

Life cycle analysis for cementitious materials

MSE-420

08th October 2025

1. General principles for Life Cycle Assessment
2. Key decisions for Life Cycle Assessment

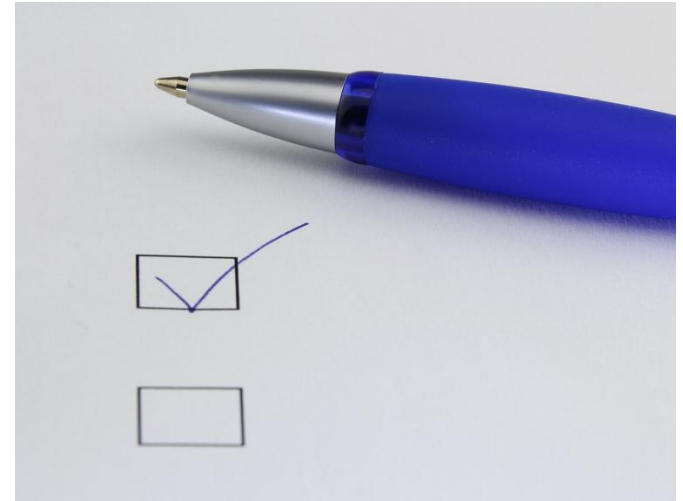
Break

3. Practice example
4. Whole Life Cycle Costing
5. 'Defence Against the Dark Arts'



Learning objectives

1. **Define** approximate ranges for embodied carbon of key constituents in cement and concrete
2. **Understand** the generic principles of Life Cycle Assessment (LCA)
3. **Select** appropriate choices for the key decisions in LCA
4. **Apply** LCA to construction materials, including how to **evaluate** sources of input data
5. **Evaluate** sustainability statements in research articles and other sources of information, and **identify** types of key mistakes



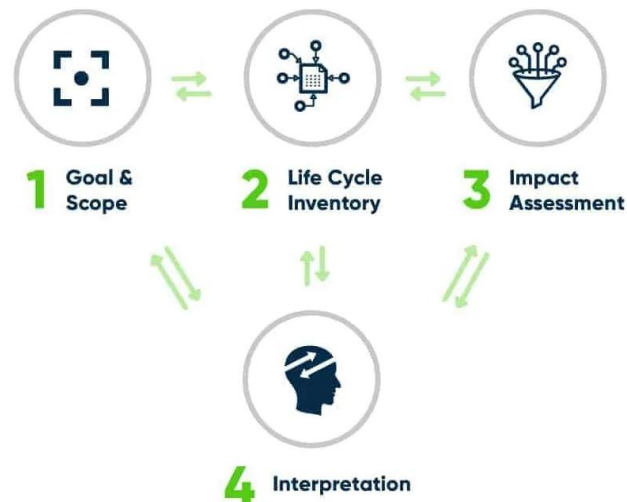
General principles for Life Cycle Assessment

What is a Life Cycle Assessment?

A life cycle assessment (LCA) is a methodology for **assessing environmental impacts** associated with all (or some) of the life stages of a product, process, or service (ISO 14040/14044)

Four stages of doing an LCA:

1. Define the goal and scope
2. Obtain input data
3. Carry out calculations
4. Check findings and answer original question



What is a Life Cycle Assessment?

- LCA measures or estimates the **environmental aspects** and **potential environmental impacts** throughout a product's life cycle
- The LCA process determines **how robust and reliable** the estimate or measurement is
- LCA can assist in...
 - Identifying **opportunities to improve** the environmental performance of products
 - Making **decisions** between designs, products or materials
 - Selecting relevant **indicators** of environmental performance

Key values for embodied carbon

- We know from everyday experience what the **typical mass** of common objects are (to an order of magnitude)

E.g. The mass of a cucumber is 100s of grams...

not milligrams...

not tonnes...

not kilograms...

(well most of the time)

- We are less familiar (from everyday experience) with **embodied carbon**.



World record = 13.4 kg!

Key values for embodied carbon

- We can state typical ranges for typical constituents, so we are familiar with the order of magnitude we are dealing with.
- If you want to know how these compare with everyday items/activities, this book is fun:



But for this class we want to know...

- Where do these numbers come from?
- How do we calculate them?
- How can we use them for our own calculations?

| Quantity of material | Embodied carbon (typical range) (kg.CO _{2eq.}) |
|------------------------------|--|
| 1 ton of clinker | 850 – 900 |
| 1 ton of cement | 600 – 850 |
| 1 ton of calcined clay | 200 – 400 |
| 1 ton of aggregate | 2 – 7 |
| 1 m ³ of concrete | 150 - 450 |

Martinez et al. (2023). Comparative environmental assessment of limestone calcined clay cements and typical blended cements. *Environmental Research Communications*, 5(5), 055002.

Anderson, J., & Moncaster, A. (2020). Embodied carbon of concrete in buildings, Part 1: Analysis of published EPD. *Buildings & Cities*, 1(1).

Key decisions for life cycle assessment

Key decisions for doing a life cycle assessment

1. Physical scope (i.e. material / structural element / structure)
2. Life cycle stage (i.e. temporal) scope
3. Functional units
4. Source data
5. Assumptions and accounting approaches
6. Impact indicators
7. Reference/benchmark scenario

Largely pre-determined by the project and question

For each of these, we will explore...

- What is our choice of options?
- How can this choice cause variation in the outcome of an LCA?
- How can we make the most appropriate choice for our study?



1. Physical scope

What is our choice of options?

1. Cement (or cement constituent)
2. Concrete (or other cementitious material)
3. Structural element (e.g. column)
4. Structure (e.g. 8-storey apartment block)



How can this choice cause variation in the outcome of an LCA?

- A structure is closest to how concrete is used in reality – gives better idea of potential impacts but...
 - More complex and longer to do
 - Additional uncertainties in scope (e.g. superstructure only? Structure and building envelope?)
 - Not straightforward to compare with other LCAs done for different structures (e.g. single storey-dwelling v. mid-rise housing)

1. Physical scope

How do we choose?

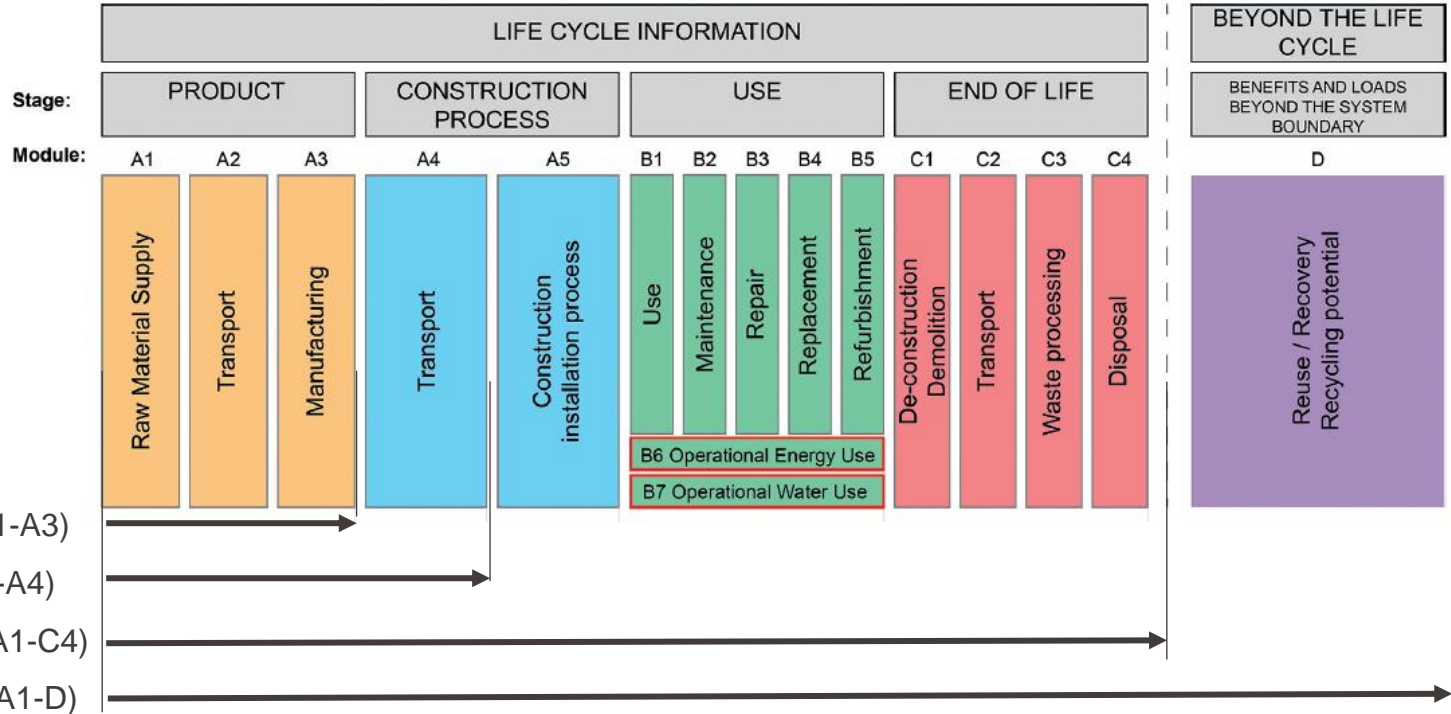
- Our choice is largely defined by the project, and the question.
- E.g. In **industrial practice** - a client wants to know whether the embodied carbon of a **new building** will be lower if we choose a different concrete mix... we choose **structure scope**.
- E.g. In **research** – we are developing a novel way of calcining clay, and we want to know if the embodied carbon of this **process** is lower than rotary kiln calcination... we choose **constituent scope**



