Climate change induced carbonation and corrosion of EU building stock: recent findings

Dimova Silvia[1], Polo López Cristina Silvia[1], Sousa Maria Luísa[2], Rianna Guido[3], Bastidas-Arteaga Emilio[4], Nogal Macho Maria[5], Gervásio Helena[6], Martorana Emilio[7], Reder Alfredo[3] and Athanasopoulou Adamantia[1]

[1]European Commission, Joint Research Centre, Italy, Silvia.DIMOVA@ext.ec.europa.eu; Cristina-Silvia.POLO-LOPEZ@ec.europa.eu, corresponding author; Adamantia.ATHANASOPOULOU@ec.europa.eu*

[2]Portuguese National Laboratory for Civil Engineering, Portugal, luisasousa@lnec.pt

[3]CMCC Foundation - Euro-Mediterranean Center on Climate Change, Italy, guido.rianna@cmcc.it; alfredo.reder@cmcc.it

[4]La Rochelle University, La Rochelle, France, ebastida@univ-lr.fr La Rochelle University, La Rochelle, France, ebastida@univ-lr.fr

[5]University of Technology, Delft, the Netherlands, M.Nogal@tudelft.nl

[6]Coimbra University, Portugal, hger@dec.uc.pt

[7]Fincons S.p.A., external consultant for the European Commission, Italy, Emilio.MARTORANA@ext.ec.europa.eu

Abstract

This paper presents the main findings of the JRC report "Impact of climate change on the corrosion of the European reinforced concrete building stock" [1]. It evaluates the climate change-induced carbonation in reinforced concrete buildings in the EU Member States up to year 2100 and the time for corrosion onset and the repair costs under moderate and extreme CO_2 emissions scenarios. The results indicate that, without climate change, natural aging of buildings would not lead to corrosion by 2100, as the carbonation depth would remain smaller than the concrete cover depth. However, if more severe climate change scenarios are considered, corresponding to the case when the emissions targets are not met, specifically the Paris Agreement's goal of limiting global warming to well below 2°C and pursuing efforts to limit it to 1.5°C, the potential economic costs and welfare losses in some EU countries could be substantial. Climate change-induced carbonation is expected to affect the 20th-century building stock, but not the recently constructed buildings meeting modern European standards for concrete cover durability. Adaptation measures for the building stock are proposed.

1 Background

Climate change poses a significant threat to humans and ecosystems, with 3.3 to 3.6 billion people living in high sensitive climate change environments (IPCC, 2023 [2]). The adaptation of the built environment to climate change is imperative for safeguarding people, property, and the economy from its detrimental effects, while fostering sustainable and equitable communities prepared for future challenges.

This priority is bolstered by several EU initiatives, including the New Circular Economy Action Plan (CEAP) (COM(2020)98) [3], the New EU Strategy on Adaptation to Climate Change (COM(2021) 82 final) [4], the Renovation Wave for Europe (COM(2020) 662) [5], and the review of the Construction Products Regulation (COM(2022)144) [6]. The current study aligns with the EU strategy on adaptation to climate change implementation report (SWD (2023) 338) [7] and in particular with the Commission Action 31, which aims to integrate climate resilience considerations into construction and renovation criteria.

Carbonation of concrete is a chemical process where carbon dioxide from the air reacts with the calcium hydroxide in the concrete to form calcium carbonate. This reaction can lead to decrease in the concrete's strength and durability, and to corrosion of the concrete's reinforcing steel. The study is the first evaluation of the implications of the climate change induced carbonation on the entire concrete building stock in the EU Member States. It provides assessment of the penetration of climate change induced carbonation in the concrete cover of the existing buildings in the EU Member States, in the period up to year 2100. It estimates the time for on-set of corrosion, and evaluates the repair costs under the moderate emissions scenario RCP4.5, and under the extreme scenario RCP8.5 (no mitigation action) [8].

