Accounting Greenhouse Gas (GHG) Emissions in Building Design: A White Paper on the GHG Emissions Timeline (GET)

October 4, 2022

Authors:

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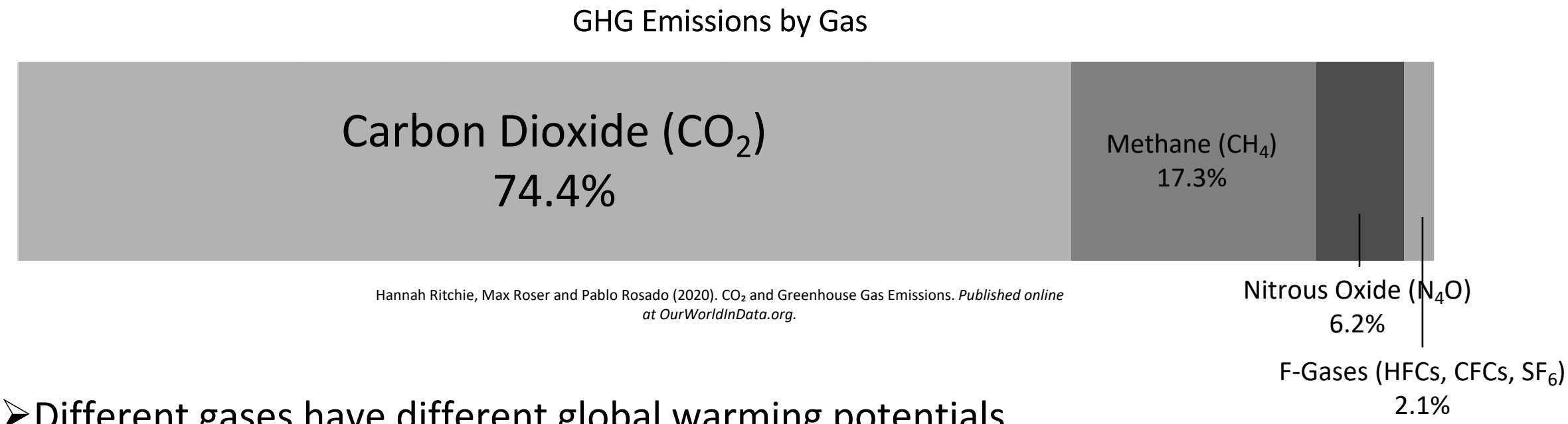
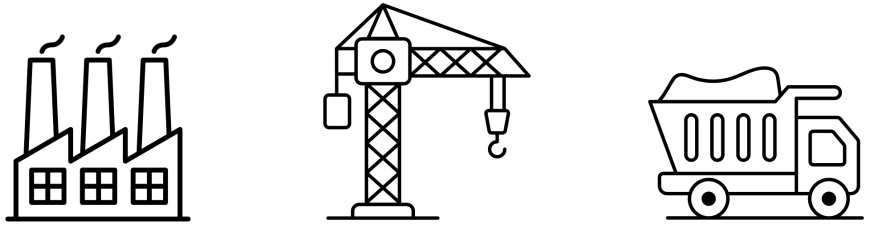
GHG Emissions



Hannah Ritchie, Max Roser and Pablo Rosado (2020). CO_2 and Greenhouse Gas Emissions. *Published online at OurWorldInData.org.*

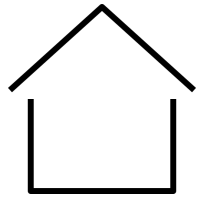
- Different gases have different global warming potentials
- Carbon dioxide equivalent (CO_2-eq) makes the effect of different gases comparable (e.g. 1 kg methane ≈ 25 kg CO_2-eq)

