A New Database of Seismic Vulnerability Functions for Carbon Emissions in Europe

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Part 0:

Why do we care?

Image source: AFP/Getty

Challenges & Motivation

Earthquakes

Turkey-Syria 2023

60,000 Deaths

$40 Billion



Seismic Damage

Repair Works

Environmental Impacts

Sustainability

CONSTRUCTION INDUSTRY

Global Warming

Climate Change

36% of greenhouse gas emissions

Earthquakes Have a Hidden Environmental Toll!

- This toll is embodied carbon, the **CO_2e** from:



100k – 10M+

tonnes CO_2e
released in recovery (e.g., 2023 Türkiye–Syria & 2010–11 Canterbury, NZ)

Yet carbon is missing from seismic risk framework!

- We instinctively measure earthquakes in **collapsed** buildings, **dollars**, **casualties**



- Carbon consequences of earthquake damage remain largely unquantified, especially at regional scales.

Objective: how much is the embodied carbon of earthquake damage in Europe?

Part 1:

Embodied Carbon of Building Replacement

1. Embodied Carbon of Building Replacement

- In seismic risk assessments, it is common to express economic losses as a fraction of full building replacement cost
- Similarly, emissions of seismic damage can be expressed as a **fraction of the building replacement embodied carbon**

Reliable estimates of:
embodied carbon of building replacement

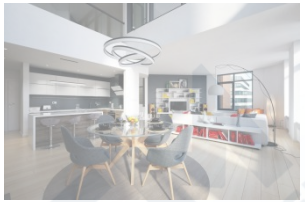


1. Embodied Carbon of Building Replacement

- To estimate the replacement embodied carbon:
  - Component types
  - Component quantities
- The estimate must account for different **building types** and **occupancy** categories



Residential





Commercial





Industrial



1a. Building Component Quantity Estimation

1. **Building Characterisation**
2. Identification of Inventory: Structural/Non-structural
3. Component Quantities



Reinforced Concrete



Earth Construction



Dressed Stone MUR



Timber

1a. Building Component Quantity Estimation

1. Building Characterisation
2. **Identification of Inventory: Structural/Non-structural**
3. Component Quantities

- Structural
  - Columns
  - Beam-Column Joint
  - .
  - .
- Nonstructural
  - Interior/Exterior Partitions
  - HVAC Components
  - Electrical Components
  - .
  - .

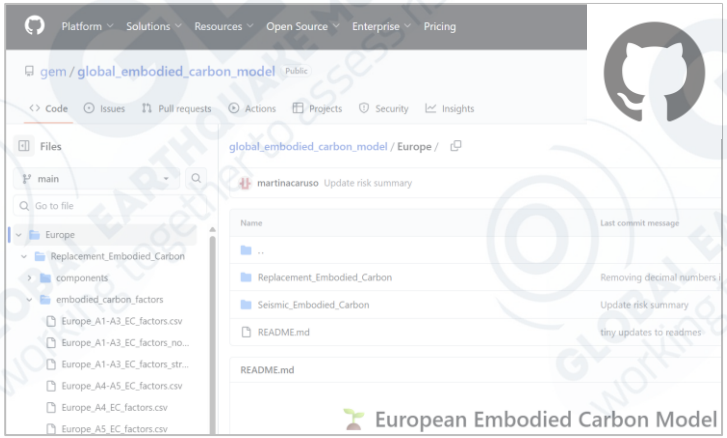
1a. Building Component Quantity Estimation

1. Building Characterisation
2. Identification of Inventory: Structural/Non-structural
3. **Component Quantities**

- Structural
  - Columns
  - Beam-Column Joint
  - per storey area
- Nonstructural
  - Interior/Exterior Partitions
  - HVAC Components
  - Electrical Components
  - per linear meter, per unit area, etc.