2. Life cycle stage / boundary conditions scope

What is our choice of options?

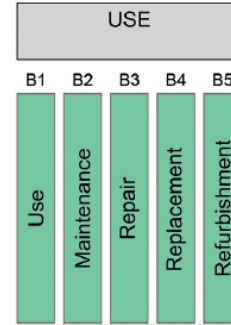
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2. Life cycle stage / boundary conditions scope

How can this choice cause variation in the outcome of an LCA?

- The more life cycle **stages** – the more **processes** we consider
E.g. Cradle-Site v. Cradle-Grave. During Use stage (i.e. Stage B)
- Maintenance and repair → *increases* embodied carbon
- In-service carbonation → *decreases* embodied carbon



How do we choose?

- Largely determined by the scope of our study, and what we have sufficient data for.
- E.g. In **industrial practice** - we are helping EPFL to design a new building on campus with the lowest possible embodied carbon... we choose a minimum of **Cradle-Grave** (ideally Cradle-Cradle)
- E.g. in **research** - we are developing a new SCM using an industrial wastes, and we want to know its embodied carbon is lower than fly ash... we choose **Cradle-Gate**
- If we do not yet know how to make concrete using a novel constituent – we do not have enough information to do an LCA for concrete scope and beyond.

3. Functional unit

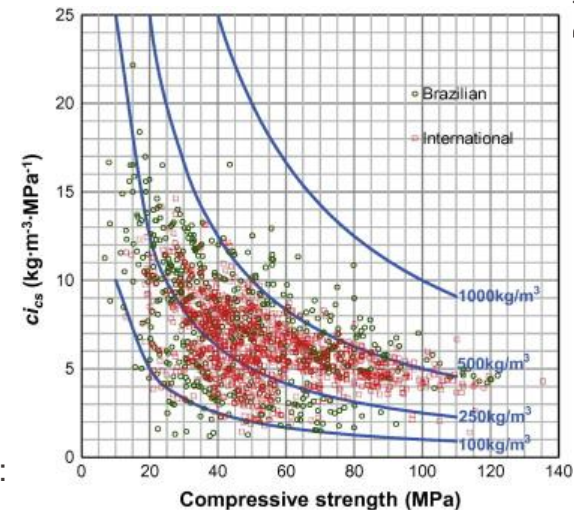
The functional unit is the **denominator** we use to describe our embodied carbon I.e. “Kg.CO₂ per XXX”

What is our choice of options?

- Kg of constituent
- Kg of cement
- m³ of concrete
- m² of floor area

(these are the most commonly used functional units)

- Growing interest in performance-based functional units for concrete. e.g.:
 - Strength - m³.MPa⁻¹ (Damineli et al., 2010)
 - Carbonation/chloride resistance – m³.F_{carb/chlor} (Gettu et al., 2018)
- But beware that these do not account for structure-specific requirements



A plot of ‘carbon intensity’ for concrete mixes

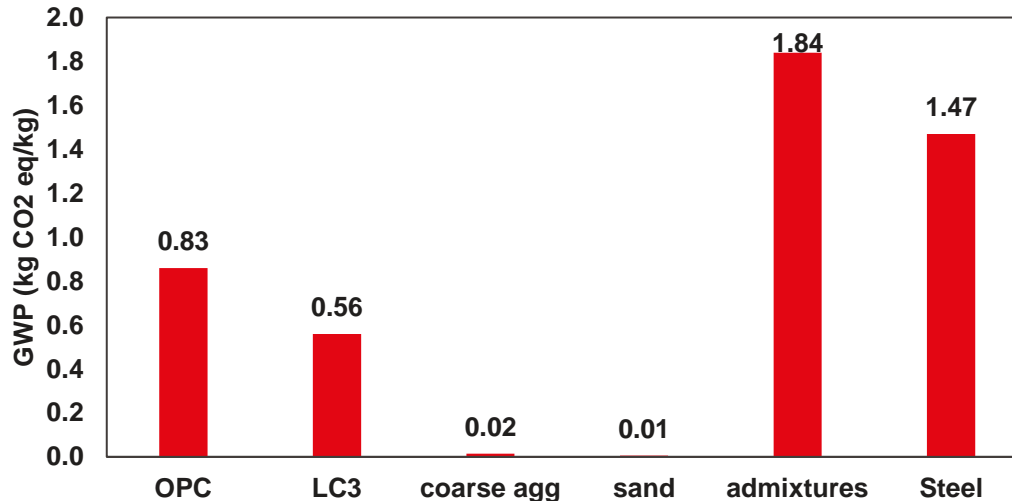
Damineli et al. (2010). Measuring the eco-efficiency of cement use. *Cement and Concrete Composites*, 32(8), 555-562.

Gettu et al. (2018). Sustainability-based decision support framework for choosing concrete mixture proportions. *Materials and structures*, 51, 1-16.

3. Functional unit

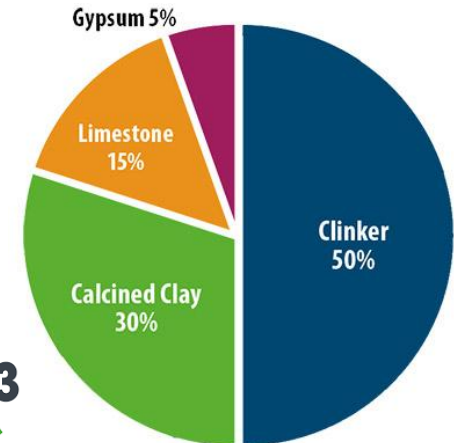
How can this choice cause variation in the outcome of an LCA?

