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How can concrete and cement industry transformation contribute to smart cities in mitigating climate change challenges?

A GCC perspective

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World demand for resources is projected to double by 2050. Sustainable reserves of rare metals, such as lanthanum and yttrium, are expected to run out. Carbon footprint would explode, and biodiversity would be devastated. Currently, only 6 percent of materials are recycled, which is strikingly low, considering the savings potential (Geng et al., 2019). This context calls for more rational and sustainable use of resources.

A quarter of global greenhouse gas (GHG) emissions are associated with materials production (Pauliuk et., 2021). Both industry-driven and demand-driven resource efficiency and circular economy initiatives have the potential to deliver emissions reductions through lower material use. Most of the modern urban environment is built of concrete – which is cement-based – and steel. Manufacturing these most pervasive industrial materials comes at a considerable cost in energy and greenhouse gas emissions. Cement and concrete are among the major manufactured materials in use, and their usage is being questioned. More than four billion tons of Portland cement are manufactured each year, equivalent to more than half a ton for every inhabitant of the planet. It builds dams, bridges, roads, towers, dykes, and parking lots of our society. It accounts for about 8% of anthropogenic greenhouse gas emissions (Pearce, 2021). Concrete is the backbone of construction in the rapidly industrializing and urbanizing world, and widely used in power systems, water, and wastewater systems, buildings – from one-floor dwellings to high-rise structures – and transportation infrastructures. Cement is a critical ingredient in both concrete and mortar, two widely used construction materials within the built environment (IAE, 2018).

Cement accounts for about 10% of global concrete volume and is presently produced at an annual rate of about four gigatons, which is equivalent to the size of food produced worldwide (Krausmann et al., 2018). The global demand for cement has increased sharply, with a ten-fold increase in global consumption during the last 65 years. Nevertheless, the fast-growing demand for cement and concrete in recent years has placed the sector as one of the leading consumers of energy and emitters of greenhouse gas emissions (GHG). Concrete is constantly accumulating in the earth's crust as a result of rapid urbanization. It is currently considered among the Anthropocene markers, with an approximate accumulation of 900 gigaton since the industrial revolution began (Monteiro et al., 2017; Habert et al., 2020), and its production is still increasing, reaching about 4.1 million tons in 2020 (USGS, 2021). It means that cement production emits as much carbon dioxide into the atmosphere as 300 million European cars, and was responsible for ~7% (10.7 ExaJoule) of the world's industrial energy consumption and 22% (2.2 gigaton) of global GHG emissions arising from industrial processes in 2014 (IAE, 2018).

Aware of the importance of curbing GHG emissions from all sectors, King Abdullah Petroleum Studies and Research Center (KAPSARC) designed an innovative framework – the so-called Circular Carbon Economy concept (CCE) that advocates for incorporating an additional 'R- remove' to the "three Rs" of the circular economy concept (Mansouri and Al-Sarihi 2021). This results in the 4Rs of CCE: Reduce, Reuse, Recycle and Remove (KAPSARC, 2020):

- Reducing the carbon that must be managed in the first place (through energy efficiency, renewables, and nuclear);
- Reusing carbon as an input to create feedstocks and fuels (including mobile carbon capture technology for transportation that captures and stores carbon onboard the vehicle using a redesigned exhaust system, and CO2-enhanced oil recovery [CO2-EOR], which uses injected CO2 to extract oil that is otherwise not recoverable);

- Recycling carbon through the natural carbon cycle with bioenergy, and, unique to circular carbon economy (through natural sinks such as forests and oceans and the use of hydrogen-based synthetic fuels to recycle CO2;
- Removing excess carbon and storing it (through CCUS).

Here, I discuss the importance of this framework to curbing GHG emissions in the cement and concrete industry in Saudi Arabia and, consequently, in the GCC-countries.

