Decoding Sustainability with a Life Cycle Assessment of Crushed Stone Aggregate Production

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Abstract:- Aggregate materials play a crucial role in various construction applications and the development of infrastructure, serving as indispensable components for the advancement of any modern economy. The primary objective of this research is to assess the carbon footprint associated with the production of crushed stone aggregate. Comprehensive data has been systematically gathered from diverse stone quarries and crusher units, encompassing various stages of the production process. This data forms the basis for quantifying the emissions of equivalent Carbon Dioxide (CO_2) throughout key phases, including quarry operations involving explosive blasting, transportation of boulders to crusher units, and the crushing process in different types of crushing units such as primary and secondary crushers.

The research methodology involves the meticulous collection of data pertaining to the actual energy consumption during different crushing activities. This detailed information has been carefully gathered and subsequently subjected to a thorough analysis to quantify the carbon footprint. The analysis has been facilitated through the utilization of advanced software tools, specifically Simapro and LCAPAVE [1], allowing for a precise assessment of the environmental impact associated with each stage of crushed stone aggregate production.

By employing these sophisticated software applications, the study aims to provide a comprehensive and accurate depiction of the carbon emissions attributed to the entire life cycle of crushed stone aggregate production. This data-driven approach ensures a nuanced understanding of the environmental implications of each step involved, enabling stakeholders to make informed decisions towards sustainable practices and carbon mitigation strategies in the aggregate production industry.

Key words:- Life cycle Assessment, Carbon Foot Print, Crushed Stone Aggregate, Global Warming

Introduction:-

Aggregate stands as a pivotal building material in the construction industry, encompassing essential components like coarse aggregate, river sand and gravel, M-sand, and aggregate tailored for diverse applications. These applications extend to road bases, railway ballasts, soling, pitching, and coastal projects. A significant portion of aggregates takes a path where they synergize with other materials, such as cement and bitumen, to serve the construction sector's needs.

The primary user segment for aggregates involves their combination with cement, constituting the cementation route. This segment stands out as the largest consumer of aggregates, and its estimation is facilitated by the well-recorded and readily available data on cement consumption

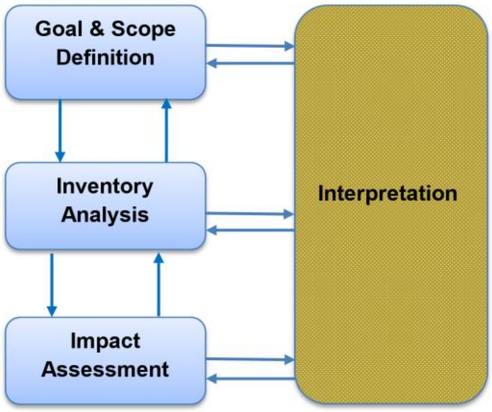
According to the Global Aggregates Information Network (GAIN)[2] report, the annual global production of aggregates amounts to 32 billion tons, which leaves enormous amount of carbon foot print globally.

In this paper study has been conducted to quantify the quantum of greenhouse gas release during the production of crushed aggregates.

LCAoverview:-

Life cycle assessment (LCA) is a methodology designed to comprehend, evaluate, and quantify the environmental impact of a specific product. Recently, there has been an escalating application of LCA to scrutinize greenhouse gas (GHG) emissions and other environmentally significant substances associated with road pavements. The increasing body of literature on LCA for pavements reflects a growing awareness of the need to enhance the sustainability of infrastructure systems.

The standardized structure of LCA was established by the International Standards Organisation. Illustrated in the subsequent figure are three fundamental stages: goal and scope definition, inventory analysis, and impact analysis.



1.1 Goal Definition and scope:-

In the Life Cycle Assessment (LCA) of any process, the initial phase involves defining the goal and scope. In undertaking LCA for any process, the overarching objective is to systematically identify all environmental impacts associated with a material and devise effective solutions to mitigate or reduce the adverse environmental effects.The objective of this study is to analyze and measure both the energy consumption and resulting carbon footprint throughout the entire lifecycle of aggregate production, spanning from the initial stages to the final gate.

