Communication and Marketing Department
Isebe loThungelwano neNtengiso
Kommunikasie en Bemarkingsdepartement

Private Bag X3, Rondebosch 7701, South Africa
Welgelegen House, Chapel Road Extension, Rosebank, Cape Town
Tel: +27 (0) 21 650 5427/5428/5674 Fax: +27 (0) 21 650 5628

www.uct.ac.za

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Emissions from global concrete production can be significantly reduced – study

A *Nature Communications* research paper co-authored by the University of Cape Town's (UCT) Emeritus Professor Mark Alexander shows how emissions from global concrete production can be significantly reduced by improving material efficiency. As a key decarbonising engineering strategy, this should be adopted urgently, said Emeritus Professor Alexander.

Cement production accounts for almost 8% of the global anthropogenic carbon dioxide emissions driving global warming. The broad concrete and construction industry, on the other hand, accounts for a substantially higher proportion of global emissions, amounting to as much as 40%. The key to decarbonising the process is to improve material efficiency by using less material to achieve the same performance, said Alexander.

Based in the Department of Civil Engineering in the Faculty of Engineering & the Built Environment, he is one of three authors of the paper, titled "Near-term pathways for decarbonizing global concrete production". His co-authors are Josefine Olsson (lead author) and Professor Sabbie Miller of the Department of Civil Engineering at the University of California.

At UCT, the Department of Civil Engineering has done extensive work on understanding the deterioration of marine concrete structures and researching ways of mitigating or preventing this. This includes life-extension methods, the area Alexander contributed to the paper.

He and Miller worked together on critical issues for a United Nations Environment Programme (UNEP) report where they are also part of an ongoing UNEP group on low carbon cement initiatives. However, the main part of the work emanated from the master's work of first author Olsson, now a PhD candidate.

High temperatures, high stakes

The climate stakes are high. Many regulatory bodies have emphasised the need for all CO2 emissions to achieve net zero within the coming decades, in accordance with the findings of the Intergovernmental Panel on Climate Change.

To limit global warming to below 1.5°C above pre-industrial levels, society must reach net-zero greenhouse gas (GHG) emissions by 2050 or face the physical risks of major heatwaves, agricultural drought, heat stress and crop duration reductions; issues that are already making their presence felt.

As the world's urban populations grow and current built infrastructure deteriorate, the demand for concrete is unprecedented. In terms of functional capacity, there are no alternatives for concrete, the authors write. Its production, particularly the hydraulic cement that glues the material together, is one of the world's largest sources of GHG emissions.

"However, when cement is used in concrete – a mixture of cement, aggregates (stone and sand) and water – or other cement-based materials such as mortar and renderings, the resulting material actually has a surprisingly low emission rating, one of the lowest of all building materials," said Alexander. "The reason for the high impact of these materials is simply the vast quantities that are used globally – amounting to about 1 cubic metre per annum, per person.

All this is mainly the result of producing clinker, a precursor to cement. Clinker is a calcined and quenched material that needs high temperatures to create the targeted physical properties in concrete.

The next 27 years will be critical for the "difficult-to-decarbonise" cement and concrete industries and new pathways to mitigation must be explored, said Alexander.

Historically, commonly discussed mitigation strategies have included:

- using alternative fuels
- using more efficient equipment
- reducing the demand for clinker using supplementary cementitious materials.

Another option is carbon capture, utilisation and storage (CCUS). But CCUS technologies are not well established for the industry, write the authors, and would add hugely to costs, something which the developing world could not afford at this stage. And while alternative cements and aggregates have been proposed, their efficacy can be hindered by resource availability, costs, or a risk-averse industry.

These aspects have all been well studied, said Alexander. However, the consequences of efficient structural design decisions on mitigating these emissions have yet to be thoroughly investigated by the industry.

Their paper presents an integrated framework to explore near-term (to 2030) transition risks and longer-term (to 2050) global physical risks for a range of plausible greenhouse gas emissions and associated temperature pathways, spanning 1.5–4 °C levels of long-term warming.

The authors also included projections for concrete demand and associated GHG emissions to the year 2100, which account for population growth, growing urbanisation, per capita demands of concrete use and national affluence. As most urban growth is along the world's coastlines, the authors used strategies for increased concrete durability in coastal areas to estimate the benefits to concrete longevity – an area in which UCT has been very active.