1b. Quantities ✖ Carbon Factors

- GEM's database for Embodied Carbon factors for construction materials/components



EC3

circular ecology

EPD Hub

EPD

EPD Hub

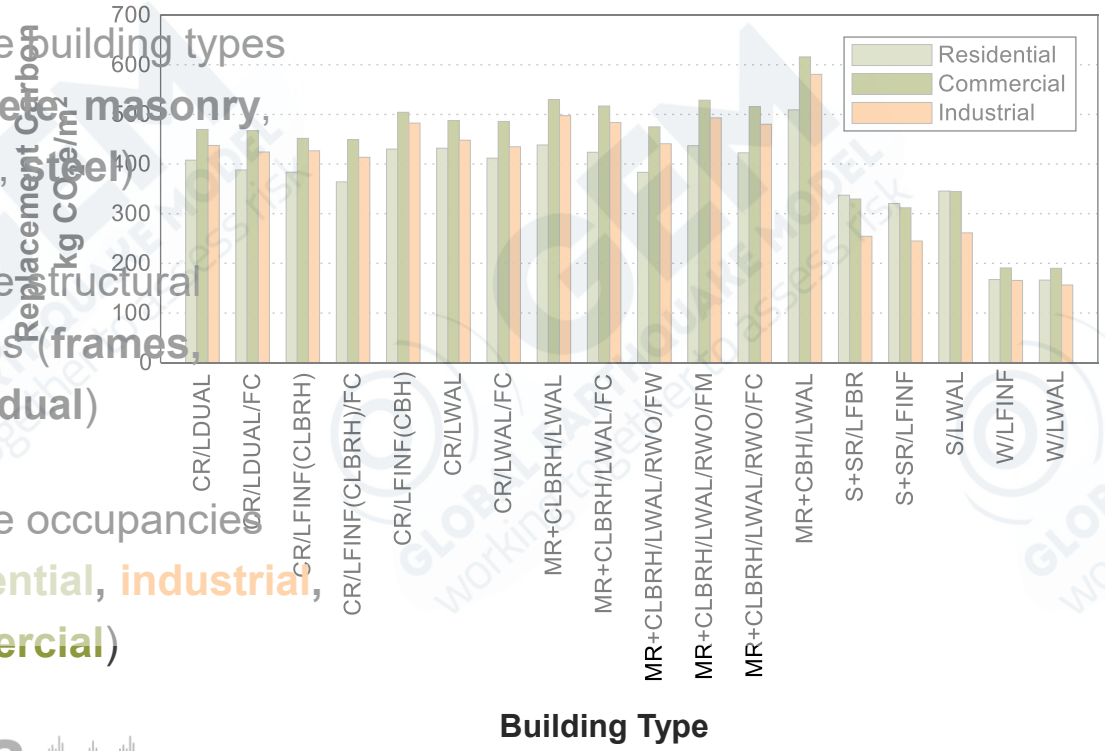
Environdec

EPD ITALY

EPDItaly (ICMQ)

1c. Replacement Embodied Carbon

- Multiple building types (**concrete**, **masonry**, **timber**, **steel**)
- Multiple structural systems (**frames**, **walls**, **dual**)
- Multiple occupancies (**residential**, **industrial**, **commercial**)

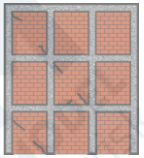


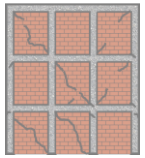
Part 2:

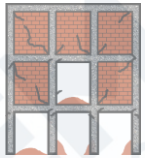
Carbon-Specific Vulnerability Functions (Structural & Non-structural)

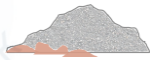
2a. Structural Vulnerability Functions

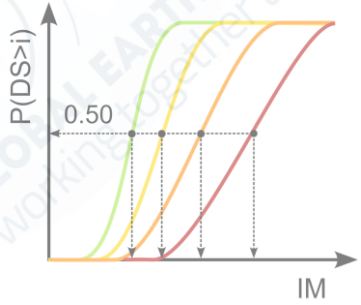
- Structural damage is characterised via global **Damage States (DSs)**


Slight (DS1)

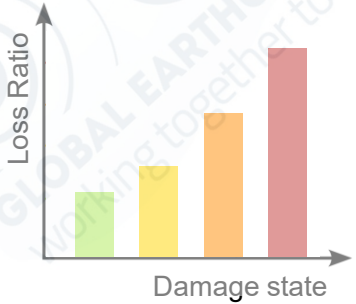

Moderate (DS2)


Extensive (DS3)

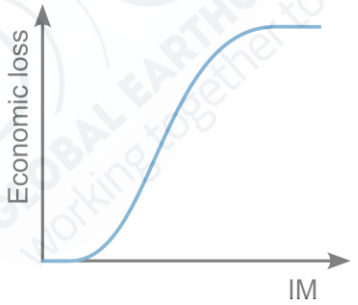

Complete (DS4)