1.2 Inventory Analysis

Inventory analysis entails the examination of an inventory flow throughout the entire life cycle of a process or product, ranging from its initial stages to its ultimate conclusion. This comprehensive analysis incorporates a thorough assessment of inputs, encompassing water, energy, and raw materials, as well as emissions to air, water, and soil at various stages of the life cycle.

1.3Impact Assessment

The impacts assessment in Life Cycle Assessment (LCA) involves evaluating the influence of activities analyzed through LCA. This assessment encompasses various categories, such as global warming potential, acidification, eutrophication, photochemical smog, and others, to comprehensively gauge the environmental effects associated with the studied processes or products.

1.4 Objectives

The primary objectives of this research are to delve into the environmental footprint of crushed stone aggregate production through a rigorous Life Cycle Assessment (LCA). By systematically examining each stage of the production process, from quarry operations to the final product, the study aims to quantify and understand the carbon emissions, energy consumption, and other environmental impacts associated with this crucial construction material. Additionally, the research seeks tocontribute valuable insights that can inform sustainable practices within the aggregate production industry, aiding in the development of eco-friendly strategies for future infrastructure projects.

1.5 Scope

The scope of this research paper is comprehensive, spanning the entire life cycle of crushed stone aggregate production. The study encompasses data collection from various stone quarries and crusher units, examining critical stages such as explosive blasting in quarries, transportation of boulders to crusher units, and the actual crushing process using primary and secondary crushers. The focus extends beyond mere data collection to a detailed analysis using advanced software tools like Simapro and LCAPAVE, aiming to quantify the carbon footprint associated with each stage. Furthermore, the research aims to contribute to the broader understanding of sustainable practices in the construction industry, providing insights that can inform decision-making for future infrastructure projects.

1.6 Inventory Analysis

In the context of my research, the Inventory Analysis constitutes a crucial phase within the Life Cycle Assessment (LCA) methodology. This analysis involves a meticulous examination of the entire inventory flow associated with crushed stone aggregate production. Starting from the initial stages, often referred to as the "cradle" stage, and extending to the end stage, the Inventory Analysis assesses the inflow and outflow of materials, energy, and emissions throughout the entire life cycle.

Specifically, the Inventory Analysis in my research scrutinizes inputs such as water, energy, and raw materials, as well as emissions to air, water, and soil at various points in the production process. This detailed examination aims to quantify and characterize the environmental aspects and resource consumption linked to each stage of crushed stone aggregate production. By thoroughly understanding the inventory flows, this research seeks to provide valuable insights into the environmental impact of the entire process, contributing to a more comprehensive and informed assessment of sustainability within the construction industry.

1.6 Impact Assessment

The total impact of energy consumed for full production of aggregate and emission of greenhouse gases are consolidated and tabulated.

1.7 Global Warming Potential

In the assessment of the global warming impact of various gases, a standardized metric known as Global Warming Potential (GWP) has been developed. GWP serves as a measure indicating the amount of energy that the emissions of one ton of a specific gas will absorb over a specified time period, relative to the emissions of one ton of carbon dioxide (CO_2). Typically, the time period considered for GWP calculations is 100 years.

One significant advantage of employing GWP is its ability to establish a common measuring unit. This facilitates the aggregation of emissions from different gases, providing a comprehensive and comparative understanding of their environmental impact. By expressing the warming potential of various gases in terms of their equivalence to CO_2 over a standardized timeframe, GWP aids in creating a unified framework for assessing and addressing the overall contributions of different greenhouse gases to global warming.