Embodied vs. Operational Emissions



Embodied Emissions

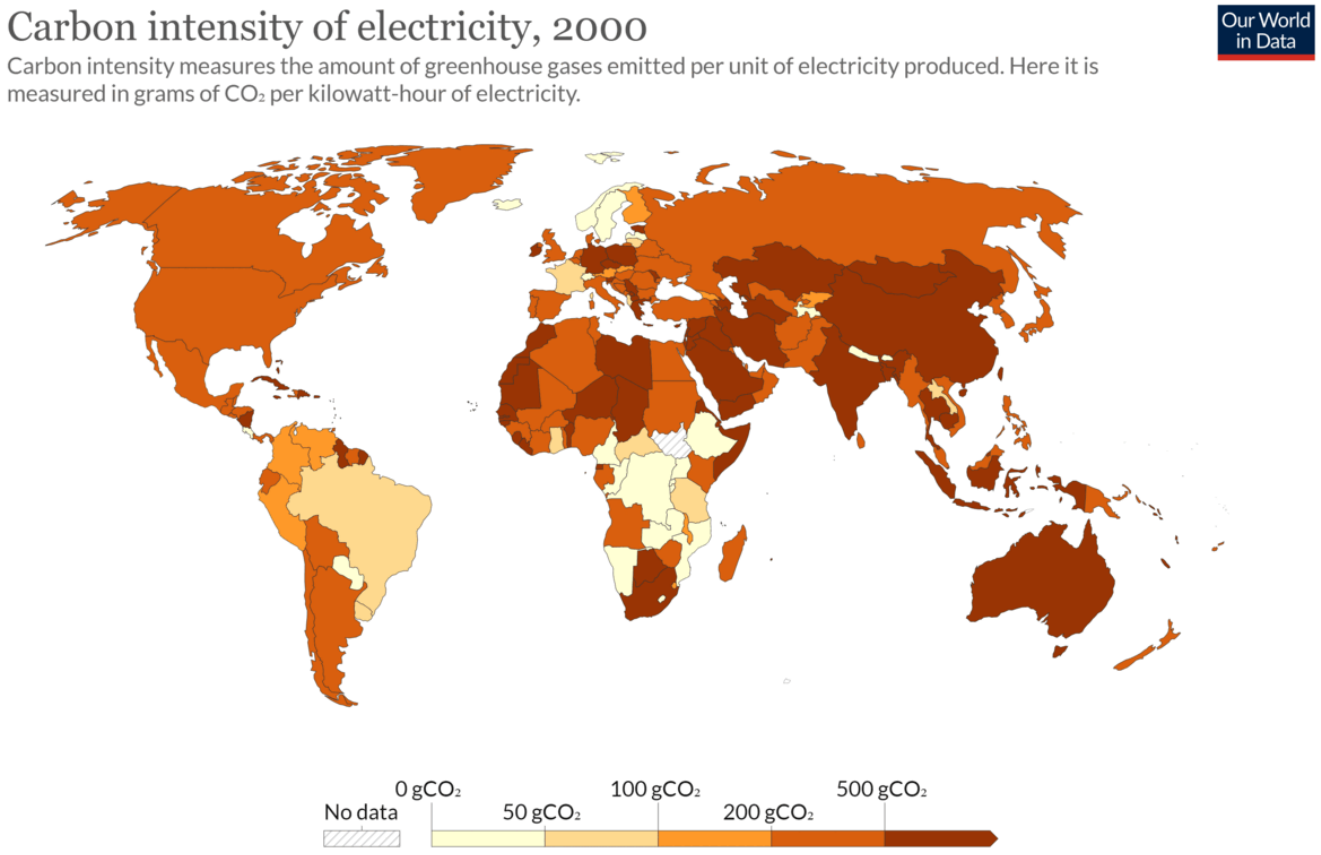
The emissions from manufacturing, transportation, installation and disposal of building materials.