- E.g. Choose kg of cement as a functional unit
 - 1 kg of clinker has a typical GWP of 0.88 kg CO₂eq
 - 1 kg of calcined clay has a typical GWP of 0.25 kg CO₂eq
 - 1 kg of limestone and gypsum have a GWP of around 0.02 and 0.05 kg CO₂eq
- LC³-50 cement reduced the GWP of a kg of cement (compared to OPC) by **40%**



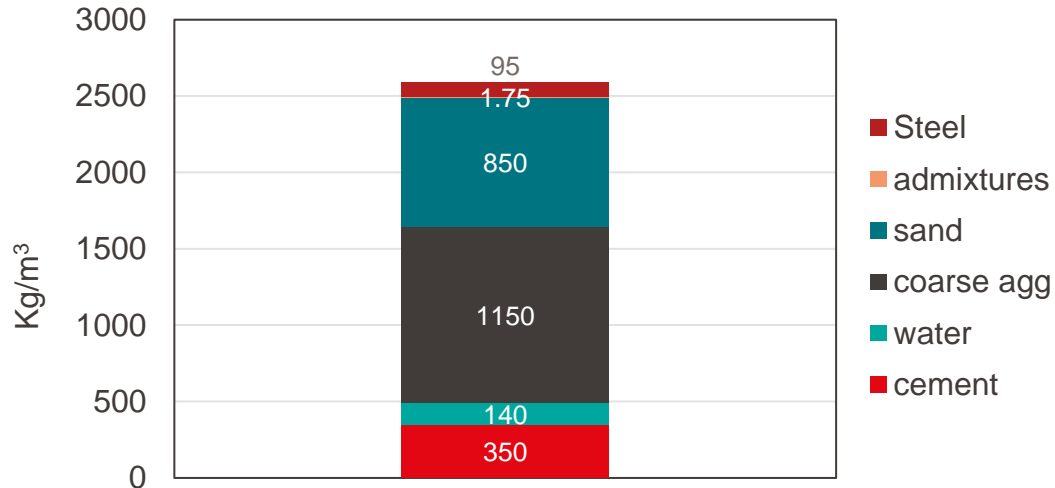
Limestone
Calcined
Clay
Cement

LC³



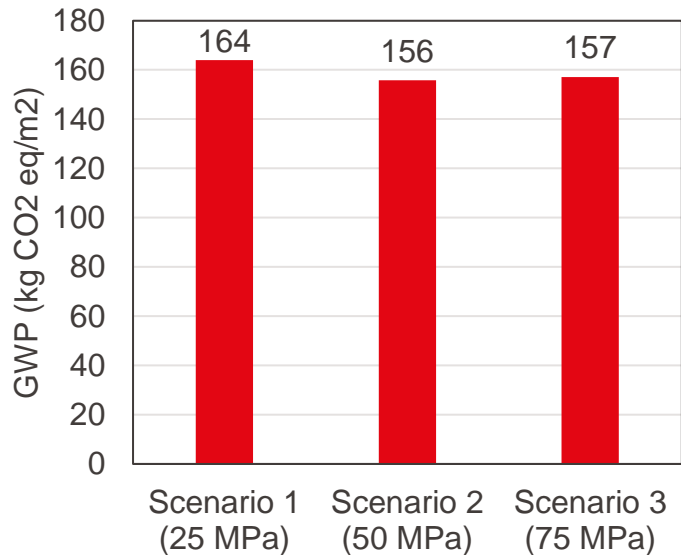
3. Functional unit

- E.g. Choose m^3 of concrete as a functional unit
 - Typical concrete mix ~15% of cement by mass
 - Typical concrete mix made using OPC - $325 \text{ kg CO}_{2\text{eq}} / \text{m}^3$
 - Typical concrete mix made using LC³-50 - $225 \text{ kg CO}_{2\text{eq}} / \text{m}^3$
- LC³ cement reduced embodied carbon per m^3 of concrete (compared to OPC concrete) by **30%**



3. Functional unit

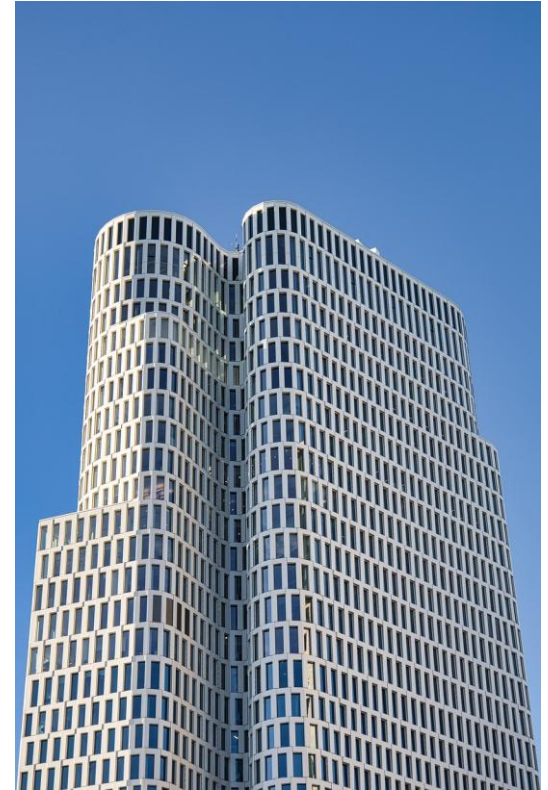
- E.g. Choose m^2 floor area as a functional unit
 - Concrete is the main component of a concrete building (finishes and envelope $\sim 25\%$ by mass)
 - A higher strength concrete might reduce the volume of concrete needed for the same loads
 - However, the impact is NOT linear



3. Functional unit

How do we choose?

- Again – largely determined by our choice of physical scope
- E.g. In **industrial practice** – we are designing a new skyscraper, and we want to know whether a new structural design and concrete mix will together reduce the embodied carbon... we choose **kg.CO₂ / m² floor area**
- The new structural design **might change the usable floor area** – so we want to compare per m² of floor area
- E.g. in **research** – we are testing whether a new superplasticizer can help us reduce the amount of cement we need in an LC³ concrete (to achieve the same strength class)... we choose **kg.CO₂ / m³ concrete**



4. Source data

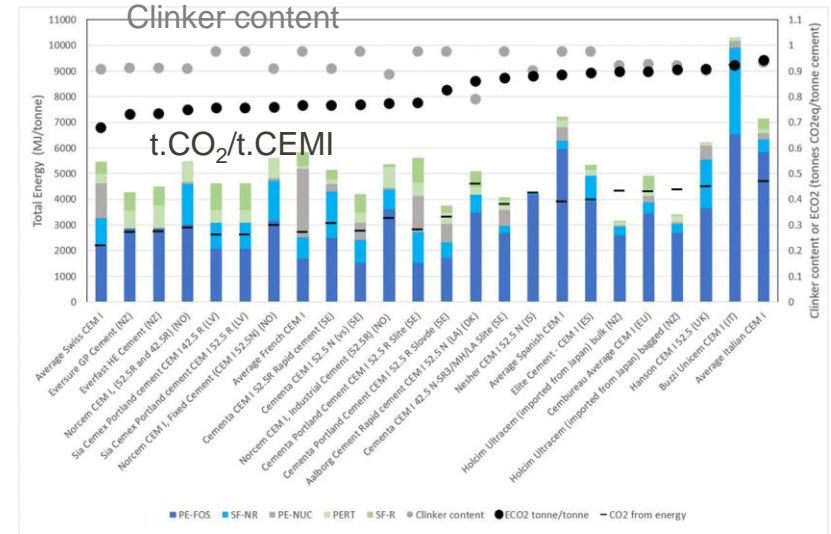
What is our choice of options?

- Primary data source (i.e. directly measured)
- Secondary data source – material/product specific (e.g. Environmental Product Declaration - EPD)
- Secondary data source – generic (e.g. LCA database, literature average)

There are many differences in production between different processes, and between different sites. E.g. for clinker production...

- Kiln type
- Grinder type
- Fuel source
- Carbon factor of electricity source

These factors result in (real!) differences in the embodied carbon of clinker produced at different sites.



Variation in embodied carbon of CEMI between countries and companies

Anderson, J., & Moncaster, A. (2020). Embodied carbon of concrete in buildings, Part 1: Analysis of published EPD. Buildings & Cities, 1(1).

