# Impact of $CO_2$ Uptake Rate on the Environmental Performance of Cementitious Composites: A New Dynamic Global Warming Potential Analysis

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THE WORLD'S GATHERING PLACE FOR ADVANCING CONCRETE

aci CONCRETE CONVENTION

# Outline

**Motivation** — **Procedure** — **Results** — **Conclusions**

Background and framework

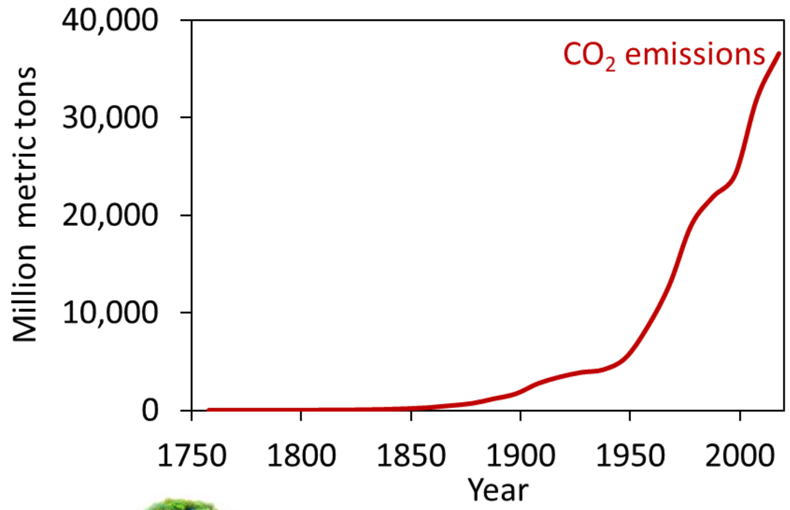
Materials and methods used

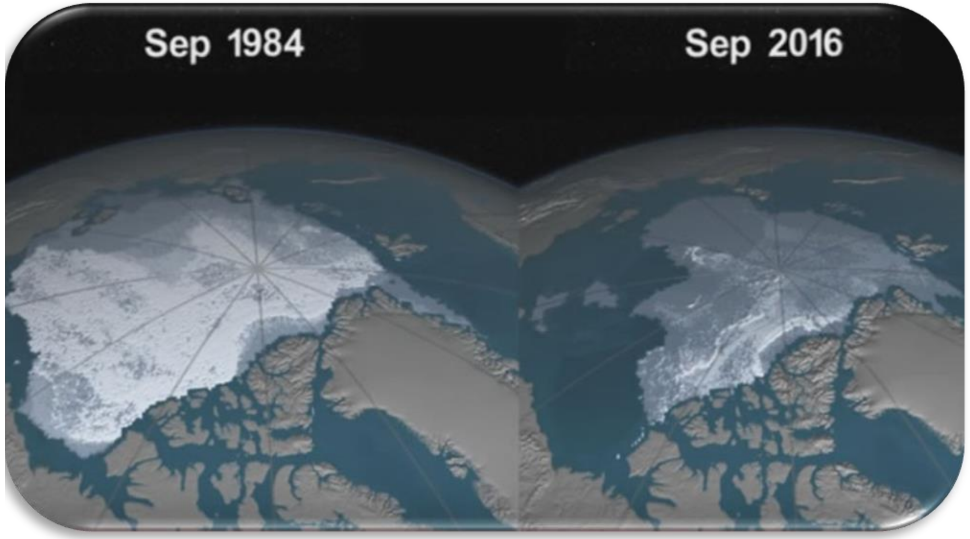
Findings and discussion

Overview of main findings

**C. Moro,** V. Francioso M. Lopez-Arias and M. Velay-Lizancos (2022). ‘“The impact of $CO_2$ uptake rate on the environmental performance of cementitious composites: A new dynamic Global Warming Potential analysis”. Journal of Cleaner Production, 375, 134155, https://doi.org/10.1016/j.jclepro.2022.134155.

Adapted from Gilfillan et al (2020)