Operational Emissions

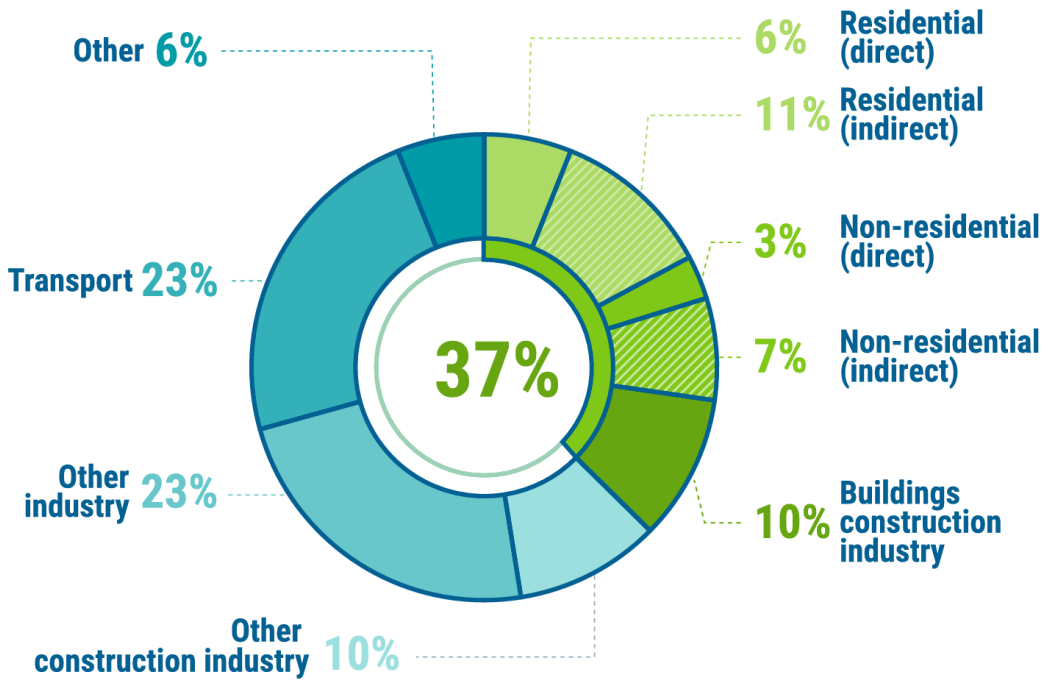
The emissions from a building's energy consumption.

Carbon Intensity of Electricity



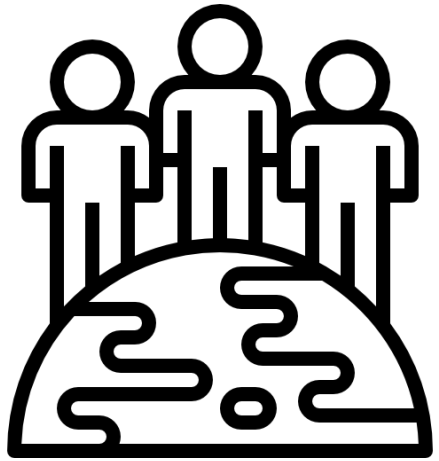
Why GHG Emissions Accounting Matters

- Buildings account for 37% of energy-related global CO_2 emissions:
  - 27% from operational emissions
  - 10% from embodied emissions



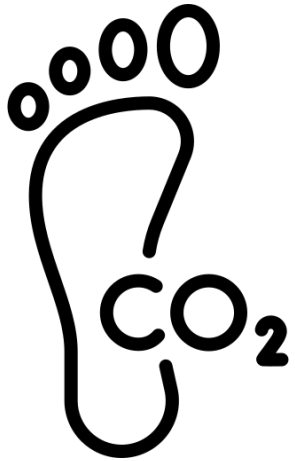
United Nations Environment Programme (2021). 2021 Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector.