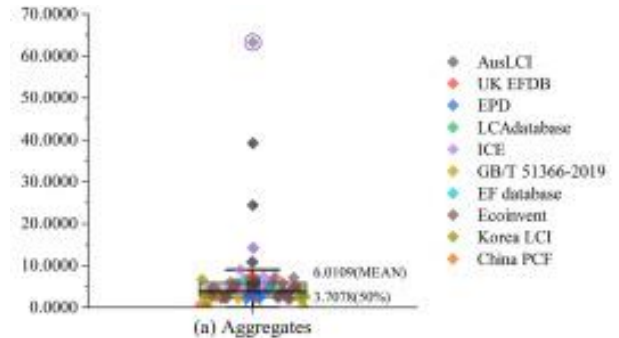
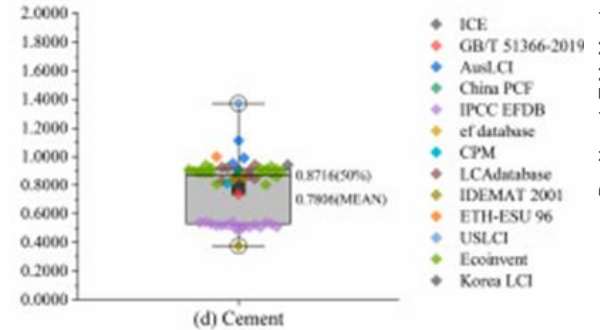
4. Source data

How can this choice cause variation in the outcome of an LCA?

- Like any model – the more **accurate and reliable** the input data is... the more accurate and reliable the output will be.

How do we choose?

- Order of preference** is: Primary > Secondary (specific) > Secondary (generic)
- Primary data** is often not feasible/accessible – and specific secondary data is not always available
- However – **secondary data** can be flawed! (e.g. unit errors in Environmental Product Declarations (EPDs))
- As general principles:
 - use the data sources that provide the **most accurate and specific data** for your processes and products
 - compare values against other sources (i.e. to check if it is very different).
 - If using secondary (generic) – choose lower/upper bound values for an uncertainty analysis



Systematic and random variations exist between databases

Teng, et al. (2023). The impact of life cycle assessment database selection on embodied carbon estimation of buildings. *Building and Environment*, 243, 110648

5. Assumptions and accounting approaches

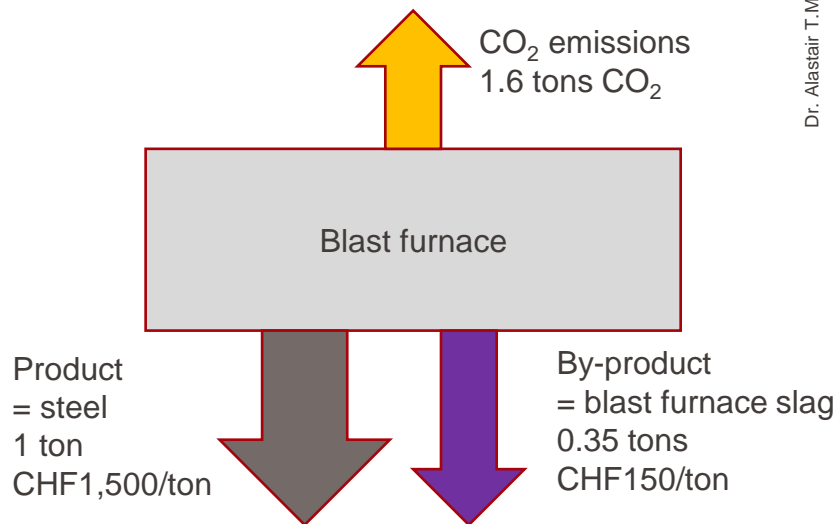
What is our choice of options?

- For secondary fuels:
 - Include combustion emissions
 - Exclude combustion emissions
- For industrial by-products and wastes:
 - Mass allocation of emissions
 - Economic allocation of emissions
 - No allocation of emissions

How can this choice cause variation in the outcome of an LCA?

- For **fuels**: emissions higher if include combustion emissions
- For industrial **by-products and wastes** (generally):

Embodied carbon: mass > economic > no allocation



| | Steel | GGBS |
|----------|--------------------------|--------------------------|
| Mass | 1.2 t.CO ₂ /t | 0.4 t.CO ₂ /t |
| Economic | 1.5 t.CO ₂ /t | 0.1 t.CO ₂ /t |
| None | 1.6 t.CO ₂ /t | 0 t.CO ₂ /t |

5. Assumptions and accounting approaches

How do we choose?

- Conventions exist for most well-established by-products used as SCMs – economic allocation is (usually) applied to GGBS and fly ash.
- However – for a novel by-product SCM, the economic value is unknown.
- The best solution – include allocation method as a variable in a sensitivity analysis (i.e. compare all options).



6. Choice of indicators

What is our choice of options?

- Acidification Potential
 - **Global Warming Potential**
 - Abiotic Depletion Potential
 - Primary energy
 - Primary energy non renewable
 - Photochemical Ozone Formation Potential

 - This is just the standard EPD list - it's a lot!
 - But where is embodied carbon??
- Waste generated
 - Radioactive waste
 - Water consumption
 - Air Pollution
 - Water Pollution
 - Total Mass Requirement
 - Abiotic Depletion Potential Elements

6. Choice of indicators

What exactly is **Global Warming Potential (GWP)**?

= the ratio of a gas's global warming strength in relation to CO_2 , usually over a 100 year period. E.g. $\text{N}_2\text{O} = 298$ (!)

Is GWP the same as **embodied carbon**?

To keep things simple, we describe all greenhouse gases by carbon dioxide equivalent emissions – units of $\text{t.CO}_2(\text{eq.})$

How is $\text{CO}_{2\text{eq.}}$ different to CO_2 ?

$\text{CO}_{2\text{eq.}}$ accounts for ALL greenhouse gases (including CO_2).

CO_2 is just CO_2 .

For cementitious constituents and materials... $\text{CO}_2 \approx \text{CO}_{2\text{eq.}}$



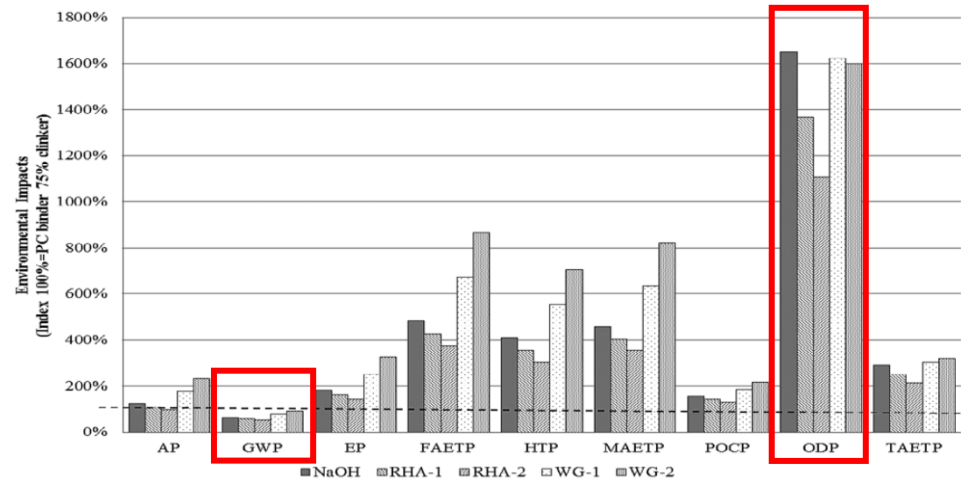
How can this choice cause variation in the outcome of an LCA?

- A material that seems better in terms of embodied carbon, is not necessarily better in terms of other impact categories.

How do we choose?

- It depends **what is most important** for the project/question.
- E.g. particulate pollution is relevant to choosing the site of a new calcined clay production site
- For **construction materials**: GWP, ozone formation, ecotoxicity, acidification and particulate pollution most relevant (Feng et al., 2023)

Comparison of geopolymers v. 20% GGBS blended cement



Passuello et al. (2017). Evaluation of the potential improvement in the environmental footprint of geopolymers using waste-derived activators. *Journal of Cleaner Production*, 166, 680-689.

Feng, H., Zhao, J., Hollberg, A., & Habert, G. (2023). Where to focus? Developing a LCA impact category selection tool for manufacturers of building materials. *Journal of Cleaner Production*, 405, 136936.

7. Reference / benchmark scenario

To give meaningful context, LCA should compare against a **reference material/element/structure** (depending on scope).