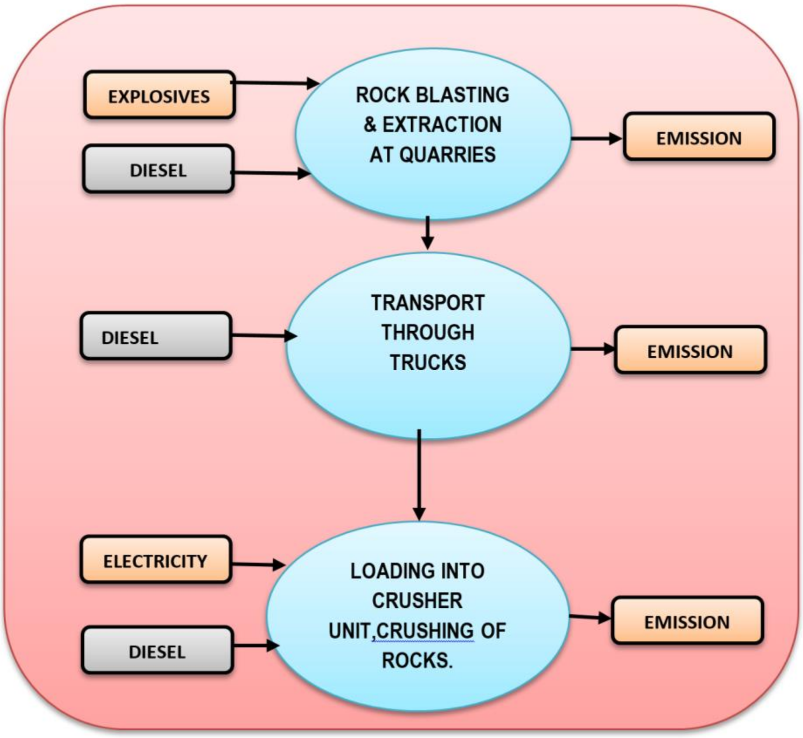
2.System Boundaries

When estimating greenhouse gas emissions from granite rock mining operations, the sources of these emissions can be categorized into two scopes [3,4]

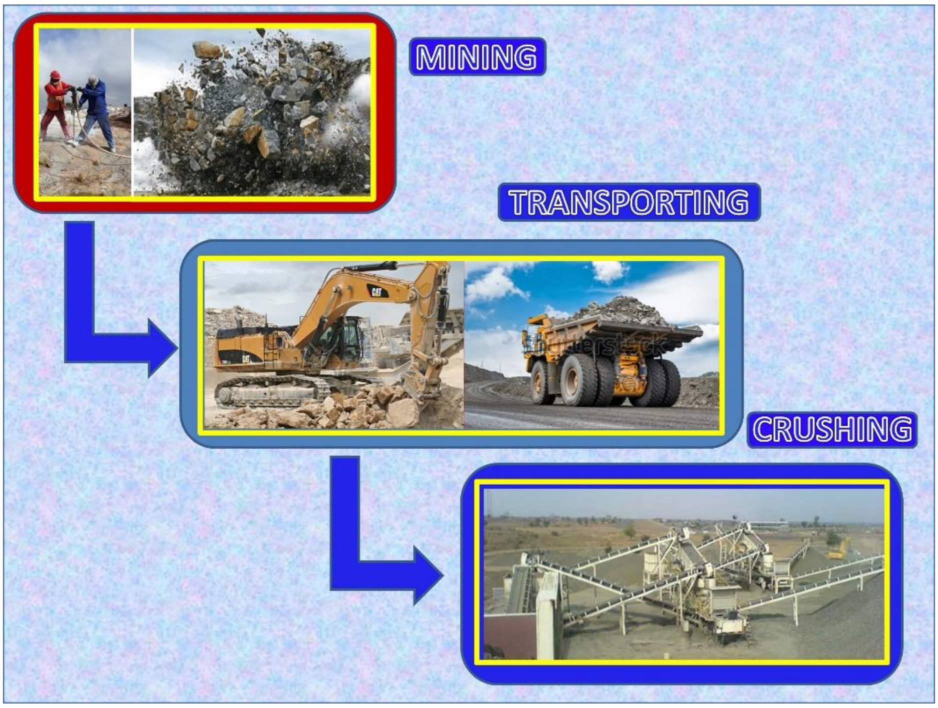
Scope 1 encompasses direct emissions, referring to greenhouse gas emissions originating from sources owned by the entity. This includes on-site activities like the combustion of fossil fuels, such as stationary emissions, and emissions from vehicles owned by the entity, known as mobile emissions.

On the other hand, Scope 2 covers indirect emissions, which arise from the entity's procurement of grid electricity, heat, or steam that it consumes but does not directly generate.