Impact of Built Environment by 2050



World population:
10 billion

Global building stock:
x2



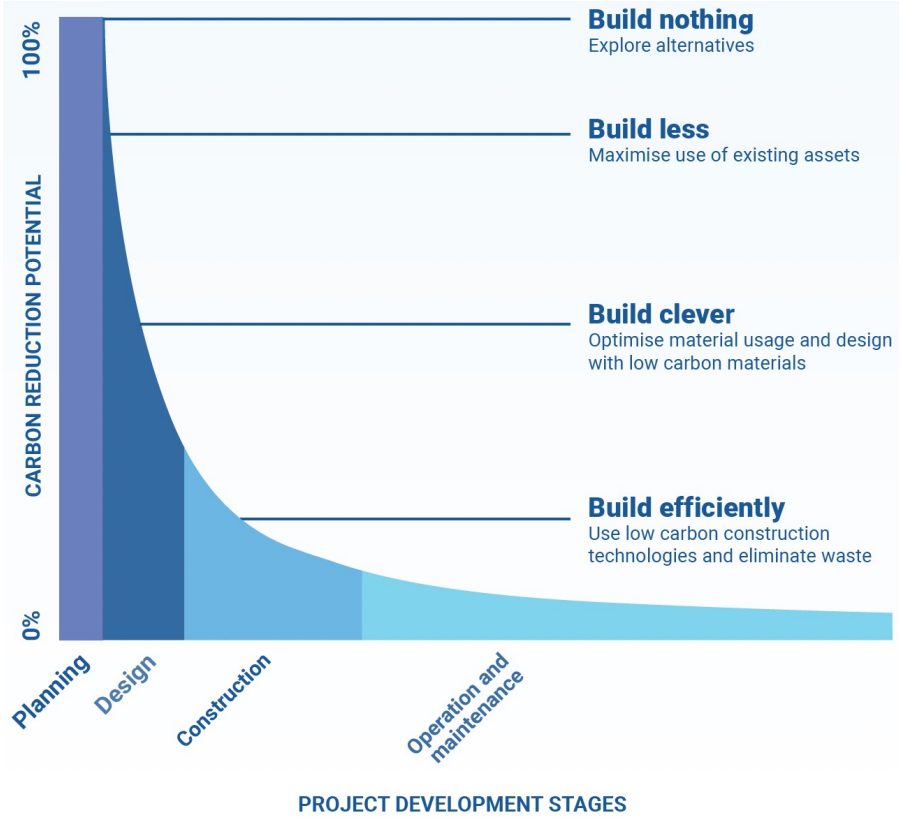
Upfront carbon:
Responsible for 50% of entire carbon footprint of new buildings

World Green Building Council's 2050 Vision

- New buildings, infrastructure, and renovations must be net zero embodied emissions.
- All buildings, including existing buildings, must be net zero operational emissions.

➢EU and IPCC have similar visions

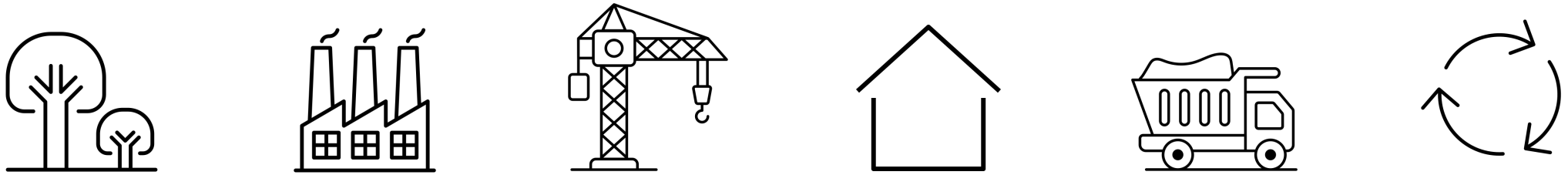
Emission Reduction Potential



World Green Building Council (2019). Bringing embodied carbon upfront: Coordinated action for the building and construction sector to tackle embodied carbon.