What is our choice of options?

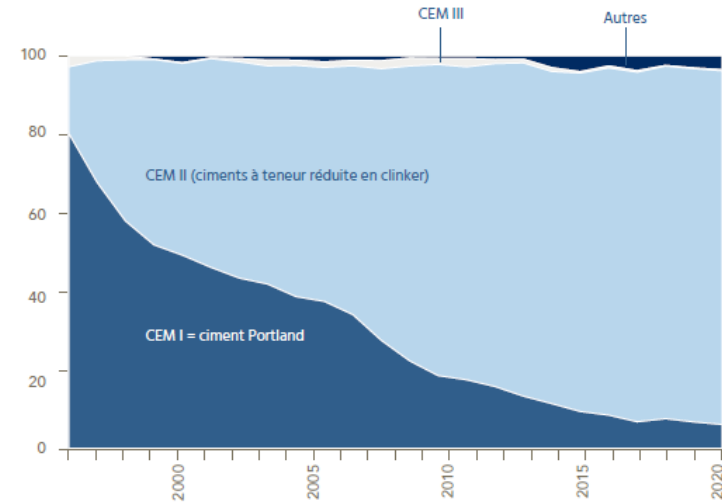
- It depends on the **location and application**...

How can this choice cause variation in the outcome of an LCA?

- CEM I** is often used as a convenient reference – BUT it has 95% clinker content, and is often not the most common cement in many regions. E.g. Switzerland
- So CEM I is not always a fair reference in practice!

How do we choose?

- It is useful to know the **most commonly used cement blend** in the region of your project.
- Decide based on application (if applicable).



Changes in market share of cement types in Switzerland (Cemsuisse, 2021)

More detailed guidance

- Useful for **basic to advanced** levels of detail
- Both available as free pdfs online:

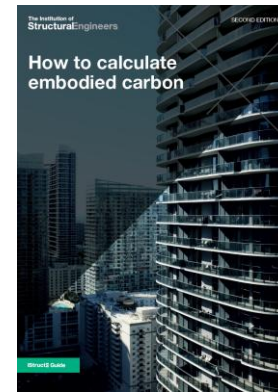
How to calculate embodied carbon (2nd edition), The Institution of Structural Engineers

Whole life carbon assessment (WLCA) for the built environment, Royal Institution of Chartered Surveyors

- Both contain lists of databases in the Appendices
- BUT, beware – designed for the construction industry (i.e. cradle-to-grave boundary conditions for whole structures)
- Not necessarily all relevant to materials research
- **More advanced** guides:

ILCD Handbook: General guide for Life Cycle Assessment (JRC, 2010)

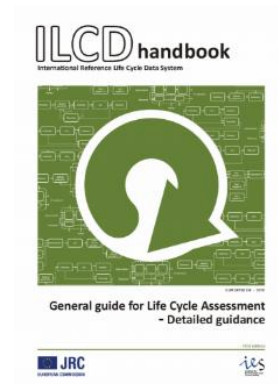
Life Cycle Assessment: Theory and Practice (Hauschild et al., 2018)



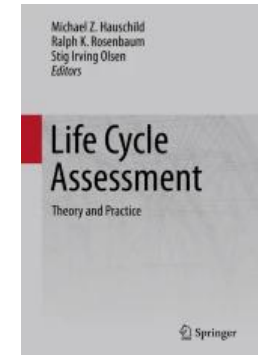
<https://www.istructe.org/resources/guidance/how-to-calculate-embodied-carbon/>



https://www.rics.org/content/dam/rics/global/documents/standards/Whole_life_carbon_assessment_PS_Sept23.pdf



<https://eplca.jrc.ec.europa.eu/uploads/ILCD-Handbook-General-guide-for-LCA-DETAILED-GUIDANCE-12March2010-ISBN-fin-v1.0-EN.pdf>



<https://doi.org/10.1007/978-3-319-56475-3>

Secondary data sources

- Inventory of Carbon and Energy v.3.0 (LCA database)

<https://circularecology.com/embodied-carbon-footprint-database.html>

- ÖKOBAUDAT database (EPDs)

<https://www.oekobaudat.de/en.html>

- ECO Portal (EPDs)

<https://www.eco-platform.org/eco-portal-access-point-to-digital-product-data.html>

Tip – EPDs can be overwhelming... to find embodied carbon data – Ctrl+F “GWP”



Embodied Carbon - The ICE Database



Practice example

Housing demand for gingerbread people is rapidly increasing...

- In the run-up to Christmas, the **population of gingerbread people** is expected to **increase rapidly**.
- Currently, there is **not enough suitable housing** for all these gingerbread people.
- Our job is to **assess the embodied carbon** of proposed gingerbread housing...
- ... and calculate the **change in embodied carbon** from **different strategies to improve their durability** to degradation.
- Now - gather into your project group teams!



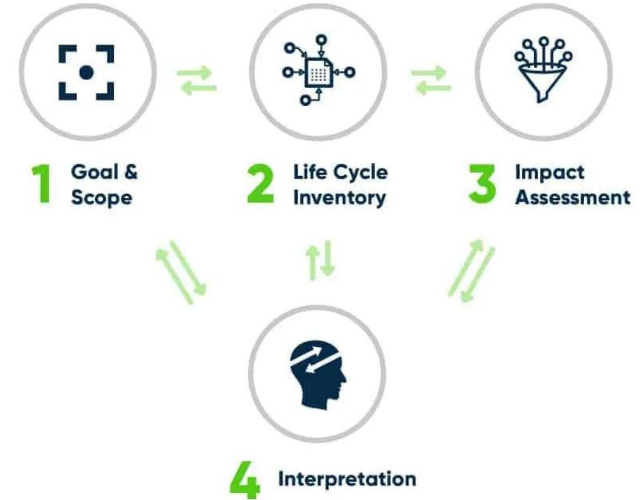
Stage 1) Goal and scope

Goal 1 = Calculate the **embodied carbon** of a single gingerbread housing unit (for a life cycle scope of **A1-A3**).

i.e. the **reference** scenario

Goal 2 = Assess the change in **embodied carbon** for a single gingerbread housing unit (for a life cycle scope of **A1-A3**), when **three different strategies to enhance durability** are used.

i.e. the **strategy** scenarios



| | | LIFE CYCLE INFORMATION | | | | | | | | | | | | BEYOND THE LIFE CYCLE | | |
|---------|---------------------|------------------------|---------------|----------------------|-----------------------------------|---------------------------|-------------|--------|-------------|---------------|----------------------------|-----------|------------------|-----------------------|---|--|
| Stage: | PRODUCT | | | CONSTRUCTION PROCESS | | USE | | | | | END OF LIFE | | | | BENEFITS AND LOADS BEYOND THE SYSTEM BOUNDARY | |
| Module: | A1 | A2 | A3 | A4 | A5 | B1 | B2 | B3 | B4 | B5 | C1 | C2 | C3 | C4 | D | |
| | Raw Material Supply | Transport | Manufacturing | Transport | Construction installation process | Use | Maintenance | Repair | Replacement | Refurbishment | De-construction Demolition | Transport | Waste processing | Disposal | Reuse / Recovery Recycling potential | |
| | | | | | | B6 Operational Energy Use | | | | | | | | | | |
| | | | | | | B7 Operational Water Use | | | | | | | | | | |

Stage 2) Life Cycle Inventory

A1: Raw Material Supply

- Composition of gingerbread in reference scenario:

| Constituents | Composition quantity (kg constituent / kg of gingerbread) | Embodied carbon of constituents (kg.CO _{2(eq.)} / kg of constituent) |
|--------------|--|--|
| Flour | 49.1 wt. % | 891.2 kg.CO _{2(eq.)} |
| Sugar | 24.5 wt. % | 656.0 kg.CO _{2(eq.)} |
| Butter | 17.5 wt. % | 9,757.9 kg.CO _{2(eq.)} |
| Eggs | 8.4 wt. % | 4,505.7 kg.CO _{2(eq.)} |
| Ginger | 0.5 wt. % | 1,132.5 kg.CO _{2(eq.)} |

A2: Transport

- Assume zero for reference scenario

A3: Manufacturing

- 15 minutes in 160°C oven (0.039 kg.CO_{2(eq.)} / minute)

Stage 3) Impact assessment – reference scenario

Reference scenario: Calculate the **embodied carbon** of a single gingerbread housing unit (for a life cycle scope of **A1-A3**).