The granite rock quarrying process involves four key steps: site preparation, mining, transport, and crushing.



System boundaries in production of crushed stone aggregates



Operation involved into the production of crushed stone aggregates

During site preparation, the prospect area is readied for mining, and a mining infrastructure is constructed to support the facility. Drilling and blasting play a crucial role in granite extraction, with drills creating horizontal boreholes up to 12 meters in depth. Blasting, carried out using explosives like ammonium nitrate fuel oil (ANFO), breaks the granite, and this process is essential for mining operations.

Once the granite is extracted, heavy-duty diesel trucks transport the broken blocks from the mine site to the processing plant. At the processing plant, comminution, which involves crushing and grinding, occurs to reduce the granite blocks into particles of the desired grain sizes. Heavy-duty trucks haul the mined rocks to a stockpile, where primary crushing, using a jaw crusher, takes place. Secondary crushing involves transferring the crushed rocks to either an impact crusher or cone crusher. Following the crushing process, vibrating screens sieve the crushed rocks into different grades, or they may be sent back to the crusher for re-crushing.

3.Collection of data

Around 50 stone quarries and the corresponding crusher units were visited and the data required to explosion the rock has been collected in the quarry itself.

Aggregate crushing unit

3.1 Explosives:-

The research findings reveal that the average amount of explosives needed for blasting and extracting one ton of rock is approximately 0.2 kg per ton of Ammonium Nitrate Fuel Oil (ANFO). This metric serves as a crucial parameter in understanding the efficiency and resource utilization in the quarrying process.

Notably, Petra Schneider et al.[5], in their research, corroborate these findings by establishing that the quantity of explosives used in aggregate production is similarly 0.2 kg per ton. This consistency in the quantity of explosives per ton across different studies suggests a standardization or common practice within the industry, emphasizing the importance of this specific ratio in optimizing the extraction process while maintaining safety and environmental considerations.

Understanding the specific dynamics of explosive usage in relation to rock or aggregate production is pivotal for quarry operations, influencing cost-effectiveness, safety protocols, and overall environmental impact. The convergence of findings across multiple studies further strengthens the reliability and relevance of the established explosive-to-ton ratio in the context of mining and quarrying practices.

3.2 *Electricity and Diesel Fuel Consumption:-*

The data collection process involved gathering the average monthly electricity consumption for operating all 50 crushers, and this information was systematically organized into a table. By analyzing the table, researchers were able to determine the average electricity consumption required for the crushing process of one ton of aggregate.

For each crusher unit, the average production of crushed aggregate was found to be 366,250 tons. In the aggregate production process for these crushers, the total electricity consumed amounted to approximately 1,549,500 kilowatt-hours (kWh). This comprehensive data allowed researchers to calculate that the average power consumption per metric ton of crushed aggregate was approximately 4.23 kWh.

To contextualize these findings, Suthirat et al. [6], in their research paper, conducted a similar analysis and reported an average power consumption range of 2.29 to 6.97 kWh per ton for crushed aggregate production. The comparison between the two studies highlights the variability in power consumption within the industry, emphasizing the importance of understanding and optimizing energy usage in the crushing process. The obtained data not only contributes to a more nuanced understanding of electricity consumption in aggregate production but also provides a basis for assessing the efficiency and sustainability of crusher units in relation to their energy use.

3.3 Water Consumption:-

Water plays a vital role in quarrying and mining operations, serving essential functions such as cooling, crushing, grinding, milling ore, transporting slurry, and storing tailings. Therefore, it is crucial to assess any climate-related effects on the quality and accessibility of water resources, as these factors can significantly impact operational efficiency and costs.

The utilization of water within the crusher unit serves multiple purposes, primarily for the cooling of machinery and the washing of fine aggregates involved in the production of manufactured sand and various grades of aggregates. A detailed analysis of water consumption across each crusher unit was conducted to discern patterns and establish an average benchmark.

Upon thorough examination, it was determined that the crusher units, on average, consume 50.2 kilograms of water for every ton of aggregate and manufactured sand production. Notably, this calculation is specific to the production of manufactured sand with a particle size of 2.36 millimeters, encompassing a thorough washing process that effectively removes all finer materials. The water is obtained from local well with pumping by electric motor, and transported to crusher unit through diesel trucks.