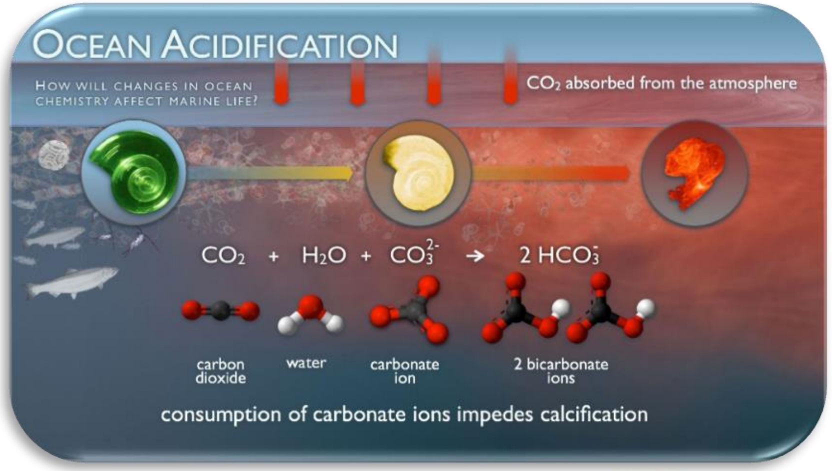




WMO, 2021

**Highest level in 3-5 Million years!**

- **Climate Change**
- Air Pollution
- Waste Production
- Natural Depletion



$$CO_2 + H_2O + CO_3^{2-} \rightarrow 2\,HCO_3^-$$

consumption of carbonate ions impedes calcification

# 7 million premature deaths per year!

WHO, 2021

- Climate Change
- **Air Pollution**
- Waste Production
- Natural Depletion

The World Bank

**2 billion tons of MSW per year!**

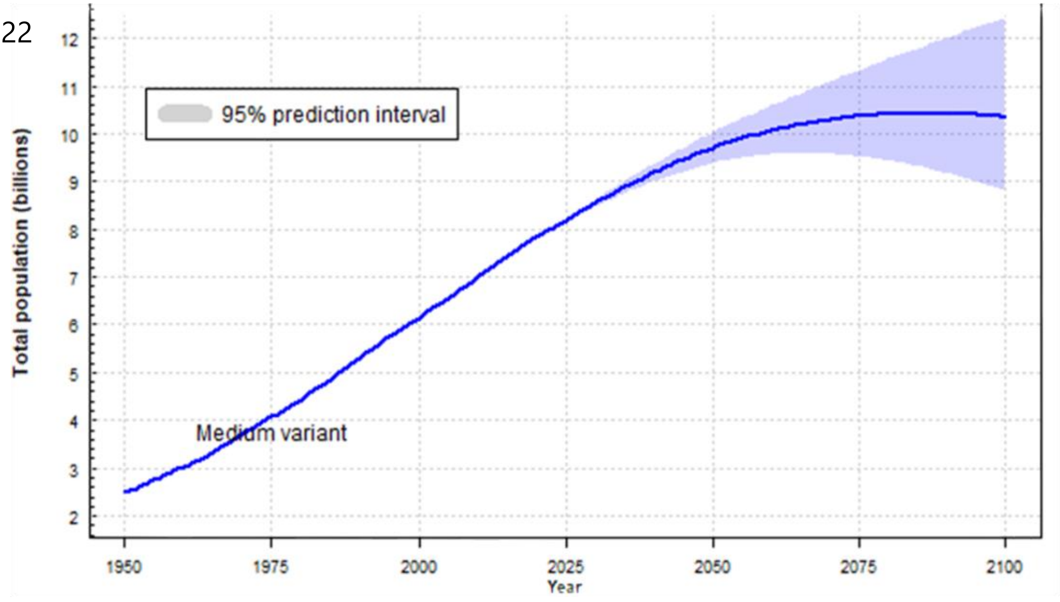
- Climate Change
- Air Pollution
- **Waste Production**
- Natural Depletion