Let's break it down into steps...

Step A) Calculate embodied carbon of the **gingerbread material** ($\text{kg.CO}_2(\text{eq.}) / \text{kg. of gingerbread}$)

Step B) Calculate embodied carbon of **all gingerbread structural elements** in the housing unit ($\text{kg.CO}_2(\text{eq.})$)

Step C) Calculate embodied carbon of the **whole gingerbread structure** ($\text{kg.CO}_2(\text{eq.})$)



Step A) Calculate embodied carbon of the gingerbread material (kg.CO_{2(eq.)}/ kg. of gingerbread)

Stage A1 – Raw materials

| Constituents | Composition quantity (kg constituent / kg of gingerbread) | Embodied carbon of constituents (kg.CO _{2(eq.)} / kg of constituent) |
|--------------|---|---|
| Flour | 49.1 wt.% | 0.89 kg.CO _{2(eq.)} |
| Sugar | 24.5 wt.% | 0.66 kg.CO _{2(eq.)} |
| Butter | 17.5 wt.% | 9.76 kg.CO _{2(eq.)} |
| Eggs | 8.4 wt.% | 4.51 kg.CO _{2(eq.)} |
| Ginger | 0.5 wt.% | 1.13 kg.CO _{2(eq.)} |

Stage A3 – Manufacturing

- Embodied carbon of oven use = (0.039 kg.CO_{2(eq.)}/ minute)
- Recipe = 15 minutes in the oven

Q1: What is the embodied carbon of the gingerbread (**A1**)? (kg.CO_{2(eq.)}/ kg. of gingerbread)

Q2: What is the embodied carbon of baking the gingerbread in the oven? (**A3**)



Step B) Calculate embodied carbon of all gingerbread structural elements in the housing unit (kg.CO_{2(eq.)})

Need to know the mass of each structural element:

- Walls = ??? g
- Roof = ??? g
- Chimney = ??? g



Q3: What is the embodied carbon of each gingerbread structural element (**A1**)?

- Walls = ??? kg.CO_{2(eq.)}
- Roof = ??? kg.CO_{2(eq.)}
- Chimney = ??? kg.CO_{2(eq.)}



Step C) Calculate embodied carbon of the whole gingerbread structure (kg.CO_{2(eq.)})

Stage A1 – raw materials

Composition of icing binder:

| Constituents | Composition quantity (kg constituent / kg of icing) | Embodied carbon of constituents (kg.CO _{2(eq.)} / kg of constituent) |
|--------------|--|--|
| Icing sugar | 80.6 wt. % | 0.66 kg.CO _{2(eq.)} |
| Eggs | 19.4 wt. % | 4.51 kg.CO _{2(eq.)} |

Mass of icing binder needed:

= 100 g (assumed)

Stage A3 – manufacturing

- Assume no additional impacts from manufacturing steps



Q4: What is the embodied carbon of the icing binder (**A1-A3**)? (kg.CO_{2(eq.)})

Stage 3) Impact assessment – reference scenario

Q5: What is the embodied carbon of the **whole gingerbread structure?** (A1-A3)
(kg.CO₂(eq.))

- i.e. sum of gingerbread structural elements + icing binder + oven heating



If each gingerbread house can house two gingerbread people...

Q6: What is the embodied carbon **per cm² of floor area?** (A1-A3) (kg.CO₂(eq.) / cm²)



Stage 3) Impact assessment – reference scenario

- The chickens of Switzerland are **threatening to go on general strike**, and refuse to lay eggs...
- Currently, we are getting eggs from **Ferme de Bassenges** (assume transport cost of zero).
- What if we have to **import eggs from France**?

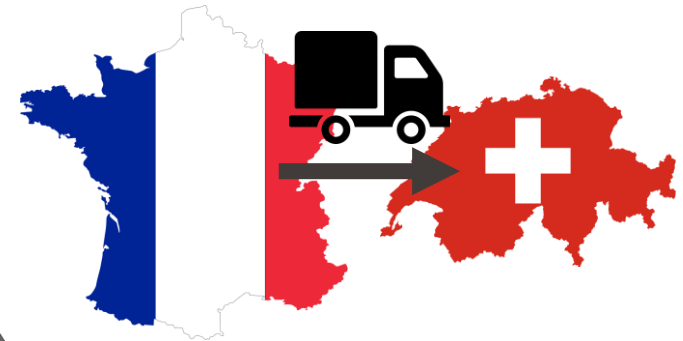
Stage A2 – transport

Mass of eggs = 0.086 kg / gingerbread house

Embodied carbon of road transport = 0.0004 kg.CO₂(eq.) / km

Distance from source of eggs in France = ??? km?

Q7: what is the additional embodied CO₂ to the gingerbread house, if we have to import the eggs from France?



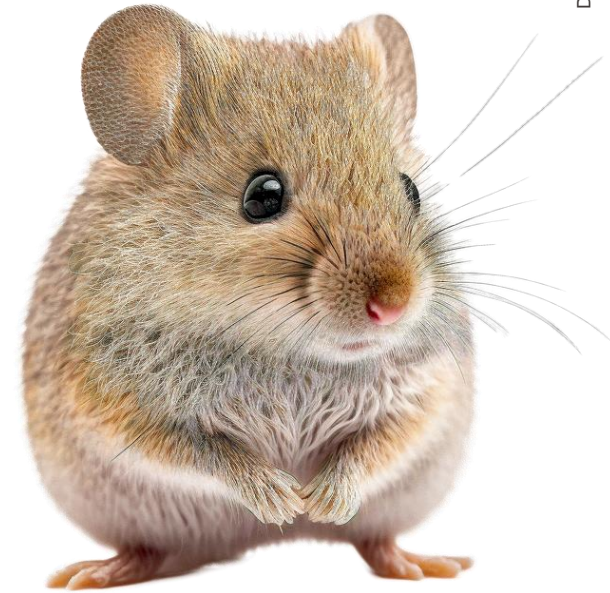
Stage 3) Impact assessment – strategies

- A **major threat to the durability** of gingerbread constructions is being **eaten by mice**.
- We will assess **three different strategies** to enhance the durability of the gingerbread structure with regards to mouse attack:

Strategy #1 = Change the gingerbread composition (stage A1)

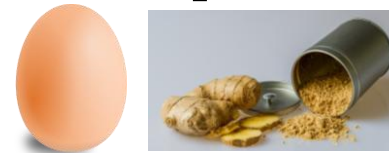
Strategy #2 = Change gingerbread processing (stage A3)

Strategy #3 = Apply a protective coating to the gingerbread (stage A1)



Strategy #1: Change the gingerbread composition

- Mice really like the egg in gingerbread, but do not like ginger so much...
- To help prevent mouse attack, we can **reduce** the amount of **egg**, and **increase** the amount of **ginger**
- Recipe for **Strategy #1**:



| Constituents | Composition quantity (kg constituent / kg of gingerbread) | Embodied carbon of constituents (kg.CO _{2(eq.)} / kg of constituent) |
|--------------|--|--|
| Flour | 50.9 wt. % | 0.89 kg.CO _{2(eq.)} |
| Sugar | 25.5 wt. % | 0.66 kg.CO _{2(eq.)} |
| Butter | 18.2 wt. % | 9.76 kg.CO _{2(eq.)} |
| Eggs | 4.4 wt. % | 4.51 kg.CO _{2(eq.)} |
| Ginger | 1.0 wt. % | 1.13 kg.CO _{2(eq.)} |

Q8: How does this **gingerbread** compare to the embodied carbon of the gingerbread in the reference scenario? (**A1**) (kg.CO_{2(eq.)} / kg. of gingerbread)

Q9: How does the **gingerbread house** for strategy #1 compare to the reference gingerbread house?(**AI-A3**) (kg.CO_{2(eq.)})



Strategy #2: Change gingerbread processing

- Mice really like nice, soft gingerbread... but they don't like gingerbread which is 'well done'.
- To help prevent mouse attack, we can bake the gingerbread in the oven for **double the length of time**.