Climate data for the study derive from 11 bias-adjusted climate projections from the EURO-CORDEX [9] initiative and the EOBSv10 observational datasets [10]. The carbonation depth progression model [11, 12] accounts for building durability characteristics and environmental exposure over time, considering atmospheric CO_2 concentration, a time-dependent temperature factor, and a parameter representing the natural aging of concrete as input variables. The report does not specifically address relative humidity (RH) variation effects on corrosion rates due to expected minor RH changes at the European level and the need for more detailed scale data for accurate estimations.

The building stock database encompasses over 30 million reinforced concrete buildings in the EU Member States. They were aggregated in two major groups to reflect their age, called “old” (assumed built before the year 2000 according to standards of the 20th century) and “recent” (assumed built after year 2000 according to the contemporary standards). The assessment of the repair cost assumes that the repair occurs after the depletion of the concrete cover and before a significant loss of cross-sectional area of the reinforcement, thus considering a corrective repair of the exposed building surface, using a uniform price across all countries.

2 Key Findings

- The results for both the old and the recent buildings conclusively show that, without climate change, the carbonation due to natural aging of buildings would not lead to corrosion.
- Recent buildings constructed to current European standards are less susceptible to carbonation-induced corrosion due to climate change. In contrast, older buildings are at a higher risk.
- By 2100, projected total repair costs for EU Member States amount to approximately EUR 76 billion under RCP4.5 and EUR 883 billion under RCP8.5, with the most affected countries varying between the scenarios. Italy, Portugal, Spain and Denmark would have to afford the highest total repair costs under RCP4.5. Under the severe RCP8.5 scenario, Poland, France, Germany, and Czechia would face the highest total repair costs.
- Corrosion processes in the buildings built before the year 2000 are expected to initiate around 2050 under the extreme RCP8.5 scenario and after 2060 under RCP4.5. After corrosion initiation, corroded bars must be cleaned but not replaced, and the polluted concrete cover must be repaired.
- Buildings in capital cities in north-eastern Europe exhibit similar carbonation depths to other EU capitals, however at lower temperatures, underscoring concrete durability's role in carbonation.
- The welfare loss is measured as the annual repair cost-to-GDP ratio, with the highest impacts on GDP in Cyprus, Portugal, and Greece under RCP4.5 (0.12%, 0.11%, and 0.8% GDP, respectively), and Croatia, Czechia, and Poland under RCP8.5 (0.87%, 0.46% and 0.42% GDP, respectively). Results for all EU Member States are shown in Table 1.

Table 1 Projected repair costs and impacts of climate change-induced carbonation on reinforced concrete buildings in EU-27 countries under RCP4.5 and RCP8.5 scenarios. Source: (Dimova et al. 2024) [1].

	RCP4.5			RCP8.5		
Country	Total Repair Costs [B€, 10^9 €]	Buildings Requiring Repair [%]	Welfare Loss [% of GDP]	Total Repair Costs [B€, 10^9 €]	Buildings Requiring Repair [%]	Welfare Loss [% of GDP]
Austria	0	0%	0%	16	88%	0.3%
Belgium	0	0%	0%	13.5	100%	0.2%
Bulgaria	0	0%	0%	11	99%	0.23%
Croatia	0.1	0.1%	0.01%	4.2	100%	0.87%
Cyprus	1.7	77%	0.12%	2.1	100%	0.21%
Czechia	0	0%	0%	85	98%	0.46%
Denmark	14	66%	0.14%	23	100%	0.14%
Estonia	0	0%	0%	2.9	100%	0.15%
Finland	0	0%	0%	13	100%	0.09%
France	0	0%	0%	131	100%	0.08%
Germany	0	0%	0%	104	86%	0.04%
Greece	11	38%	0.08%	19	75%	0.22%
Hungary	0	0%	0%	12	92%	0.12%
Ireland	0	0%	0%	9	100%	0.03%
Italy	17	27%	0.07%	63	99%	0.07%
Latvia	0	0%	0%	5.3	100%	0.27%
Lithuania	0	0%	0%	5.8	100%	0.17%
Luxembourg	0	0%	0%	0.9	100%	0.02%
Malta	0.2	30%	0.13%	0.9	100%	0.13%
Netherlands	0	0%	0%	53	100%	0.9%
Poland	0	0%	0%	204	100%	0.42%
Portugal	16	67%	0.11%	21	96%	0.11%
Romania	0	0%	0%	15.6	82%	0.09%
Slovakia	0	0%	0%	12	100%	0.17%
Slovenia	0	0%	0%	4.7	99.7%	0.13%
Spain	15	35%	0.05%	30	64%	0.05%
Sweden	0.9	5%	0.08%	21	100%	0.08%