- Climate Change
- Air Pollution
- Waste Production
- **Natural Depletion**

**There will be almost no fish in 2050!**

NPR, 2006

The United Nations, 2022



# Even more impacts if we continue along this line!

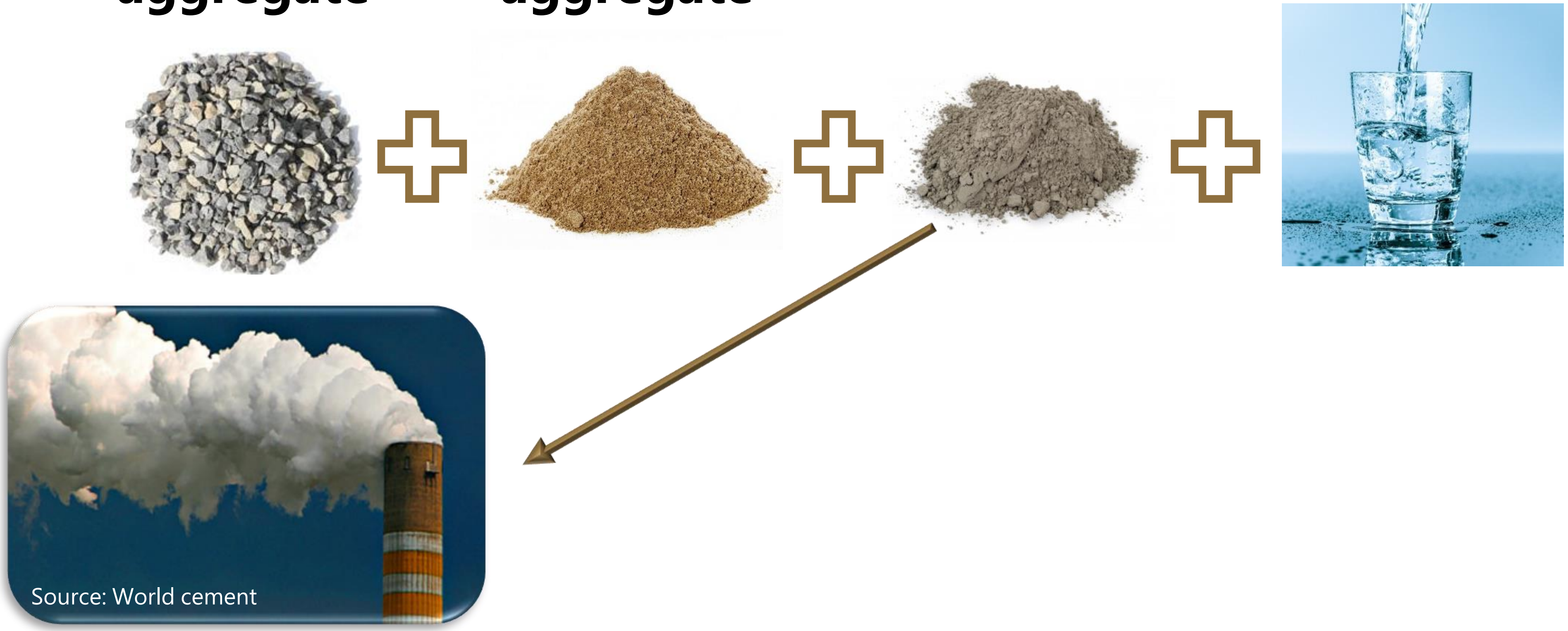
The United Nations, 2022

**More than 40% are directly related to sustainability!**

↓

# Top priority!

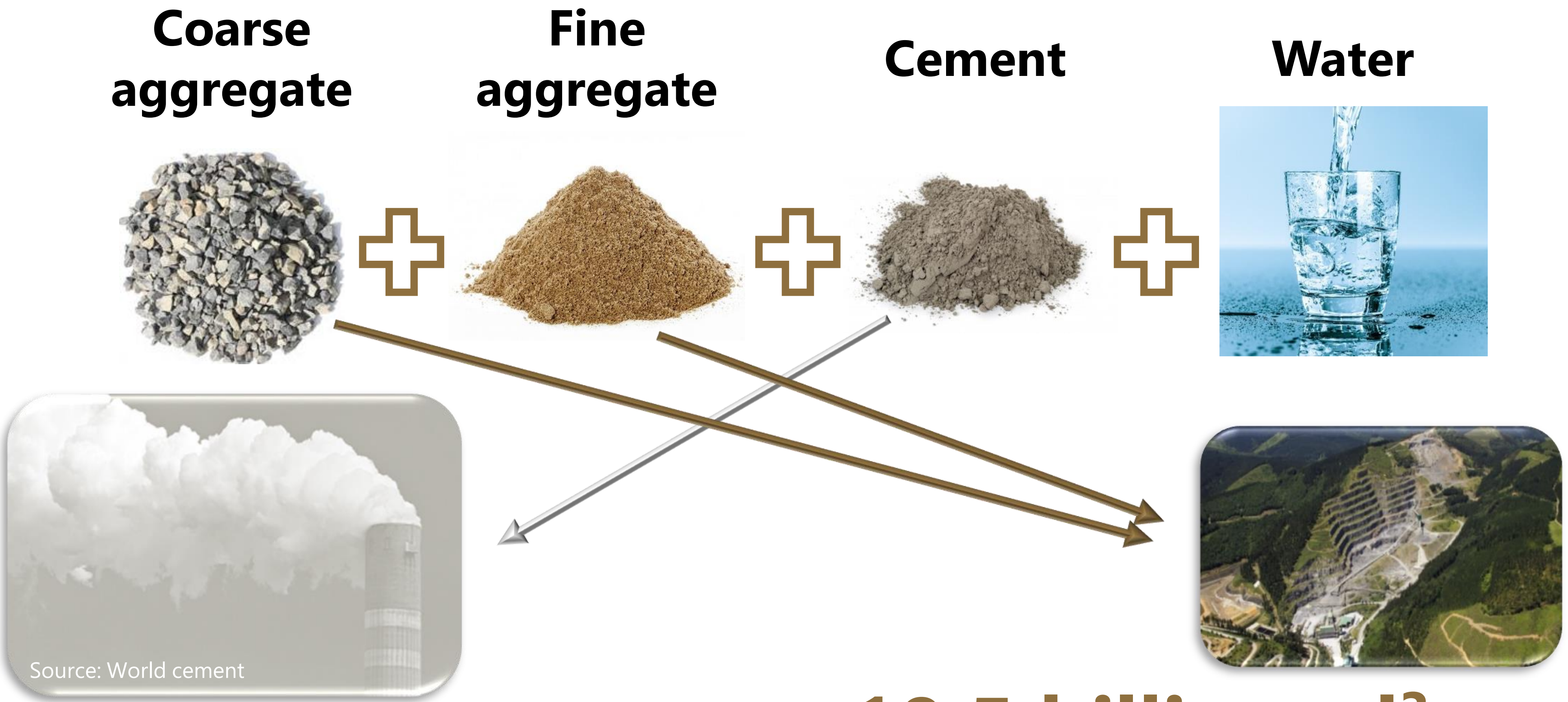
**Coarse aggregate** **Fine aggregate** **Cement** **Water**



Source: World cement

**8% of the total $CO_2$ emissions each year**

Andrew, 2018



**Coarse aggregate** + **Fine aggregate** + **Cement** + **Water**

Source: World cement

8% of the total $CO_2$ emissions each year

Andrew, 2018

**10.5 billion yd$^3$**

**each year**

Monteiro et al., 2017

**Second most used** **material in the world (after water)**

**with 30 billion tons each year**

Monteiro et al., 2017

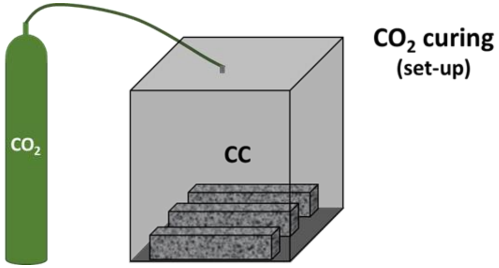
Cement-based materials are known for sequestering $CO_2$ during their service life.

**43%** of the $CO_2$ produced by cement industry 1930-2013 (excluding fossil use).

Xi et al. (2016)

**Active**

Moro et al. (2021a),
Zhang et al. (2017),
Moro et al. (2022)



**Passive**

Xi et al. (2016)
Moro et al (2021b)

**Traditional Methods**

**However!**

Different $CO_2$ uptake rates

Moro et al. (2021a),
Moro et al. (2021b),
Moro et al. (2022)

**Cradle-to-gate** – Picture at year 0

Imbalance
$CO_2$ emitted vs. $CO_2$ uptake?

**Cradle-to-grave** – Picture at year 100

**3 Different Types of Concretes:**

- Reference Concrete (100% OPC)
- Fly Ash Concrete (75% OPC + 25% FA)
- Slag Concrete (60% OPC + 40% GGBFS)

## Functional Unit

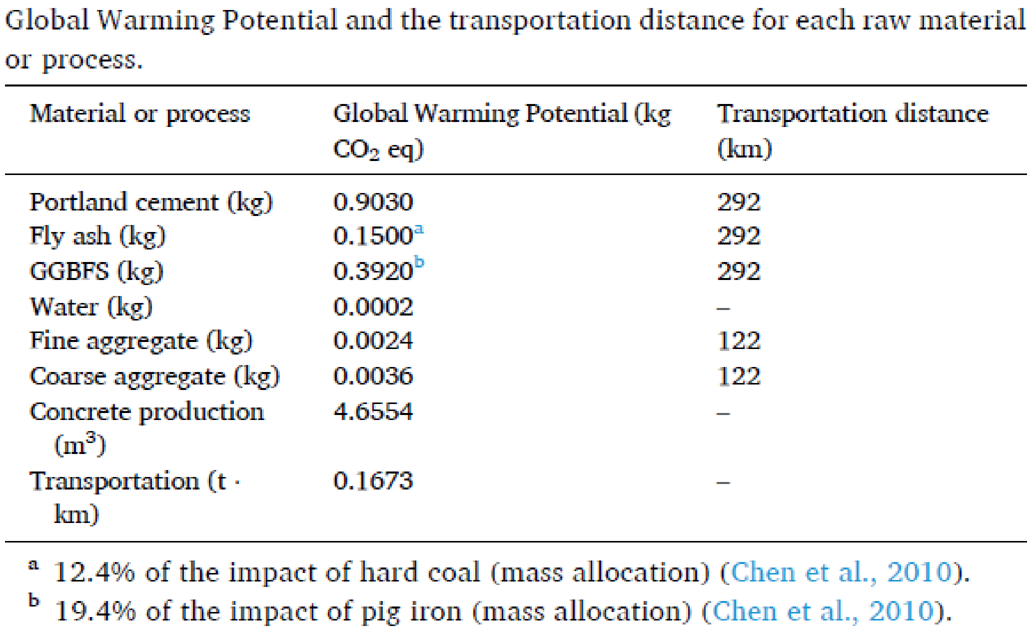
**1 $m^3$ of concrete with 30-MPa compressive strength**

**Estimation of Mix Design:**

- Assumed that all types of concretes would possess the same compressive strength with the same water-to-binder ratio (w/b).
- Obtained w/b using different formulas (Abrams, ACI, Bolomey and Slater).
- 25% Paste, 35% Fine Aggregate and 40% Coarse Aggregate.
- Volume Substitution of SCM (FA and GGBFS).