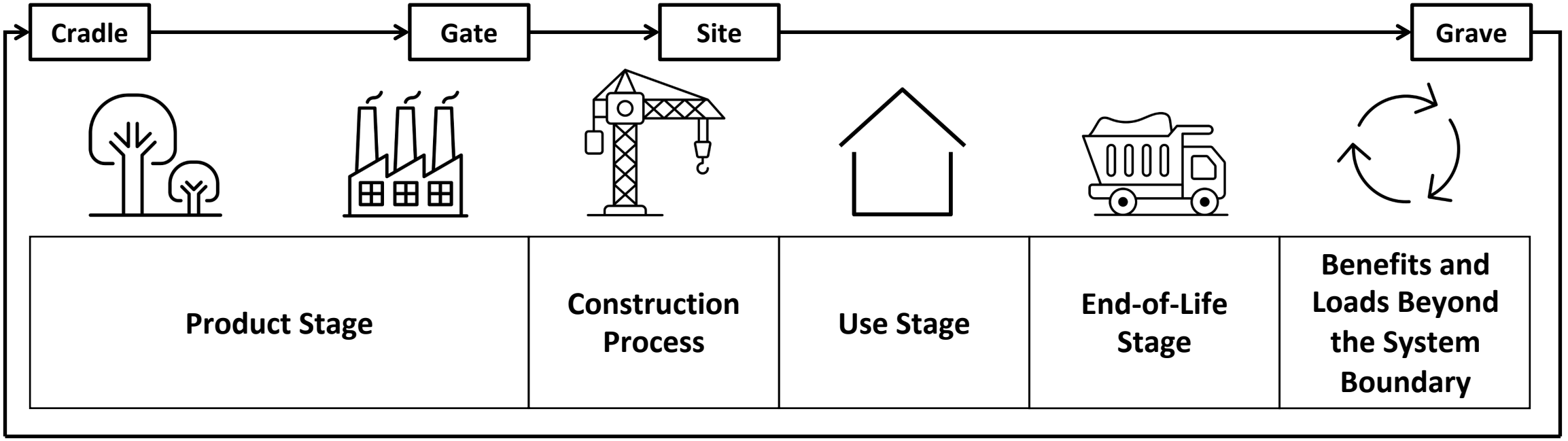
Life Cycle Stages – Overview

According to EN 15804



Product Stage	Construction Process	Use Stage	End-of-Life Stage	Benefits and Loads Beyond the System Boundary
Raw Material Supply and Production of Building Products	Transport	Use	Deconstruction/ Demolition	Reuse-Recovery-Recycling-Potential
Transport	Construction Process	Maintenance	Transport	
Manufacturing		Repair	Waste Processing	
		Replacement	Disposal	
		Refurbishment		
		Operational Energy Use		
		Operational Water Use		

