Case studies analysis on life cycle assessment of the production of recycled aggregates

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Introduction

In the construction industry, known for its significant environmental impact, prioritizing sustainability across economic, social, and environmental dimensions is crucial. This applies not only during the construction phase of new buildings but also throughout their service life and eventual demolition. Globally, the construction sector is a major contributor to CO_2 emissions, with operations and management accounting for a historic peak of about 10 Gt of CO_2 emissions. When considering emissions from building material production (like cement, steel, aluminum, glass and bricks), for a total of 3.6 Gt of CO_2, buildings were responsible for about 37% of global CO_2 emissions in 2021(United Nations Environment Programme, 2022). Additionally, the construction industry is a significant consumer of raw materials and generates vast amounts of waste, with Europe producing around 800 million tons of construction and demolition waste (CDW) annually. Therefore, the recovery and recycling of these materials are essential for the sector's environmental sustainability(Eurostat, n.d.).

Despite some countries, such as the Netherlands and Germany, achieving high recycling rates exceeding 90%, others like Bulgaria and Slovakia lag with rates below 50%(Eurostat, n.d.). Italy, with a recycling rate of approximately 80%, stands out as one of the leaders in recycling CDW(Ispra, 2023). However, concerns persist among designers and customers regarding the incorporation of these recycled aggregates (RA) into new constructions, highlighting the need to educate end-users and demonstrate how these materials meet both technical and environmental standards.

In order to assess the environmental sustainability of using demolition waste, the Life Cycle Assessment (LCA) methodology is becoming increasingly relevant. LCA enables the identification and measurement of energy and materials consumed throughout a product's entire life cycle, including emissions such as greenhouse gases, toxic substances, and waste. Through LCA, the benefits of utilizing RA can be quantified, further emphasizing the importance of sustainable waste management practices in the construction industry.

Materials and methods

The study will focus on the environmental impacts related to the production of 1 ton of RA from CDW, using LCA and related hot spot analysis on the most impactful contributions identified during the analysis.

The study followed the LCA methodology outlined in the UNI EN ISO 14040:2021 (Ente italiano di normazione, 2021a) and UNI EN ISO 14044:2021 (Ente italiano di normazione, 2021b) standards. The system boundaries considered for all production processes of recycled aggregate are defined as "from cradle to gate", as per UNI EN ISO 15804:2021 (Ente di normazione italiano, 2021). These boundaries cover the A1-A3 product phases, including the extraction of raw materials (only applicable for natural aggregates), transportation of raw materials, and product manufacturing.

The case studies, from which primary data for analysis were collected, are treatment plants located in the provinces of Brescia and Bergamo. All processes considered in the analysis are required to produce RA, including acquiring, transportation, recovery treatment, and final production of the material. The main difference among the analyzed plants lies in the primary energy source and the quantities of waste processed. Specifically, two out of the three plants operate using diesel, while one operates using electric power. Details regarding the quantities analyzed are summarized in the Table 1.

Table 1. Analysis of processing times for the three plants.

Treatment plant	Treated CDW (t/days)	Treated CDW (t/hour)	Treated CDW (t/min)	Time to treat 1 t of CDW (min/t)
	Total	Total	Total	
Plant 1	1217,1	152,1	2,5	0,4
Plant 2	329,9	41,2	0,7	1,5
Plant 3	1080,0	135,0	2,3	0,5

In the present work, transport to the site has been considered; specifically, the average values considered for all treatment plants refer to 20 km.

The impact categories evaluated are all those required by UNI EN ISO 15804:2021. The software used to perform the LCA analysis was SimaPro 9.1.

Results

The results related to the total environmental impacts associated with the production of RA in the three analyzed plants are presented in Figure 1.

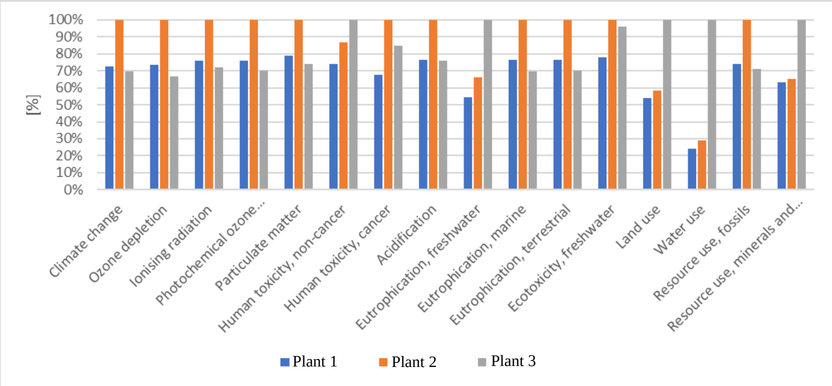

Figure 1. Environmental impacts of recycled aggregates production in the three analyzed plants [%].

Overall, the analysis of environmental impacts across three plants reveals that Plant 2 tends to have the highest impact in many categories, while Plant 3 often exhibits the lowest impact. However, there are exceptions that underscore the diversity of environmental impacts associated with each plant. The graph has been normalized with respect to the maximum value.

Specifically, in categories such as Climate Change, Ozone Depletion, Ionizing Radiation, Photochemical Ozone Formation, and Particulate Matter, Plant 2 demonstrates a more significant impact compared to Plant 3. This is well represented in Figure 1, which confirms the findings and helps to understand the impact differences across categories. In contrast, Plant 3 stands out for having the highest impact in categories such as Human toxicity non-Cancer, Land use, Water use, Eutrophication Freshwater, and Resource use, minerals and metals. This divergence is primarily attributed to differences in energy sources and the construction of fixed crushing plants.

Moreover, the comparison between Plant 1 and Plant 2, both diesel-powered, highlights the significant role of processed waste quantity and operational efficiency. The reduced need for multiple waste movements of Plant 1 and greater processing capacity optimizes crusher usage and decrease environmental impacts.

This comparison underscores the importance of examining energy mix combinations to better understand environmental implications across different plant types. Such analysis is crucial for interpreting results effectively and making informed decisions regarding environmental sustainability.

Concluding Remarks

The scenario analyzed the impact of different energy mixes on RA production, involving two diesel-powered plants and one electric-powered plant. RA produced with electric power showed lower impacts in categories like ozone depletion and marine eutrophication, but higher impacts in mineral and metal resource use, as compared to diesel-powered plants. Varying the energy mix revealed that solely renewable energy-based mixes had the lowest environmental impact, while other mixes had variable advantages and disadvantages, depending on environmental categories, such as ionizing radiation and nuclear energy use or freshwater eutrophication and hydroelectric energy use.

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