# Global Warming Potential of each concrete at year 0

Ecoinvent and Marinkovic et al. (2017)



Global Warming Potential and the transportation distance for each raw material or process.

| Material or process | Global Warming Potential (kg $CO_2$ eq) | Transportation distance (km) |
|---|---|---|
| Portland cement (kg) | 0.9030 | 292 |
| Fly ash (kg) | 0.1500[a] | 292 |
| GGBFS (kg) | 0.3920[b] | 292 |
| Water (kg) | 0.0002 | – |
| Fine aggregate (kg) | 0.0024 | 122 |
| Coarse aggregate (kg) | 0.0036 | 122 |
| Concrete production ($m^3$) | 4.6554 | – |
| Transportation (t · km) | 0.1673 | – |

[a] 12.4% of the impact of hard coal (mass allocation) (Chen et al., 2010).

[b] 19.4% of the impact of pig iron (mass allocation) (Chen et al., 2010).

**$GWP_0$** – At Year 0

$CO_2$ (%,max)

**$GWP_{100}$** – At Year 100

$$\boxed{GWP_{100} = GWP_0 \cdot \left[1 - \left(\frac{CO_2\ (\%, \max)}{100}\right)\right]}$$

## Steinour equation

Steinour (1959)

$CO_2$ (%,max) = 0.785 · [CaO (%) − 0.7 · $SO_3$ (%)] + 1.091 · MgO (%) + 1.420 · $Na_2O$ (%) + 0.935 · $K_2O$ (%)

## Intermediate years

(Fick's law)

$$GWP_i = GWP_0 - \left[ (GWP_0 - GWP_{100}) \cdot \sqrt{\frac{t_i}{t_{100}}} \right] i \in [0,100]$$

**Different $CO_2$ uptake rates?**

1. Weathering carbonation or conventional.
2. Acceleration of $CO_2$ uptake due to nanomodification (83% increase in the $CO_2$ uptake during the first 6.8 years).
3. $CO_2$-cured mixture assuming a $CO_2$ uptake equal to 15% of the cement mass during $CO_2$ curing.

## Intermediate years

(Fick's law)

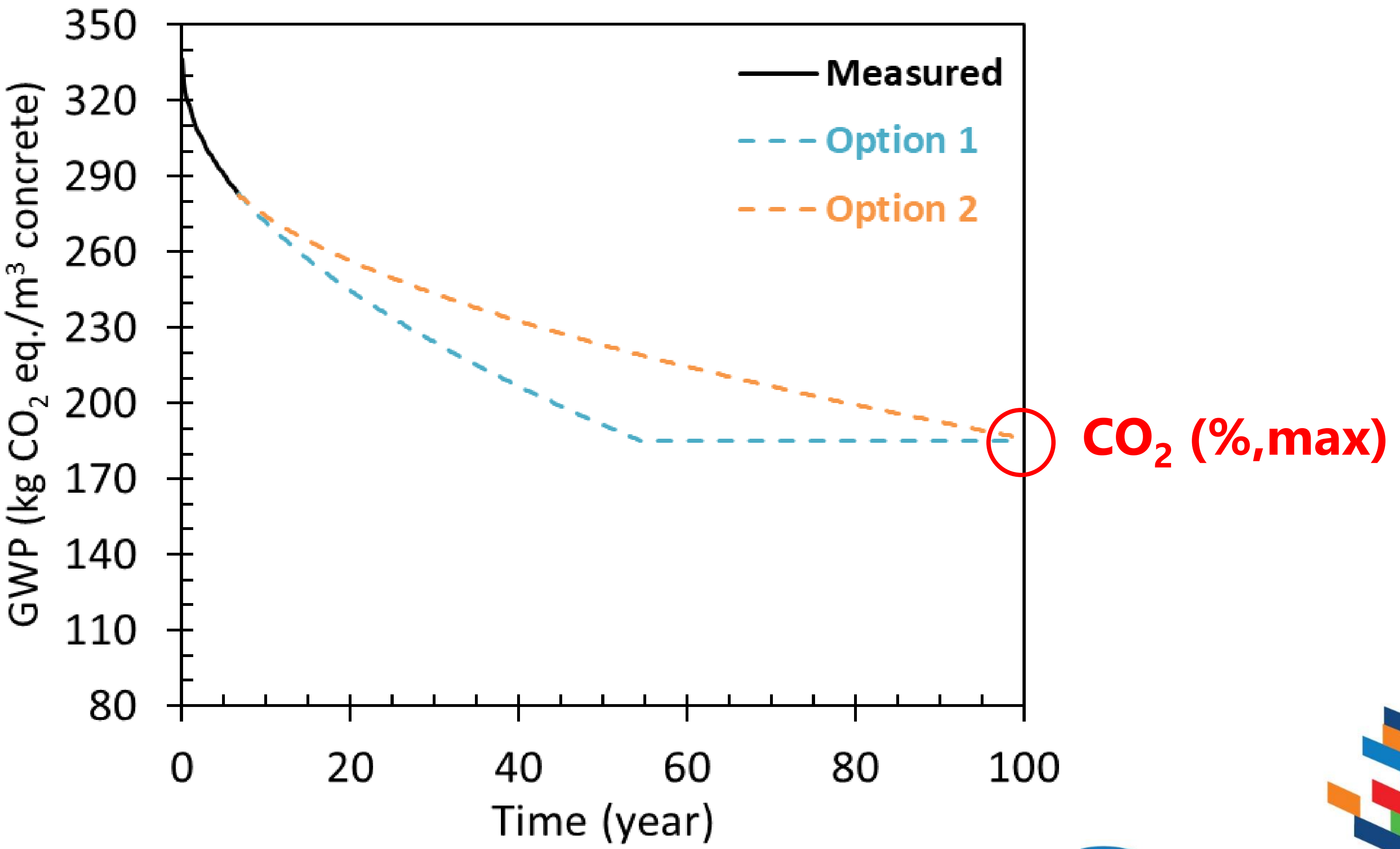
$$\mathrm{GWP_i} = \mathrm{GWP_0} - \left[ (\mathrm{GWP_0} - \mathrm{GWP_{100}}) \cdot \sqrt{\frac{t_i \cdot (1 + k_A)}{t_{100}}} \right] i \in [0,100]$$