Fragility functions



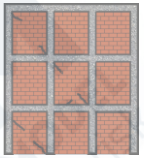
Damage-to-loss ratios

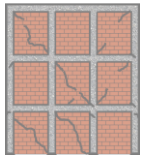


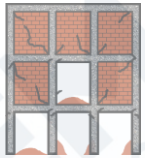
Vulnerability functions

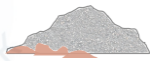
2a. Structural Vulnerability Functions

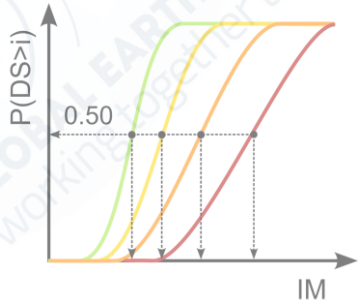
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Slight (DS1)

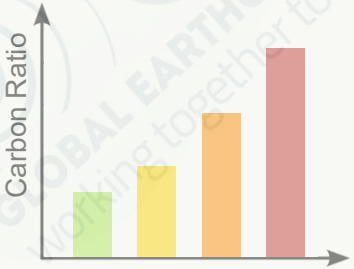

Moderate (DS2)


Extensive (DS3)

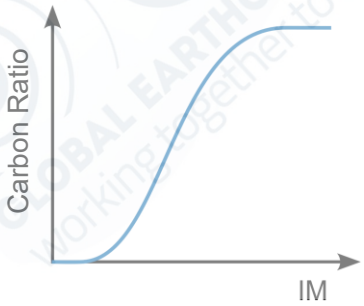

Complete (DS4)