As a result of the construction boom, concrete and cement production is already making a significant contribution to the total GHG emissions in the Saudi economy. Fuels allocated to cement production in 2013 accounted for 5.5% of the total final energy consumption in the country (Matar and Elshurafa, 2017). Saudi Arabia has one of the highest production capacity among the GCC countries, reaching 72.4 million tons per year, and was the world's eighth-largest producer of cement in 2014, with a production of about 63 million tons (USGS, 2015). This is massive if we compare it to the 80 million tons produced in the USA during the same year. Despite the significant drop in production in recent years due to the mega construction projects' slowdown and the decrease in energy subsidies, the production remains sustained, with about 44.3 million tons produced in 2019.

This trend is expected to continue and cause a surge in concrete demand, as GCC-countries have a vibrant construction sector fueled by the economic and social performance of the young population in recent decades. Within this context, it is crucial to take proactive measures to mitigate the construction sector's carbon footprint impact within the next few years. Notwithstanding, the ecological footprint of GHG emissions resulting from the concrete industry is beyond the scope of mitigation strategies alone, and further technological breakthroughs are required to achieve GHG abatement goals.

As Saudi Arabia adopted the circular carbon economy approach (CCE) as an implementation framework to reach its net-zero target by 2060, tackling emissions in the cement and concrete sector is pivotal for fulfilling the CCE reducing and removing Rs, it might take the leadership for all the GCCs. Large-scale strategies implementation to enhance concrete manufacturing efficiency, including cement content and clinker content of cement optimization, supplementary cementitious materials use, and construction enhancement and efficiency design may play an essential role in alleviating construction sector environmental impact in the coming years. Regarding CEE removal R, aggressive technological breakthroughs, including concrete products carbon-capture and sink acceleration, and alternative cement use, have a great potential to improve the construction industry's long-term sustainability and achieve a zero-carbon concrete goal.

Another viable solution lies in the circular economy and recycling of concrete and construction waste generalization. Hence, construction and demolition waste recycling should be implemented throughout the value chain, from clinker to cement, concrete, or building. Currently, scientific evidence highlights the capability of some disruptive innovations, with a low environmental footprint, in substituting cement production, fully or partially (Miller and Myers, 2019). Nevertheless, some barriers make this option unrealistic from resource or technical perspectives and challenging to reach large-scale technical maturity in the short term. These barriers mainly lie in the technical shortcoming of certain alternative technologies and the high cost of materials.

In addition to the supplementary cementitious materials use, carbon cuts in the cement production process may be gained during the use and at the end-of-life phases. In fact, cement fulfills a dual function within the global carbon cycle. While its extensive production contributes substantially to global anthropogenic GHG emissions, its hydrated formulations progressively reabsorb significant quantities of future atmospheric GHG emissions. Nevertheless, the contribution of this sponge effect throughout the cement cycle (including manufacture, use, and disposal) in mitigating GHG emissions remains poorly or even unexplored until now. Therefore, scholars recommend that any initiatives or strategies designed to decarbonize the concrete and cement sector should include this sponge effect, as this passive sequestration magnitude is at least similar to the active carbon capture and sequestration process. Total future CO2 reabsorption will be substantial, accounting for about 30% of aggregate emissions from 2015 to 2100. According to the current research, profound decarbonization of the cement cycle on a global scale requires both passive and active CO2 sequestration while pointing out that these actions probably would not be sufficient to achieve the 1.5°C climate target. Thus, more innovative or radical decarbonization strategies are necessary.

Nevertheless, widespread and intensifying demand for concrete dramatically impacts the health and environment, combined with water consumption, material extraction, heavy metal, and particulate emissions. It is broadly recognized that a circular economy is supposed to accomplish sustainability goals through resource efficiency, sustainable material management, and circular use (Mongo et al., 2021a, 2021b; Tiba and Belaid, 2021). The rapid population growth and urbanization expected over the next few decades in the world, and in the GCC-countries in particular, suggests that the demand for cement and concrete will keep increasing, requiring urgent measures and strategies to limit their negative impact on the environment and climate change. Considering efficiency at all stages of the construction value chain and a small large-scale enhancement of concrete manufacturing significantly affect GHG emissions reduction. Accordingly, coordinated efforts involving all stakeholders are necessary to drive the maximum marginal gains from the construction sector transformation.

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