GDP* Data extracted on 27/10/2023 19:35:40 from [ESTAT] https://ec.europa.eu/eurostat/databrowser/view/tipsau10/default/table?lang=en

- Out of the over 30 million concrete buildings considered, 14% may require repair by 2100 under RCP4.5, rising to 90% under RCP8.5 (see Fig.1). Poland, Germany, and Italy would be the most impacted in terms of the number of buildings requiring repair under RCP8.5.

- The impacts of carbonation evaluated in this study are compatible with the climate change impacts evaluated by PESETA IV [13] for no mitigation action (RCP8.5) and for the moderate mitigation emissions scenario (RCP4.5), and can enrich the impact categories of PESETA IV with the built environment.

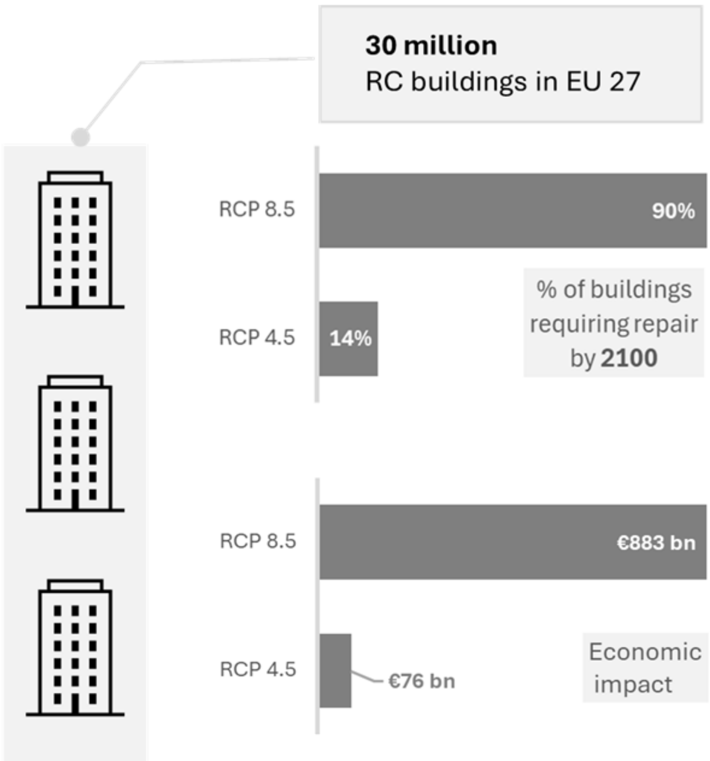

Fig. 1 Projected repairs and economic impact of climate change-induced corrosion on reinforced concrete EU-27 buildings by 2100 under two different climate scenarios.

3 Policy Recommendations

This study underscores the significant economic and structural health challenges posed by climate change-induced carbonation and the urgent need for adaptive measures across the EU Member States. Recommendations include:

1. Developing and implementing guidance and regulations to mitigate the effects of climate change-induced carbonation, and integrating adaptation strategies into building renovation and maintenance practices. The on-going renovation of the facades of the buildings to improve their energy efficiency provides a good opportunity to inspect the state of carbonation of the concrete and implement adaptive measures, where needed.
2. Encouraging adaptation strategies during the service life of existing buildings that include reparative actions for the damaged reinforced concrete, and protection measures against future corrosion.
3. Promoting the adoption of resilience-centric framework for new buildings, based on a dual approach: (i) design-phase adaptation measures based on the level of confidence we have in climate change predictions, and (ii) preventive maintenance strategy that evolves with climate change data.
4. Supporting refined assessments of repair costs for specific building categories or individual buildings, considering their unique features and local repair prices.
5. Advocating for assessments of climate change impacts on carbonation in reinforced concrete transport infrastructure.

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