Fragility functions



Damage-to-Carbon Ratios

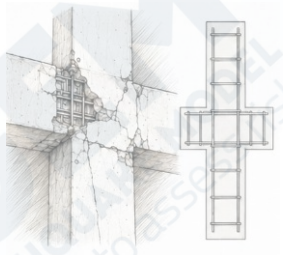


Vulnerability functions

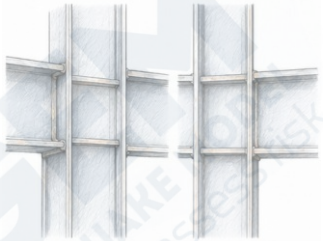
2a. Structural Vulnerability Functions

1. Define the **main structural units** in five macro building classes

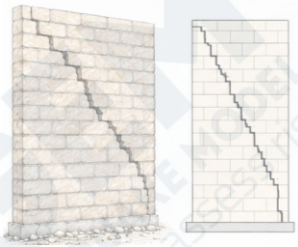
RC Beam-column Joint



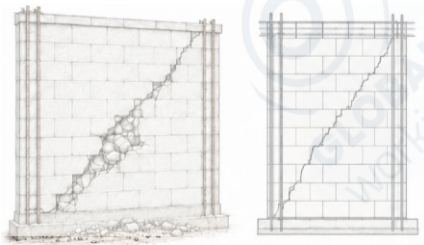
Steel Beam-column Joint



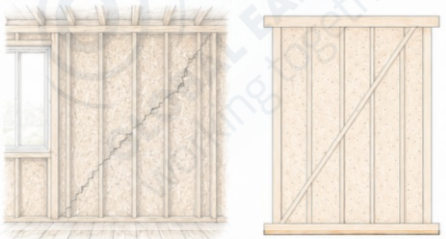
Unreinforced masonry wall