This finding sheds light on the significant role that water plays in the operational processes of the crusher unit, impacting both the cooling mechanisms for machinery and the cleanliness of the final aggregate products. Understanding the average water consumption per ton allows for informed assessments of resource management, operational efficiency, and environmental considerations within the context of aggregate and manufactured sand production.

3.4 Diesel consumption :-

The consumption of diesel is integral to several stages in the production of aggregates, playing a crucial role in diverse operations:

3.4.1 Drilling Operation in Quarry:

- Diesel is utilized during the drilling operation to extract rock from the quarry.

3.4.2 Front-End Loaders for Loading Rocks into the Tipper, and water tankers:

- Diesel powers front-end loaders, facilitating the loading of extracted rocks into the tipper, as well as transportation of water through tankers.

3.4.3 Transportation of Rocks to the Crushing Plant:

- Diesel is employed in the transportation of rocks from the quarry to the crushing plant using tippers.

3.4.4 Front-End Loader for Loading Rocks into the Primary Crusher:

- Diesel is utilized once again in the operation of front-end loaders, assisting in loading rocks into the primary crusher.

Taking into consideration all these activities collectively, the comprehensive analysis indicates that the average diesel consumption for the aforementioned tasks amounts to 0.5 litres per ton of aggregate production. This metric encapsulates the aggregate fuel requirements for drilling, loading, transportation, and the primary crushing phase, providing a consolidated understanding of the diesel consumption associated with each crucial step in the aggregate production process. This insight is essential for evaluating the overall efficiency and environmental impact of diesel usage in aggregate production.

The total input required for production of one ton of crushed stone aggregate is tabulated as follows, based on actual consumption at site.

Sl.No	Input	Qty	Remarks
1	Explosives	200g	ANFO
2	Water	50.2 Kg	From Well.
3	Diesel	0.5 litre	For transportation, Front end loader Etc
4	Electricity	4.23 kwh	Obtained from local grid

4. Impact Assessment :-

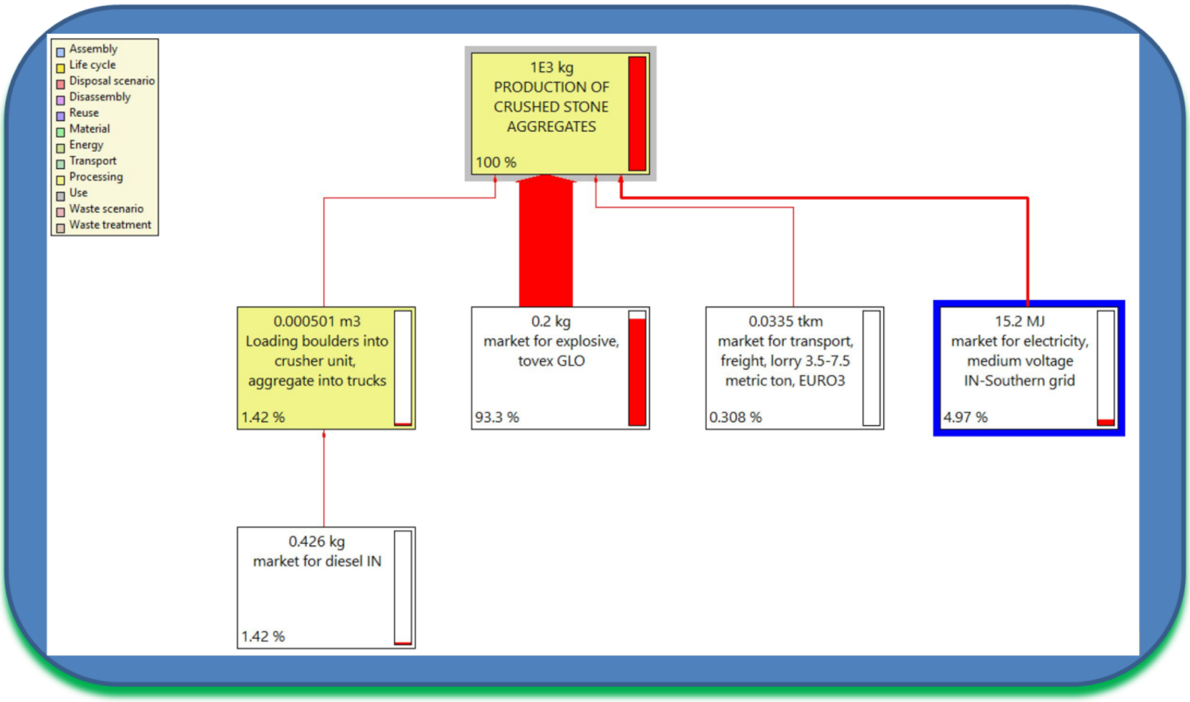
Various software options are available for analyzing the impact of life cycle assessments, specifically to quantify the carbon footprint during the production of crushed stone aggregates. In their research paper, Samuthirakani.v et al[1] have introduced a tool model, LCAPAVE, designed to measure the carbon footprint in the construction of flexible road pavement. Utilizing this tool model with specified inputs allows for the easy determination of the energy required and the resulting equivalent carbon dioxide emissions.