Integrating multiple methods

The paper examined emissions reductions from four areas:

- manufacturing changes that have the potential to lower GHG emissions

- changes to concrete mixture constituents and proportioning (such as reducing cement content through partial replacement with supplementary cementitious materials)
- variations in the concrete compressive strength selected, the reinforcement ratio selected and design code implemented for reinforced concrete members such as beams, columns and slabs
- the effect of increasing the service life of buildings and infrastructure.

"These multiple methods are integrated to determine the cumulative effect of emissions reductions, some of which have been established or studied in isolation," said Alexander.

The implications are critical in understanding how the engineering industry could drive alternative material technologies that significantly reduce GHG emissions, and policies that will guide appropriate applications and use of concrete to meet societal demands, while mitigating emissions.

To get a picture of the variability in the amount and longevity of the concrete produced, whether in residential or non-residential buildings or civil infrastructure, the authors focused on 10 regions across the world. These were: Noth America; Latin America; Europe; Commonwealth of Independent States (Eurasia); China; India; Africa; the Middle East; Developed Asia and Oceania; Developing Asia.

The authors calculated estimates for global GHG emissions for cement-based materials production from resource extraction to the factory gate. They adapted these models to reflect the influence of a variety of manufacturing improvements on emissions reductions.

Finally, they studied the impact of design-based improvements on reaching net-zero GHG emissions goals. These improvements included: concrete mixture proportioning; selecting appropriate steel reinforcement ratios to meet design standards while limiting emissions; and improving concrete in-service use periods.

Improve material efficiency

Their results showed that improving material efficiency (using less material to achieve the same performance) and low-emission material alternatives are key to mitigating the environmental impacts. They recommend that the role of engineering structural design in promoting efficient concrete systems should be urgently investigated.

The authors write, "The paper shows that a combination of manufacturing and engineering decisions could reduce over 76% of the GHG emissions from concrete and cement production (some 3.6 gigatonnes of CO2 equivalent) lower emissions by 2100.

"The studied methods similarly result in more efficient use of resources by lowering cement demand by up to 65%, leading to an expected reduction in all other environmental burdens. These findings show that the flexibility within current concrete design approaches can contribute to climate mitigation without requiring heavy capital investment in alternative manufacturing methods or alternative materials."

Some may ask: What about steel? While alternatives such as steel frames offer a lower emissions alternative to concrete in certain circumstances, the authors' focus is only on concrete. Steel frames are highly dependent on the structural system under consideration – and the results vary from case to case, said Alexander.

As for greener alternatives, there is always a role and a niche for these, said Alexander.

"But when it comes to the sheer bulk of infrastructure that is needed in coming decades, mainly in the Global South, there is no viable alternative to the concrete scenario. But as the paper argues, using the existing technologies but pulling the correct levers can reduce the GHG emissions by as much as 76%.

He added: "Rather, it is critical that we consider the service life of our concrete systems as substantial environmental benefits can be achieved by leveraging shifts in material use at this stage."

The degree of GHG emissions mitigation possible through the efficient use of cement and concrete, achieved through design improvements within current design codes, could be used to inform engineers, material scientists, policy makers (or code writers) and other stakeholders.

But urgent action is needed.

"The inclusion of environmental impact assessments to calculate GHG emissions reduction within conventional codes, material specifications and procurement/design is critical. Because such methods can already be implemented, they should be put into effect immediately," said the authors.

However, this will take a combined effort from all stakeholders.

"This needs governments to put appropriate policies and regulations in place to drive this and create enabling environments for the industry to benefit from the changes," said Alexander. "I am not convinced there is yet sufficient political will in either government or industry to achieve this."

Story by Helen Swingler, UCT News

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Issued by: UCT Communication and Marketing Department

Anovuyo Tshaka
Media Liaison & Monitoring Graduate Intern
Communication and Marketing Department
University of Cape Town
Rondebosch
Tel: (021) 650 1561
Cell: (073) 547 0549
Email: Anovuyoz.Tshaka@uct.ac.za
Website: www.uct.ac.za