- Embodied carbon of oven use = $0.039 \text{ kg.CO}_{2(\text{eq.})} / \text{minute}$)
- Recipe for reference scenario = **15 minutes** in the oven
- Recipe for **strategy #2** = **30 minutes** in the oven



Q10: How does the **gingerbread house** for strategy #2 compare to the reference gingerbread house? (A1-A3) ($\text{kg.CO}_{2(\text{eq.})}$)

Strategy #3: Apply a protective coating to the gingerbread

- Another way to protect the gingerbread house from mouse attack is to apply a **coating of icing** to **all the external surfaces**.
- From reference scenario, embodied carbon of icing = $1401.1 \text{ kg.CO}_{2(\text{eq.})} / \text{kg. icing}$
- For **strategy #3** – an **additional 300 g of icing** is needed to coat the whole house.



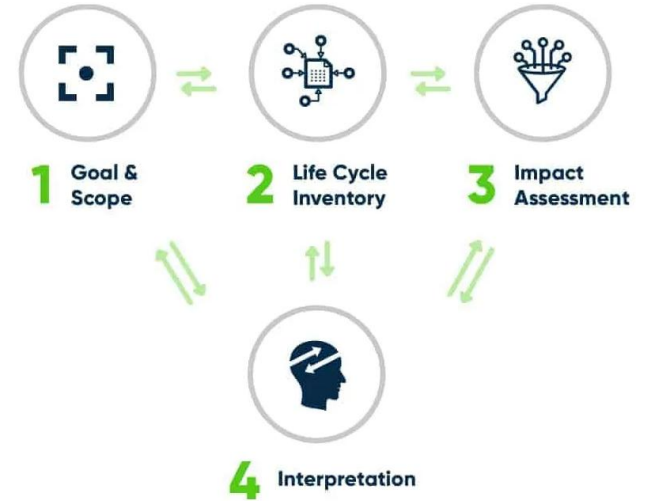
Q11: How does the **gingerbread house** for strategy #3 compare to the reference gingerbread house? (**A1-A3**)
($\text{kg.CO}_{2(\text{eq.})}$)

Stage 4) Interpretation

We assessed the impact of **three different strategies** to improve the durability of the gingerbread house with regards to mouse attack.

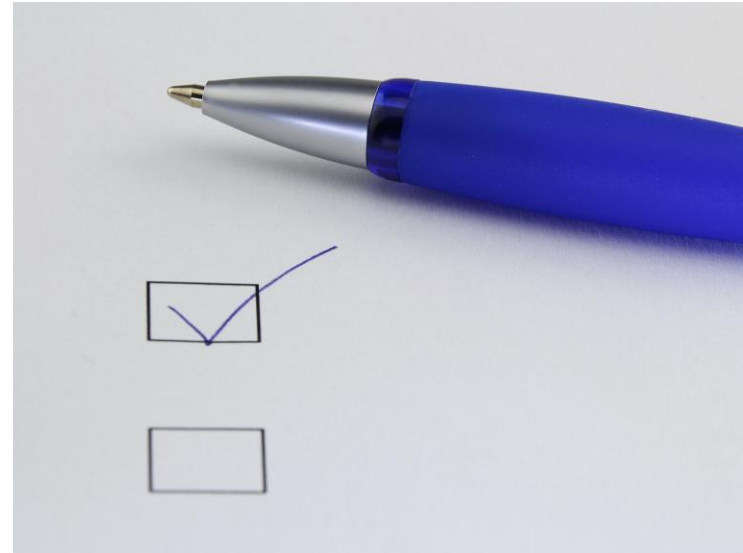
Q12: Which of the three strategies has the lowest additional embodied carbon cost?

1. Changed recipe with less egg and more ginger?
2. Longer baking time?
3. Protective coating of icing?



Practice example – learning points

- We have now practiced all the **types of calculations** you will need for the assessment.
- The mathematics is not complicated... but there are **several steps** to keep track of.
- For the assessment, I recognise using a **spreadsheet system** to keep track of values and calculations.
- Keep track of **units!** Kg.CO₂ per constituent, or Kg.CO₂ per material, are easily mixed up.



How did I organise my spreadsheet?

- Not perfect, or the only way to do this... but there are several **good habits** I try to follow:
 - Separate column for units
 - Separate column for source
 - State assumptions or important observations
 - Break down operations into several small steps
 - Avoid 'hard coding' wherever possible
 - Explanatory titles for each sheet, and table

| Embodied carbon calculations - ingredients, cooking time and recipe proportions | | | | |
|---|-----------------|--------------|---|--|
| This spreadsheet lists the source values and calculations for the gingerbread house exercise, in the LCA lecture for the MSE-420 course. All units of CO2 are CO2 eq. | | | | |
| <i>For gingerbread:</i> | | | | |
| Ingredient | Embodied carbon | Units | Source | Comments |
| Flour | 891.2 | kg.CO2e / kg | https://myemissions.co/resources/food-ca | No comment on scope. Assume Scope 1 and 2. |
| Sugar | 656.0 | kg.CO2e / kg | https://myemissions.co/resources/food-ca | No comment on scope. Assume Scope 1 and 2. |
| Butter | 9757.9 | kg.CO2e / kg | https://myemissions.co/resources/food-ca | No comment on scope. Assume Scope 1 and 2. |
| Eggs | 4505.7 | kg.CO2e / kg | https://myemissions.co/resources/food-ca | No comment on scope. Assume Scope 1 and 2. |
| Ginger | 1132.5 | kg.CO2e / kg | https://myemissions.co/resources/food-ca | Entry for "Allspice". No comment on scope. Assume Scope 1 and 2. |
| <i>For icing:</i> | | | | |
| Ingredient | Embodied carbon | Units | Source | Comments |
| Icing sugar | 655.99 | kg.CO2e / kg | https://myemissions.co/resources/food-ca | No comment on scope. Assume Scope 1 and 2. |
| Eggs | 4505.69 | kg.CO2e / kg | https://myemissions.co/resources/food-ca | No comment on scope. Assume Scope 1 and 2. |
| Oven cooking time | | | | |
| Parameter | Value | Units | Source | Comments |
| Power rating | 3.033 | kW | https://bura.brunel.ac.uk/bitstream/2438/ | Average value, SI Table 1. UK data |
| Embodied carbon for energy consumption | 0.775 | kgCO2e/kWh | https://bura.brunel.ac.uk/bitstream/2438/ | UK data. Electricity and gas carbon factors stated in the table caption. |
| Energy consumption per minute | 0.051 | kWh | n/a | |

Whole Life Cycle Costing

What is « Life Cycle Costing » ?

= a method that assesses costs over the life cycle of a product or a system.

What is the **purpose** of Life Cycle Costing?

'Ex-ante' LCC

- Before starting a project – to evaluate likely overall costs (and different options)
→ Based on **estimated** costs

'Ex post' LCC

- At the end of a project – to evaluate in hindsight
→ Based on **real, incurred** costs



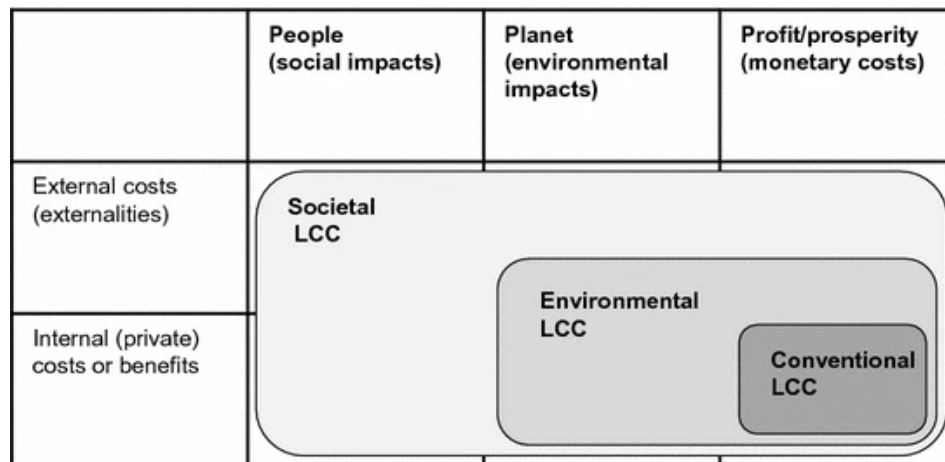
How is Life Cycle Costing different from Life Cycle Assessment?