**Accelerator factor of the $CO_2$ uptake rate**

**$k_A$**

- **Conventional and $CO_2$-cured concretes - $k_A$ = 0** at years [0, 100]
- **Nano-modified A concretes - $k_A$?** (83% increase in $CO_2$ uptake during the first 6.8 years)

Moro et al. (2021b)


350
320
290
260
230
200
170
140
110
80
GWP (kg $CO_2$ eq./$m^3$ concrete)
0
20
40
60
80
100
Time (year)
Measured
Option 1
Option 2
$CO_2$ (%,max)

# Intermediate years

(Fick's law)

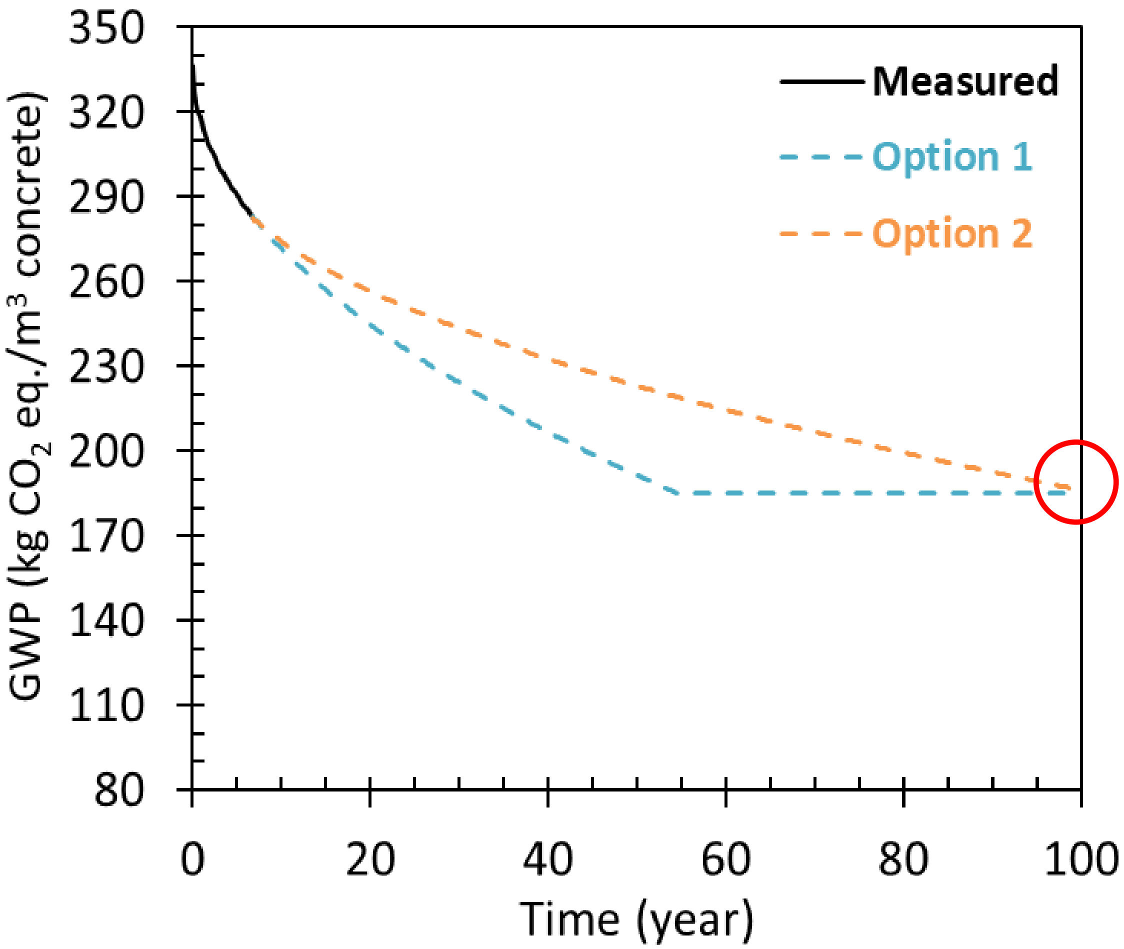
$$GWP_i = GWP_0 - \left[ (GWP_0 - GWP_{100}) \cdot \sqrt{\frac{t_i \cdot \mathbf{(1 + k_A)}}{t_{100}}} \right] i \in [0,100]$$

**Accelerator factor of the $CO_2$ uptake rate**

$k_A$

- **Conventional and $CO_2$-cured concretes - $k_A = 0$** at years [0, 100]
- **Nano-modified A concretes - $k_A = 0.83$** until $CO_2$,max (%)
- **Nano-modified B concretes - $k_A = 0.83$** at years [0, 6.8] and **$k_A = 0$** at years [6.8, 100]