Reinforced masonry wall

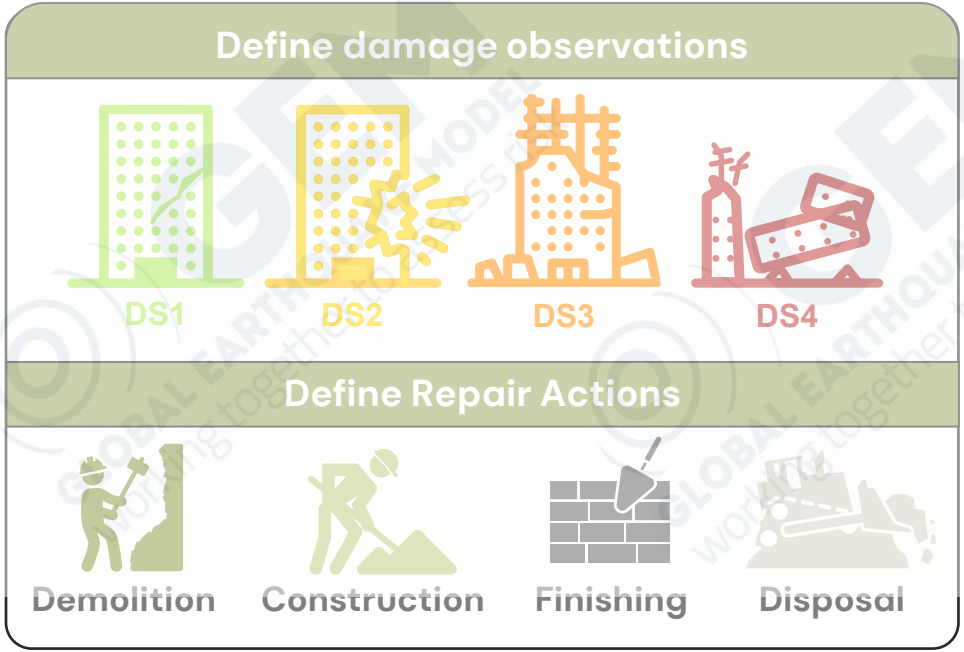


Wood frame & sheathing



2a. Structural Vulnerability Functions

2. Define **damage observations** and relevant **repair actions** to get **material quantity**

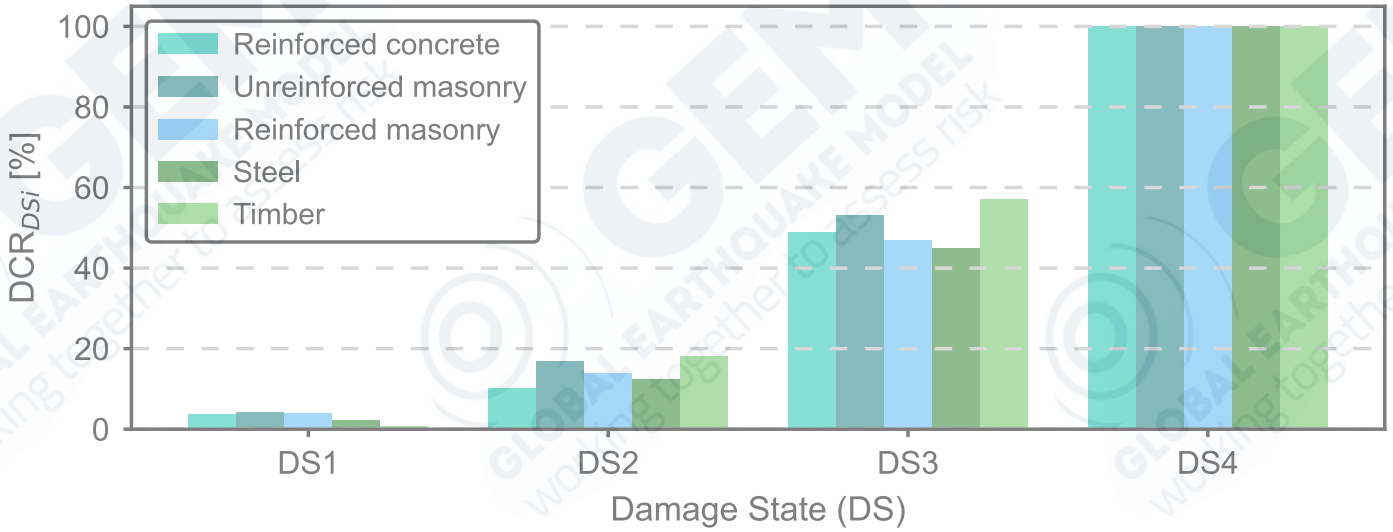






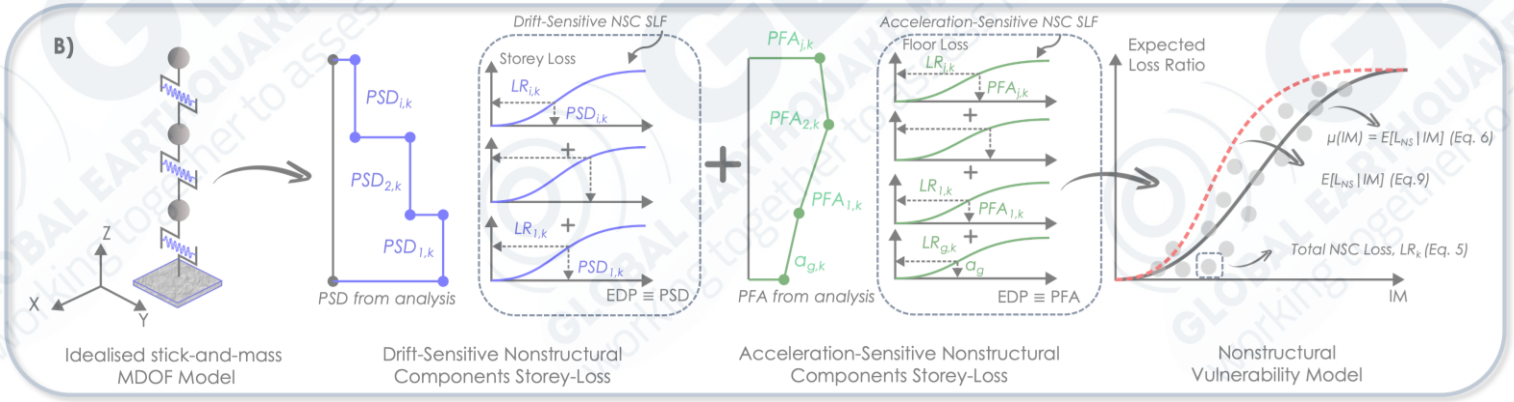
2a. Structural Vulnerability Functions

3. Derive the damage-to-carbon ratios (DCRs)



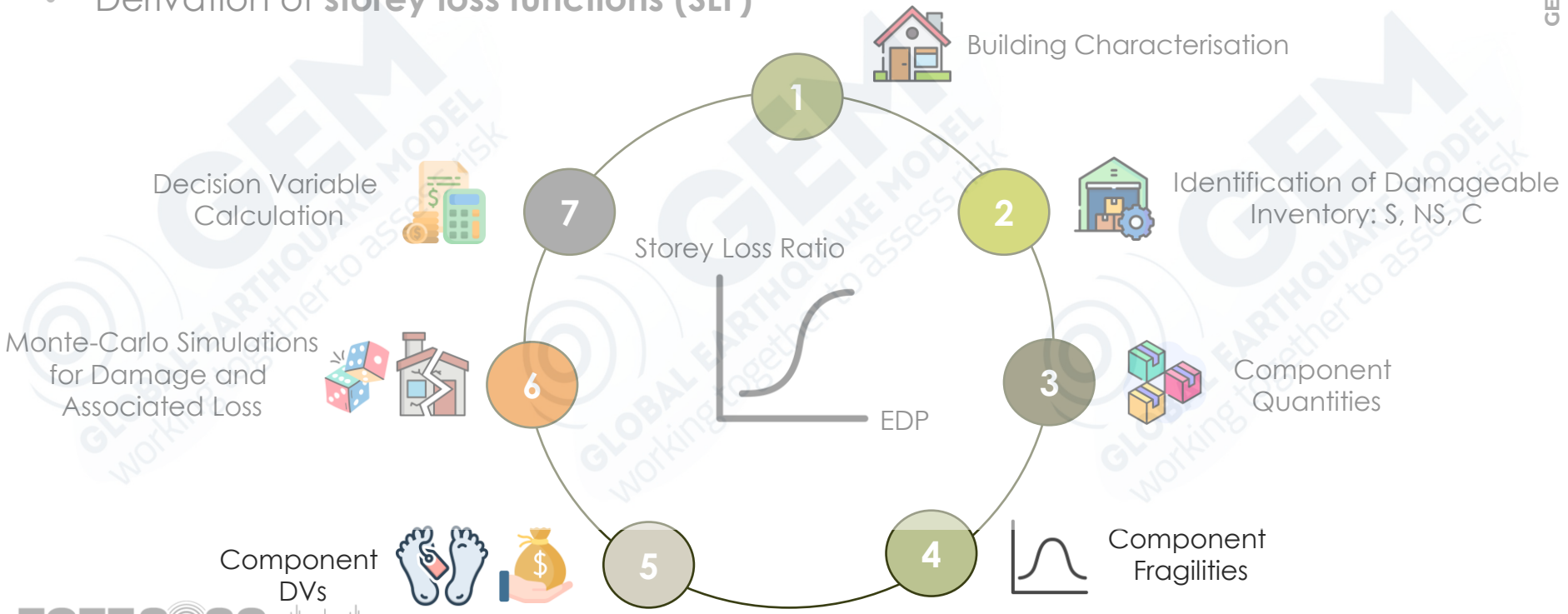
2b. Non-structural Vulnerability Functions