Life Cycle Costing only counts monetary costs (not environmental impacts).

- **Conventional Life Cycle Costing** only covers monetary costs, from a single actor's point of view.

However, there can be some similarities in different variants.

- **Environmental Life Cycle Costing** accounts for costs from all relevant actors, including costs resulting from environmental impacts.



Rödger et al. (2018). Life cycle costing: an introduction. Life cycle assessment: Theory and practice, 373-399.

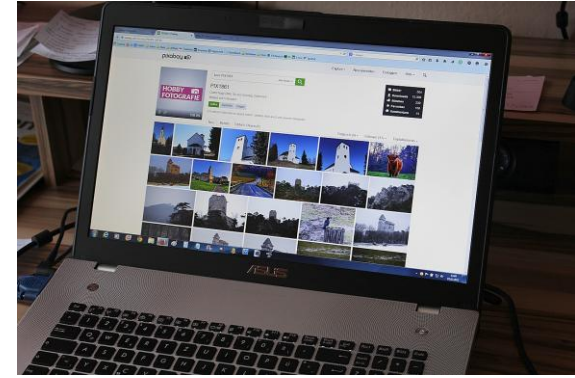
How to apply Life Cycle Costing to cementitious materials?

At a basic level, for Conventional Life Cycle Costing...

- Use the same life cycle stages as for LCA
- Inventory data = costs for different materials (e.g. cement) and processes (e.g. transport)

Where to find cost data?

- More complicated (and variable) than for GWP
- Cost databases are not publicly available
- Company websites are a good place to look
- If the website doesn't say... ask them!



Defence Against the Dark Arts

How to avoid and identify common mistakes

A person in a small boat is navigating a narrow, dark canyon. The sky is filled with a large, glowing, orange-yellow moon. The canyon walls are dark and jagged. The water is dark and reflects the moonlight. The overall atmosphere is mysterious and challenging.

Knowledge for
a sustainable
future

Lobbying / vested
interests

TOO MUCH
evidence

How will
you find
your way?

Poor quality
evidence

Differing
opinions

TOO LITTLE
evidence

'Scholarly bullshit'
(Kircherr, 2023)

You

www.dontforgetthebubbles.com

There are **several common errors** you will see in **statements about sustainability...**

- ...sometimes by accident or from ignorance
- ...sometimes on purpose (!)

Learn to recognise **what** these errors are, and **why** they are misleading, so you can...

- Identify them in research articles and other places
- Avoid making them yourself



Mistake #1: Claims of sustainability without reference to a specific impact category

E.g. « *Cement X is a **more sustainable alternative** to cement Y* »

- Sustainability incorporates **many aspects** - some (but not all) of these can be measured and quantified.
- Embodied carbon is important (especially for cement and concrete) – but **lower embodied carbon \neq more sustainable**
- Better to say...

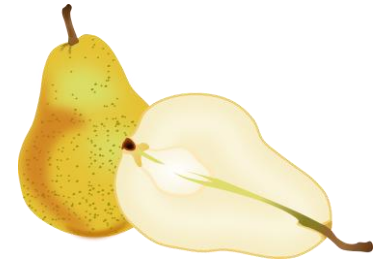
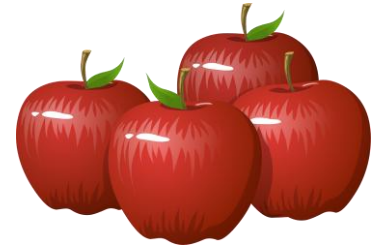
E.g. « *Cement X has **lower [impact category X]** than cement Y (with reference to evidence!)* »



Mistake #2: Comparisons per unit mass when not appropriate

E.g. « *Material X is a **lower carbon alternative** to material Y – material X has an embodied carbon of **350 kg.CO₂/tonne** compared to 1200 kg.CO₂/tonne for material Y* »

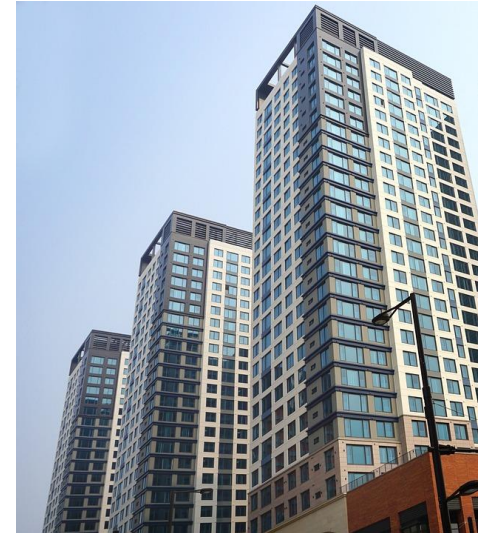
- Seems sensible – there are specific numbers?
- But remember...
 - Materials have different **densities**
 - Materials have different **mechanical properties**
 - Structural design depends on **material properties**



Mistake #2: Comparisons per unit mass when not appropriate

- **Per unit mass** comparisons are only valid for materials with **similar density**, used in the **same structural way**.
 - Concrete v. concrete - **Yes**
 - Concrete v. timber - **No**
- When comparing materials which have different density and are used in **different ways structurally**, better to use the **same functional unit of unit floor area**:

E.g. « *Material X can be a lower carbon alternative to material Y – for a **mid-rise housing typology**, material X has an embodied carbon of **300 kg.CO₂/m² floor area** compared to 450 kg.CO₂/m² for material Y (reference evidence)*»



Mistake #3: Comparisons with an inappropriate benchmark for the application

E.g. « *Sorel cement is a **lower carbon alternative to ordinary Portland cement** – Sorel cement has an embodied carbon of **500 kg.CO₂/tonne** compared to **750 kg.CO₂/tonne** for OPC»*

- Seems reasonable? Both materials are cements, so a per mass comparison is ok?
- Yes, but... Sorel cement (i.e. a magnesium oxychloride cement) is soluble in water! So could only be used for **internal, non load-bearing applications** (e.g. plaster).
- Sorel cement has a **different functional value** to OPC – it's a misleading comparison.



Mistake #3: Comparisons with an inappropriate benchmark for the application

- More fair to **benchmark** against a **material used for the likely application**. Better to say...

E.g. « *Sorel cement is a low-carbon material for **interior render applications** – Sorel cement has an embodied carbon of **500 kg.CO₂/tonne** compared to **730 kg.CO₂/tonne** for **lime** »*



Mistake #4: Claims of sustainability without any reference to function, metrics or evidence

E.g. « *Material X is an **innovative, sustainable material*** »

Or « *Cement X is made with a **novel green process** which can make a more sustainable construction sector* »

- No specific metrics... no statement of likely applications... **no evidence!**
- It is reasonable to predict that a material in development may have certain benefits.
- However, need to ensure that:
 - The statement is clearly a **prediction**, rather than appearing as fact
 - A **likely application** is suggested



E.g. « *Cement X has the **potential to be a low-carbon material** given that **no high-temperature processing** is required, and has suitable characteristics for use in **pre-cast concrete elements*** »

Learning objectives

1. **Define** approximate ranges for embodied carbon of key constituents in cement and concrete
2. **Understand** the generic principles of Life Cycle Assessment (LCA)
3. **Select** appropriate choices for the key decisions in LCA
4. **Apply** LCA to construction materials, including how to **evaluate** sources of input data
5. **Evaluate** sustainability statements in research articles and other sources of information, and **identify** types of key mistakes