# Static o Dynamic Effects?



**Always same?**

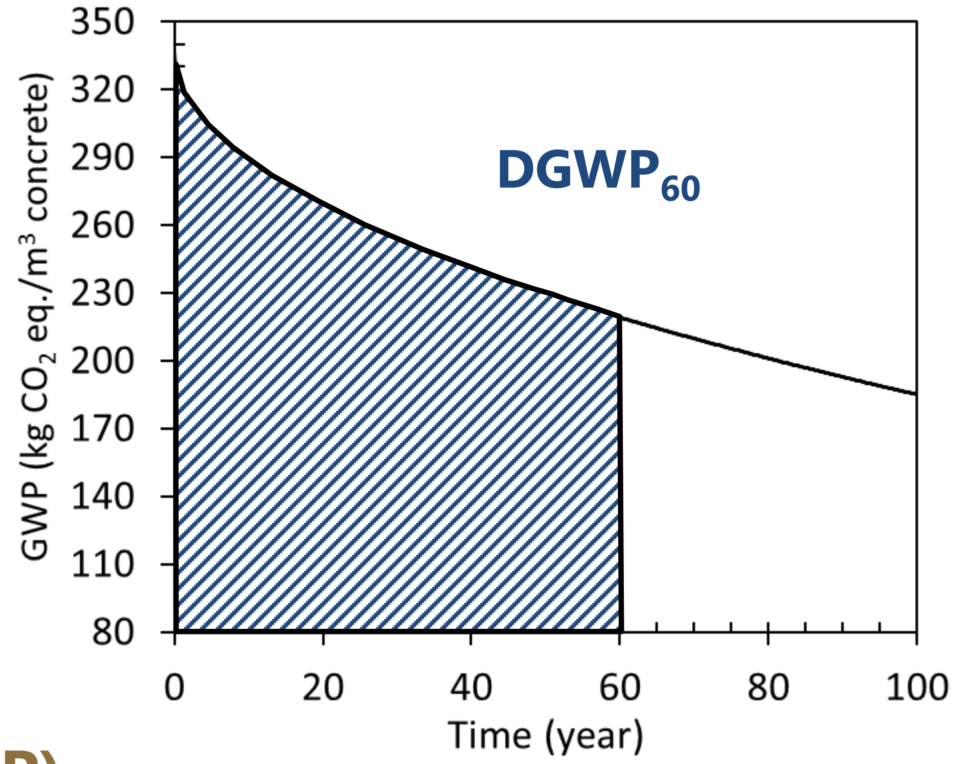
## Dynamic Global Warming Potential (DGWP)

$$\mathrm{DGWP}_0 = 0 \text{ when } i = 0$$

$$\mathrm{DGWP}_i = \sum_{k=i}^{1} (t_k - t_{k-1}) \left( \frac{\mathrm{GWP}_k + \mathrm{GWP}_{k-1}}{2} \right);$$

$$i \geq 1; i \in (0,100]$$

**Units?**



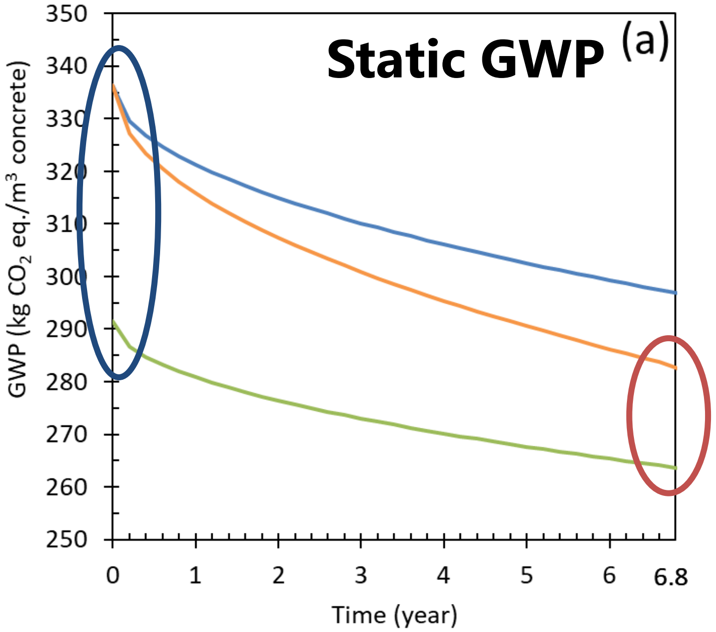
## Equivalent Global Warming Potential (Equiv. GWP)

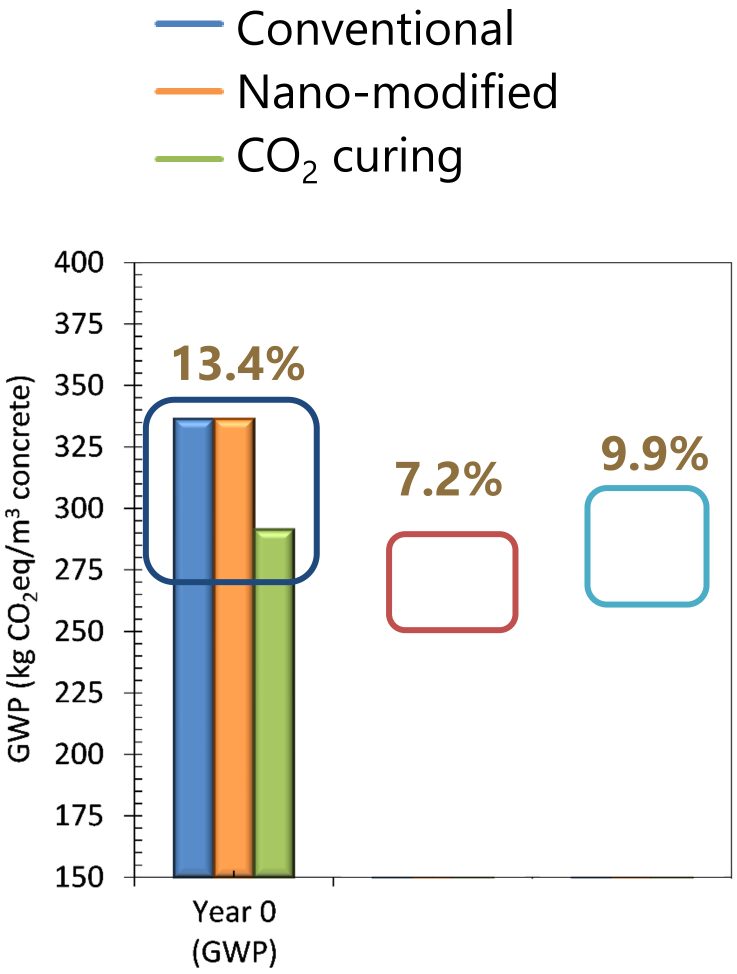
$$\boxed{\text{Equiv. GWP}_i = \frac{\mathrm{DGWP}_i}{i}; i \in [0,100]}$$