Life Cycle Principles



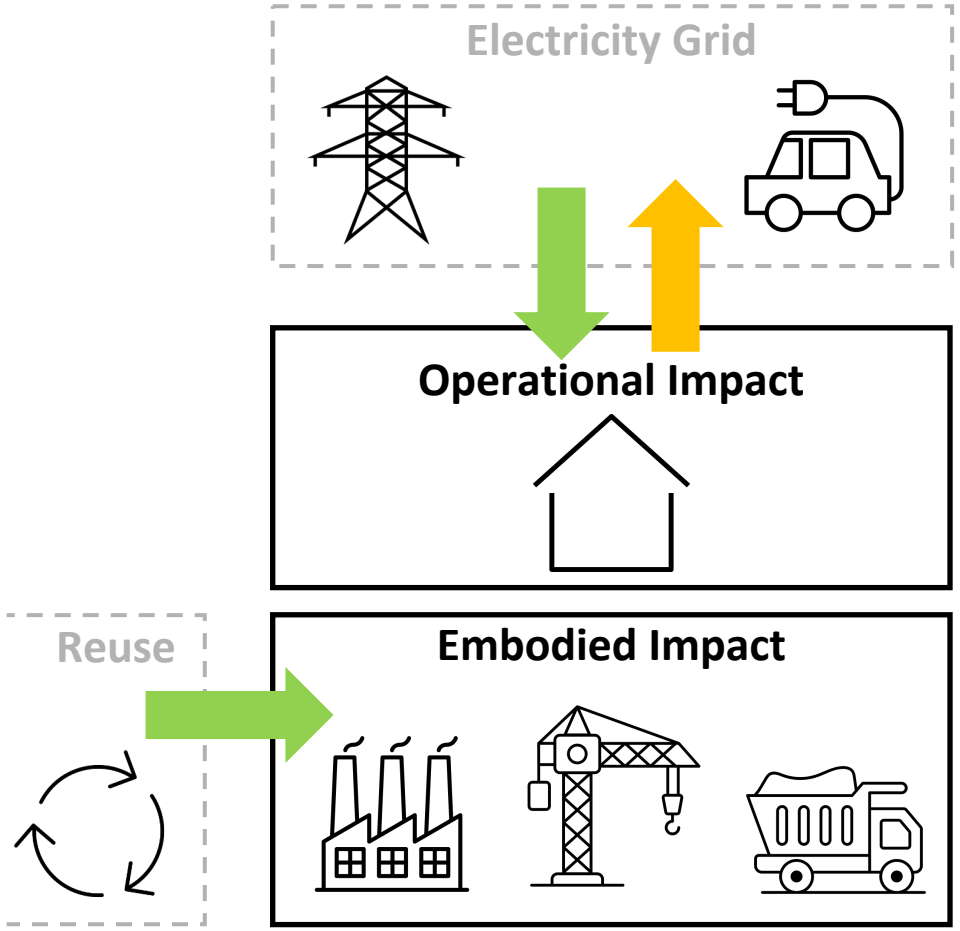
Net-Zero and LCA

- The concept of net-zero emissions and the single number indicator for LCA can lead to misunderstandings:

  A large PV roof can ‘numerically’ offset embodied emissions of a newly built concrete building, turning it into a ‘net-zero emissions building’ without capturing a single molecule of CO_2.

➢ It is important to understand the evolution of GHG emissions over time to identify critical parameters in the climate emergency state.

System Boundaries



Extended Boundary

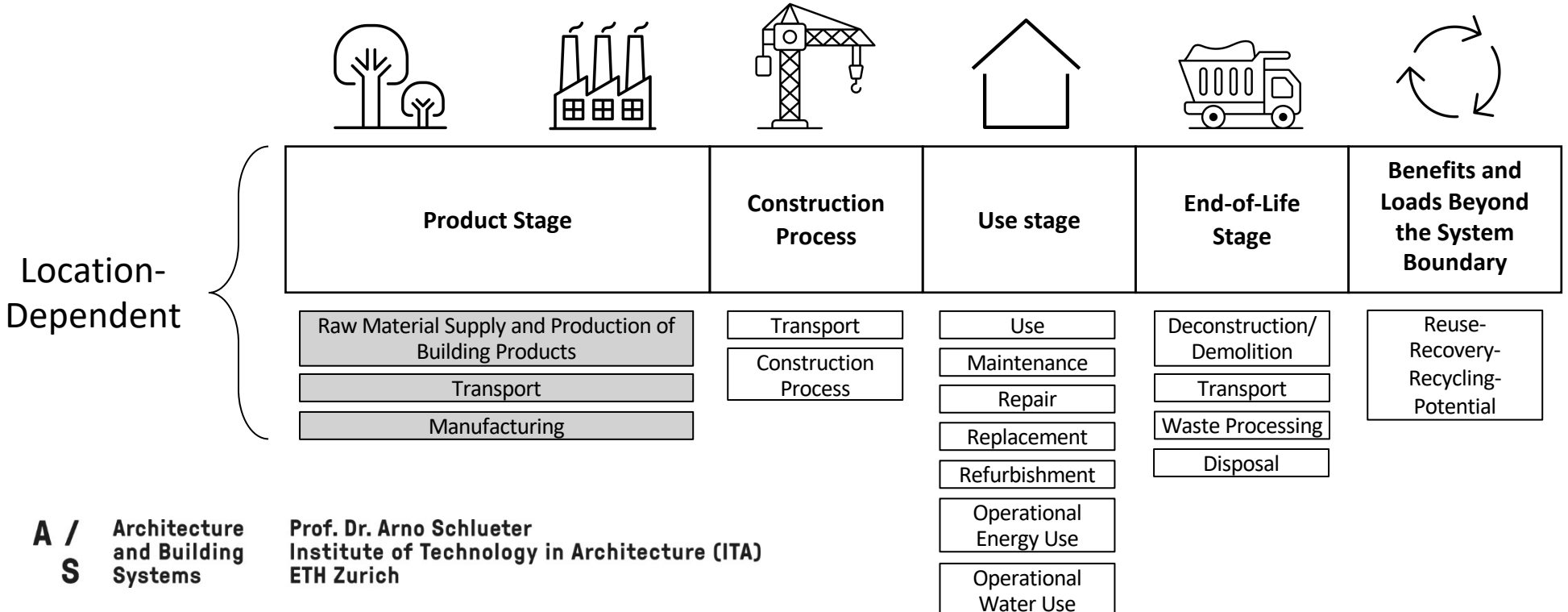
Building Boundary

Life Cycle Stages

- Upfront Emissions in $kgCO_2$-eq/m^2
- Operational Emissions in $kgCO_2$-eq/(m^2a)
- Stored Biogenic Carbon in kgC/m^2
- End-of-Life Emissions in $kgCO_2$-eq/m^2

