capture technology alongside its cost-benefit assessment:

- **Post-combustion CO2 Capture**. This technique utilizes the substance monoethanolamine (MEA) that reacts in chemistry towards carbon dioxide. Gas emission from clinker fabrication were recirculated inth a Flue Gas Desuplhurisation system to then be cooled into a temperature of 50 degree Celsius, to which then MEA were introduced into the chamber to induce carbon deposition towards the ground. The deposited carbon can then be encapsulated and buried underground. This technique effectively erased 74% of total carbon emission of a cement plant, with the energy cost of 107 Euro/ton CO2 (figure not corrected to inflation rates since year 2009).
- **Oxy-combustion CO2 Capture**. This technique identified that 95% of carbon dioxide emission happens during limestone ignition to produce clinker happens in the process of preheating and precalciner. This technique installs an auxiliary pipe between the preheater and the precalciner, to which then oxygen (O2) were funneled into, resulting in the manipulation of low air pressure in the auxiliary pipe due to the combustion of oxygen. This low air pressure functions as a suction to funnel carbon dioxide emission made in the precalciner, into a separate plant where carbon dioxide can then be cooled down and deposited low for collection,

encapsulation, and burying underground. This technique effectively erased 61% of total carbon emission of a cement plant. However, due to the installment of auxiliary funnel pipe alongside a separate plant and oxygen combustion, its total effectiveness were down to only 52% of total carbon emission of the plant. On the other hand, the energy cost were a surprising low of 40 Euro/ton CO2 (figure not corrected to inflation rates since year 2009), far more efficient than the Post-combustion CO2 Capture technique.

Prior research done by (Barker et al, 2009) has shown two carbon capture and storage technology suitable to reduce carbon emission in cement fabrication plants. Technology requires significant time and money investment, but offer scalability and long-term sustainability in cement fabrication, that may offer a steady reduce in carbon emission to continuously acquire carbon credit.

5.3 Alternative Fuel in Cement Fabrication

According to prior research by (Hasanbeigi & Bhadbhade, 2023) there were identified alternative sources as fuel for combustion in cement fabrication. The use of waste such as car tires, plastic waste, sewage sludge, municipal solid waste, biomass, and chemical waste can be used as combustion fuel as long as toxicity levels were below acceptable threshold in accordance to the European Commission. Alternative fuel can be categorized into three states: solid waste, semi-solid waste, and liquid waste. Pre-treatment is necessary to purify and separate the substance suitable as a use for fuel. The use of alternative fuel puts the process of recycling and non-fossil fuel usage as the main drive towards reducing carbon emission.

The following is a technical description of alternative fuel as described by the author to have been used as fuel in the cement industry:

- **Scrap Tires**. Scrap tire waste has been used as alternative fuel in roughly 10-20% of alternative fuel usage in cement plant globally. Scrap tire waste can be used as is without pre-treatment, and will leave 24% of its total mass after combustion, which can be used as aggregate in clinker production.
- **Municipal Solid Waste (MSW)**. Due to its organic and non-organic nature, pre-treatment is necessary to separate its combustible constituents to its non-combustible parts. MSW is most suitably used in clinker combustion, and the burning of MSW is most efficient to reduce carbon emission compared to other alternative fuel usage.
- **Plastic Waste**. Plastic waste is the most widely available form of waste and has a high calorific value, making it an excellent fuel for prolonged combustion. However, burning plastic will produce hydro chloride, dioxins, and furan which are highly toxic, as such the use of plastic as fuel should be limited to not exceed 0.7% of all fuel usage in order to both maintain a safe work environment and clinker quality.
- **Sewage Sludge**. The sewage sludge referred to must come from a water treatment plant. This waste can be used both for fuel and clinker aggregate, but pre-treatment is needed to reduce its moisture content to that of below 1% for effective combustion. Substitution of fossil fuel in clinker production by sewage sludge will decrease carbon emission, but will introduce sulfur dioxide (SO2) emission into the air. It is to be noted that sewage sludge has the highest

concentration of mercury compared to other waste described, as such proper work and safety equipment must be maintained.

- **Biomass**. Biomass waste has the safest toxicity pollutants emitted when burning compared to other waste products, as such the recycling of biomass as fuel is a top priority for cement plants. Most common of biomass waste comprise of agriculture waste and refuse. Even though biomass burning is relatively safe, many research has been done to challenge its "carbon neutrality" assumption. Biotic waste emits a substantially higher carbon emission than fossil fuels, even after counting its recycling aspect of carbon emission mitigation.
- **Chemical and Hazardous Waste**. Dangerous and highly toxic waste as byproducts of waste oils, spent solvents, obsolete pesticides, paint residue, and heavy metal industries. Waste oils and spent solvents has the highest calorific value for a long combustion time. The burning of chemical and hazardous waste will reduce carbon emission, at the cost of toxic pollutants that will endanger public and worker health, and environmental sustainability.

The use of alternative fuel in the form of waste in cement fabrication has proved to be effective to reduce carbon emission. This practice has been—and remain used to this day in the cement industry, however whilst it is correct that the carbon emission has been reduced and is a viable avenue to acquire carbon credit, in its place were taken other pollutants that are equally—or rather more dangerous than carbon dioxide for the environment. The usage of alternative fuel should be followed by their own discretion, and note of action done that may impact corporate sustainability theme of each of their Good Corporate Governance principles.

6. Conclusion, Implication, and Recommendation

This study has identified three promising avenues to reduce carbon dioxide emission in cement fabrication. Alternative aggregate material FABA provides most promising short-term adoption to cement plants that are in close vicinity to a coal power plant, carbon capture and storage technology trades significant time and money investment for scalability and steady carbon credit, and lastly the use of alternative fuel while effective in reducing carbon dioxide emission by way of non-utilization of fossil fuel combustion—will introduce toxic pollutants in its place that may prove more dangerous to the environment and harms sustainability. All avenues can be adapted into decision making for players in the cement industry according to their capabilities and risk tolerance for the pursuit of carbon credit to acquire capital remains a feasible strategy.

This study is limited in scope as a literature review to identify, explain, and cost/benefit analysis if applicable with an objective of identifying ways in which players in the cement industry can reduce their carbon dioxide emission to pursue capital gain in the form of carbon credit acquirement. As such, for a more technical description, sourced authors and papers were to be consulted.

This study functions as a literature review to provide foundation for further—more technical studies in ways to reduce carbon emissions to be built upon. The findings this study has identified, if continued, should be with empirical tests of proving the quantifiable result to carbon emission reduce and carbon credit feasibility studies in developing nations.

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