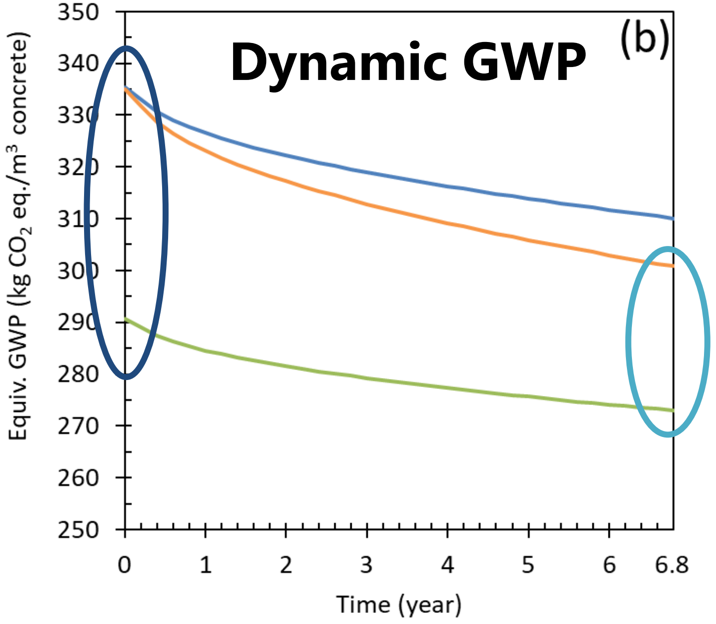
$$\text{Equiv. GWP}_{60} = \frac{\mathrm{DGWP}_{60}}{60}$$