- Non-structural damage and carbon is evaluated at the storey level!
- **By means of storey loss functions (SLF)**



2b. Non-structural Vulnerability Functions

- Derivation of **storey loss functions (SLF)**



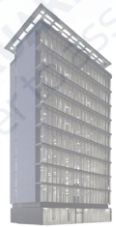
2b. Non-structural Vulnerability Functions

- We need adequate **component inventory** (RES, COM, IND) and **component quantities**

Residential



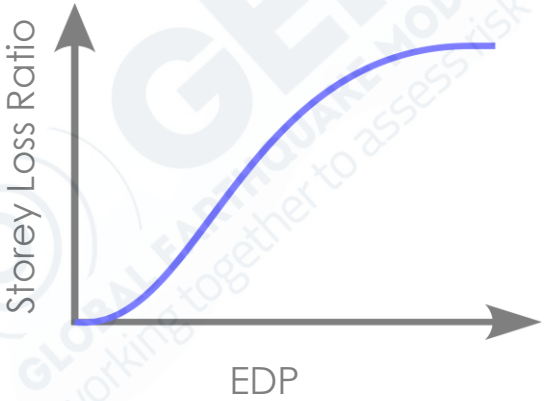
Commercial



Industrial

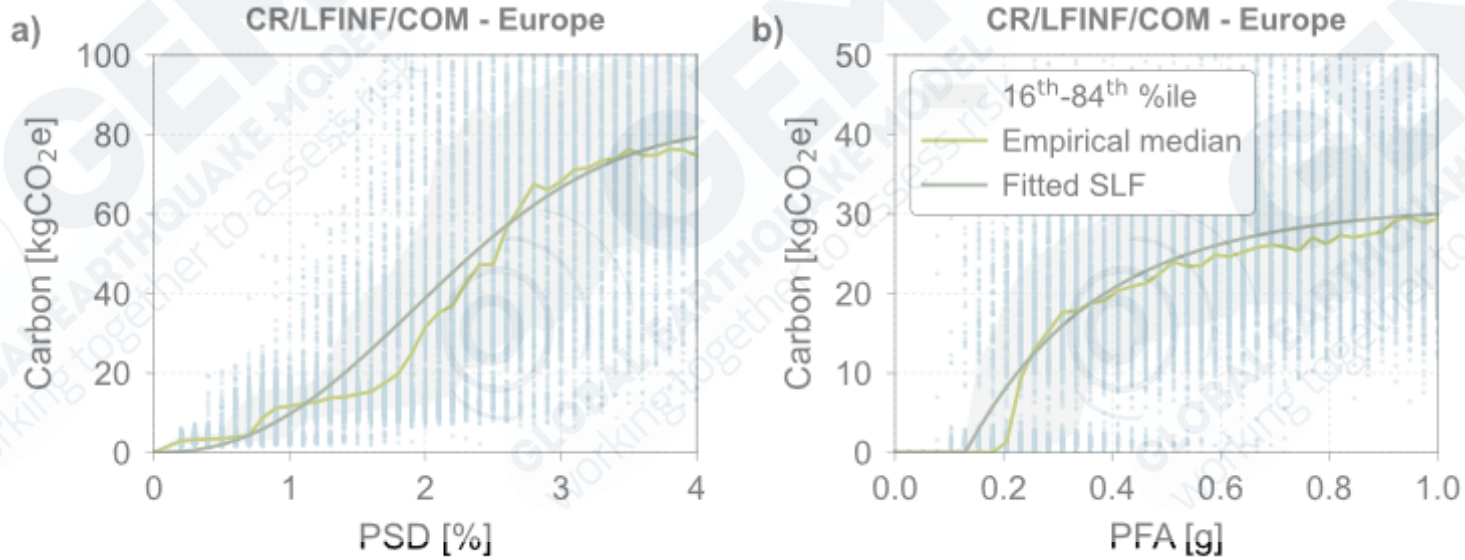






2b. Non-structural Vulnerability Functions

- Derivation of **storey loss functions (SLF)**



Part 3:

Embodied Carbon due to Seismic Risk

3a. Embodied Carbon Seismic Risk

- Use the Average Annual Embodied Carbon Ratio (AAECR): carbon incurred yearly due to seismic damage, considering all possible shaking scenarios

- We conducted **event-based seismic risk assessment**:

Hazard



Exposure



Vulnerability

OPENQUAKE
calculate share explore

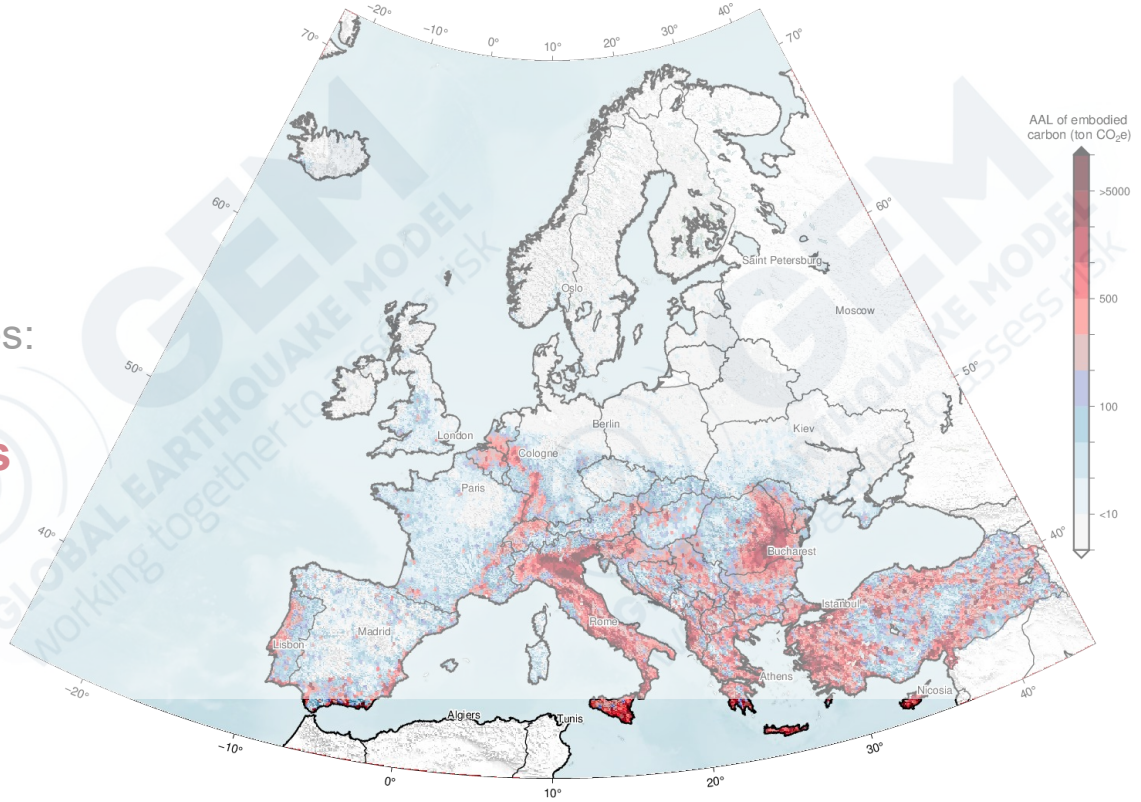
> 3 million ground-shaking scenarios

Average Annual Embodied Carbon Ratio (AAECR)	×	Replacement Embodied Carbon [kg CO_2e]	=	**Total AAEC [kg CO_2e/yr]**