Alternatively, SIMAPRO software provides another avenue for carbon footprint quantification. This software utilizes the ecoinvent database to assess the carbon footprint and other related environmental impacts, offering a comprehensive approach to life cycle assessment in the context of aggregate production.

This paper involves an analysis performed through the utilization of SIMAPRO software, and the ensuing impact is systematically presented in the table provided below.

IMPACT CATEGORY	UNIT	TOTAL IMPACT	DIESEL AS FUEL	EXPLOSIVE	TRANSPORT	ELECTRICITY
Abiotic depletion	kg Sb eq	1.64E-05	2.78E-07	1.19E-05	8.59E-08	4.16E-06
Abiotic depletion (fossil fuels)	MJ	92.986478	21.62912	7.3016693	0.26432297	63.791365
Global warming (GWP100a)	kg CO2 eq	7.9203439	1.5460273	0.87240033	0.018365042	5.4835511
Ozone layer depletion (ODP)	kg CFC-11 eq	3.55E-07	2.84E-07	3.60E-08	3.06E-09	3.24E-08
Human toxicity	kg 1,4-DB eq	1.2666069	0.070244354	0.26250733	0.004475585	0.92937968
Fresh water aquatic ecotox.	kg 1,4-DB eq	0.039379148	0.007011181	0.009454893	0.00020788	0.022705194
Marine aquatic ecotoxicity	kg 1,4-DB eq	6208.4153	55.42228	543.31238	2.8057153	5606.8749
Terrestrial ecotoxicity	kg 1,4-DB eq	0.009278628	0.000351971	0.00116032	2.58E-05	0.007740505
Photochemical oxidation	kg C2H4 eq	0.001355864	0.000359225	0.000171676	2.90E-06	0.000822067
Acidification	kg SO2 eq	0.032785951	0.006906193	0.003729115	8.23E-05	0.022068321
Eutrophication	kg PO4--- eq	0.004967487	0.001364893	0.000679803	1.58E-05	0.002906945

Results of Analysis through SIMAPRO software



Network Diagram from Simapro

Results and conclusion:-

The issue of global climate change is widely recognized as one of the most critical environmental challenges in the contemporary era. Addressing and mitigating carbon emissions have emerged as formidable tasks for our society. The primary goal of this study is to undertake a comprehensive estimation of the quantity of greenhouse gases (GHGs) released into the atmosphere during the process of mining granite rock and crushing into various grades in the crusher unit. In this research ,an in-depth examination was conducted on active stone quarries and crushing units in India. The precise consumption of explosives, diesel, water, and electricity for the production of one ton of crushed aggregate was gathered from diverse units, and an average energy requirement was determined. Employing SIMAPRO software with the European method and CML-IA Baseline-3.7 version, incorporating World 2000 Normalization, impact categories were assessed. The global warming impact was quantified, resulting in an estimated

7.9 kilograms of CO2 equivalent emissions for the production of one ton of crushed stone aggregate.

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