# Effects during the first 6.8 years of service

**100% OPC**



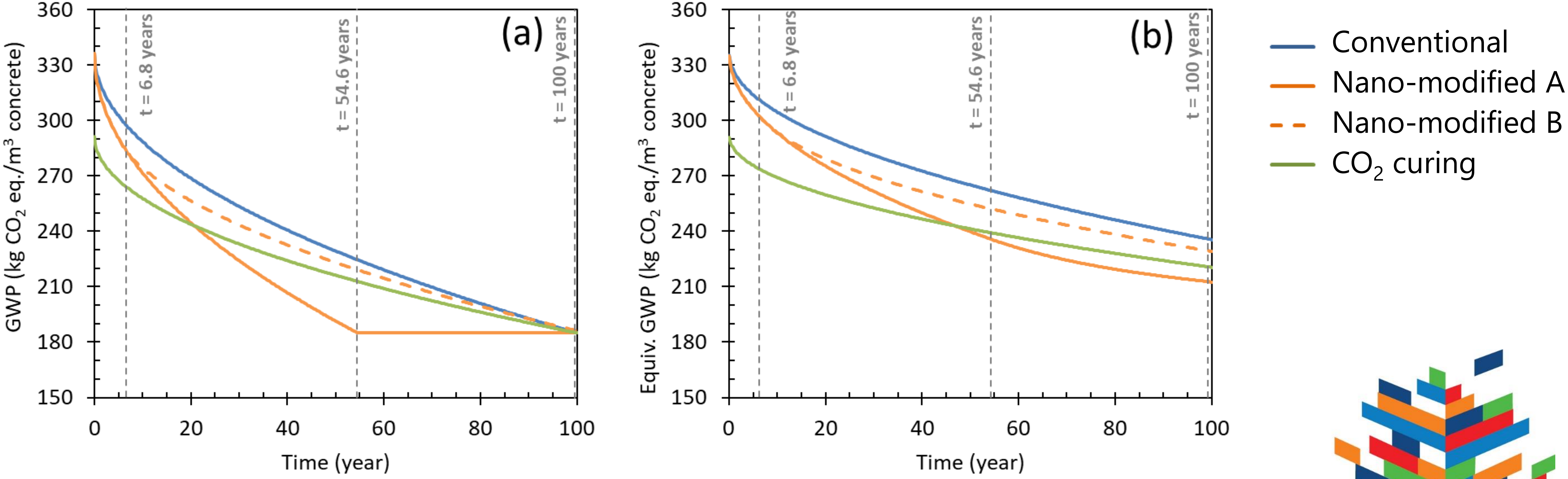




## Effects during 100 years of service

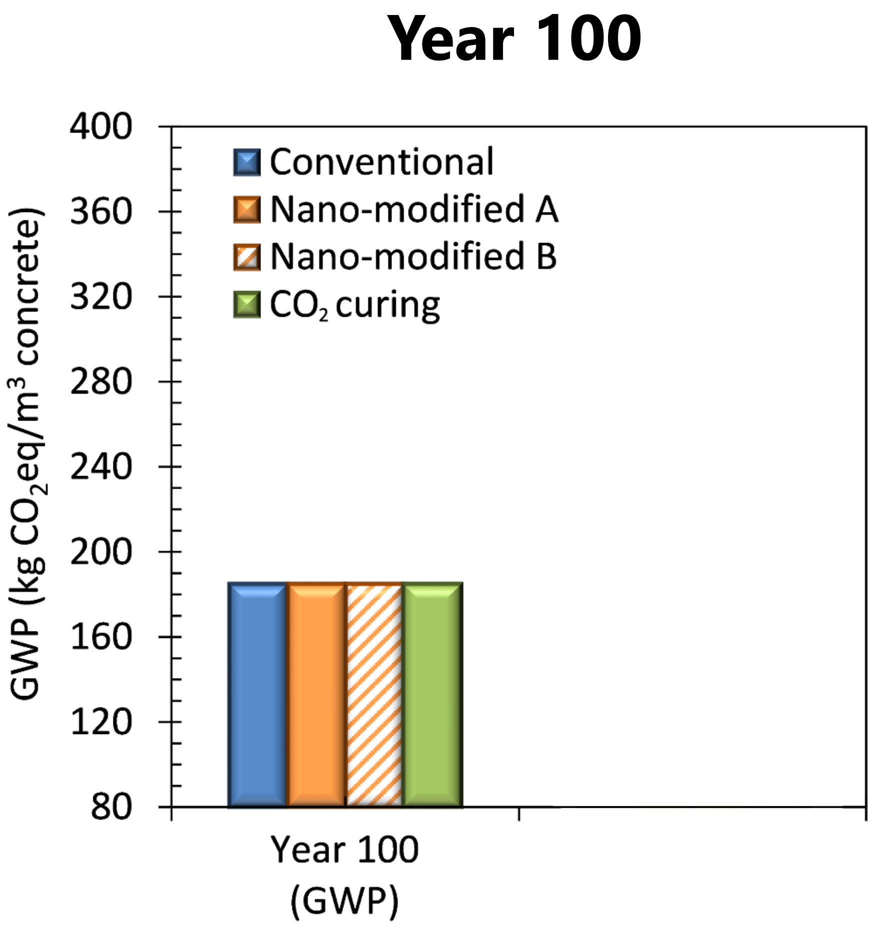
**100% OPC**

**Static GWP** **Dynamic GWP**



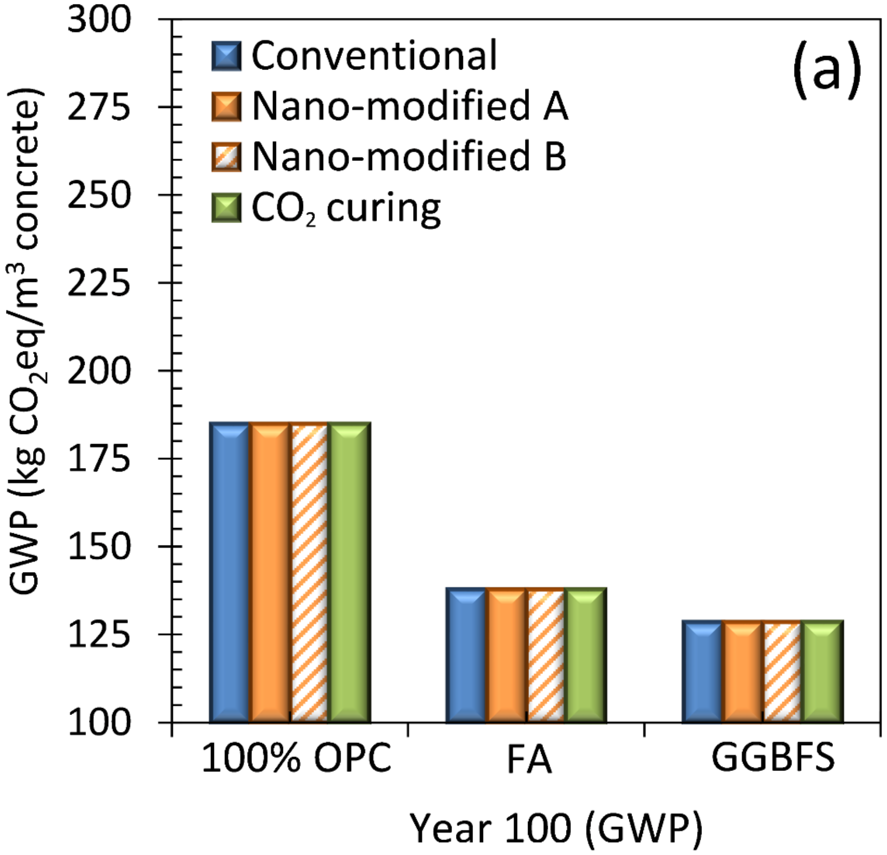
# Effects during 100 years of service

**100% OPC**

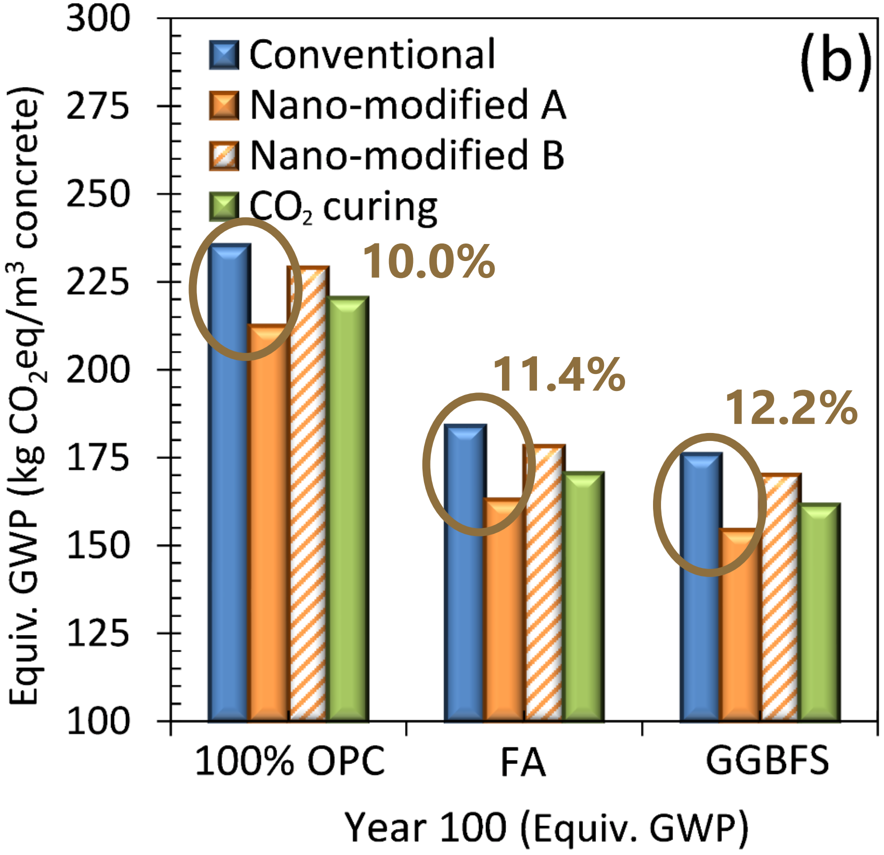


# Effects of the SCMs

## Static GWP



## Dynamic GWP



- Even though **$CO_2$-cured concretes** possessed the **lowest** Equiv. GWP right after their production (or **year 0**), **nano-modified A concretes** exhibited the **lowest** Equiv. GWP **at year 100**.
- Results showed that the proposed dynamic analysis (Equiv. GWP) **successfully quantified the effect of $CO_2$ uptake rate on the GWP** associated with cementitious composites.
- The dynamic method employed in this study may be applied to **other impact categories or even the holistic LCA**, leading to a **more realistic assessment** of the environmental performance of cementitious composites.

# Thank you for your attention!
# Want to know more? Scan this code!

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**Journal article:**