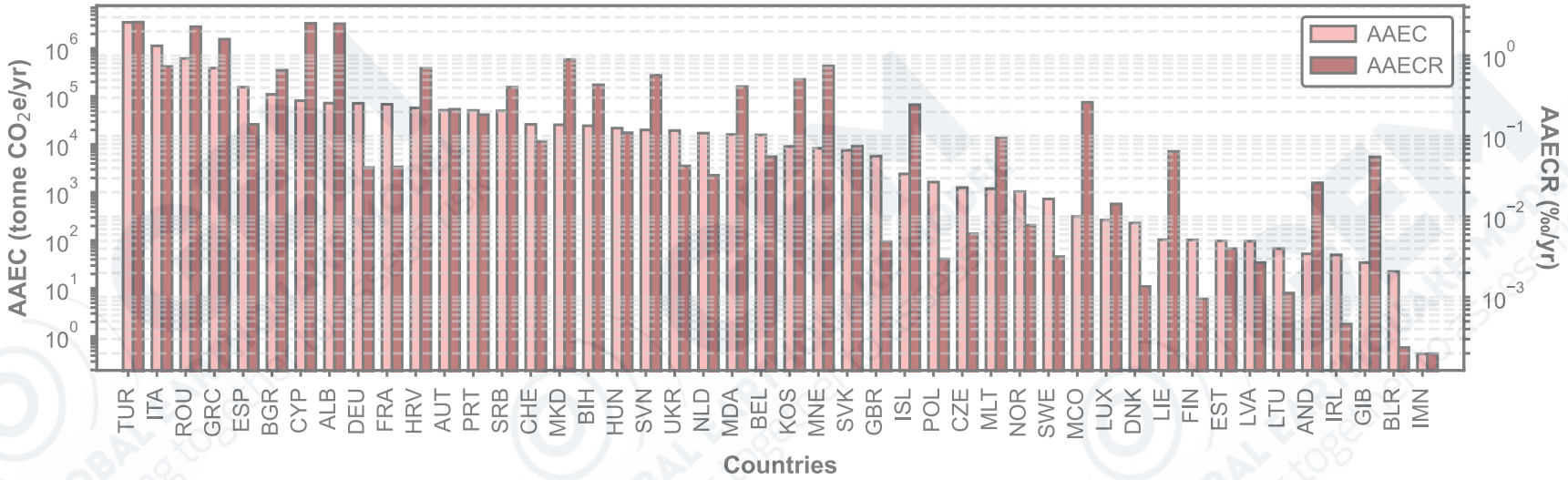
3b. Risk-based Map of Embodied Carbon

- Average Annual Embodied Carbon (**AAEC**)
- Summing the contribution across 46 European countries:

Total = 6.1 million tonnes CO_2e



3c. Country-based Contributions



Türkiye, Italy, Romania, Greece, Spain, Bulgaria **represent combined > 90%**

Part 4:

How much scary are these numbers?

4. Do these Numbers Matter?

- Compare the AAEC to other significant contributors to carbon footprint

AAEC =

6.1 million tons CO_2e

Flight Emissions



33,000 one-way flights from Paris to New York

Annual exhaust emissions



3.9 million diesel car emissions (mid-size)

Caruso M, Silva V, **Aljawhari K**, Nafeh A, Galasso G. (2026) Unveiling the Environmental of Earthquakes in Europe. ***Nature Communications 17, 1366***. https://doi.org/10.1038/s41467-025-68120-6

GitHub Repository

Link to Our Paper!

THANK YOU



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https://carminegalassoresearch.com/

The 2026 Global Embodied Carbon Vulnerability Model

A Comprehensive Global Vulnerability Model for Improved Earthquake Loss Modelling

A.M.B. Nafeh, K. Aljawhari, V. Silva



Session S02-SS04-AVMRR on Advancing Vulnerability Modelling for Regional Risk Assessment and Resilient Communities

Time: Wednesday 16/09/2026 (02:45 PM – 04:10 PM)

Location: S010

A New Global Embodied-Carbon Seismic Risk Model

M. Caruso, K. Aljawhari, A.M.B. Nafeh, V. Silva, C. Galasso



Session S03-16-SRAMH on Seismic Risk Assessment and Multi-Hazard Risk (incl. Tsunami and NaTech) \

Time: Monday 14/09/2026 (4:35 PM – 6:00 PM)

Location: S03