Life Cycle Stages – Upfront GHG Emissions

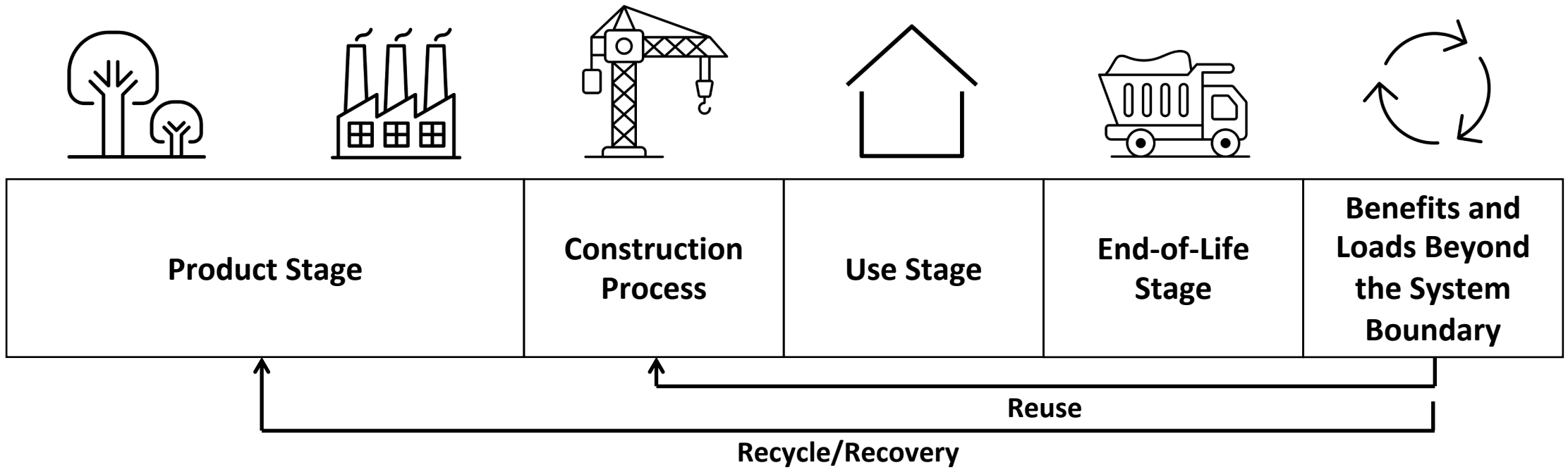
- Occur during production of components
- Are emitted into atmosphere before building is put into operation
- Are normalized to the energy reference area or usable floor area
- Can regionally differ depending on energy mix and production methods



A / S Architecture and Building Systems
Prof. Dr. Arno Schlueter
Institute of Technology in Architecture (ITA)
ETH Zurich

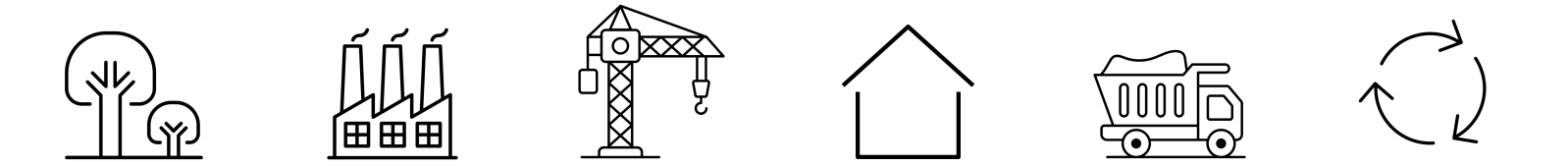
Reuse Potential

- Reused components are associated with lower upfront emissions (transportation only)
- Not included in end-of-life analysis to avoid double counting



Life Cycle Stages – Operational Emissions

- Occur due to use of energy sources that cause emissions during conversion
- Are calculated for the first year of operation, so that future changes in the system are not taken into account



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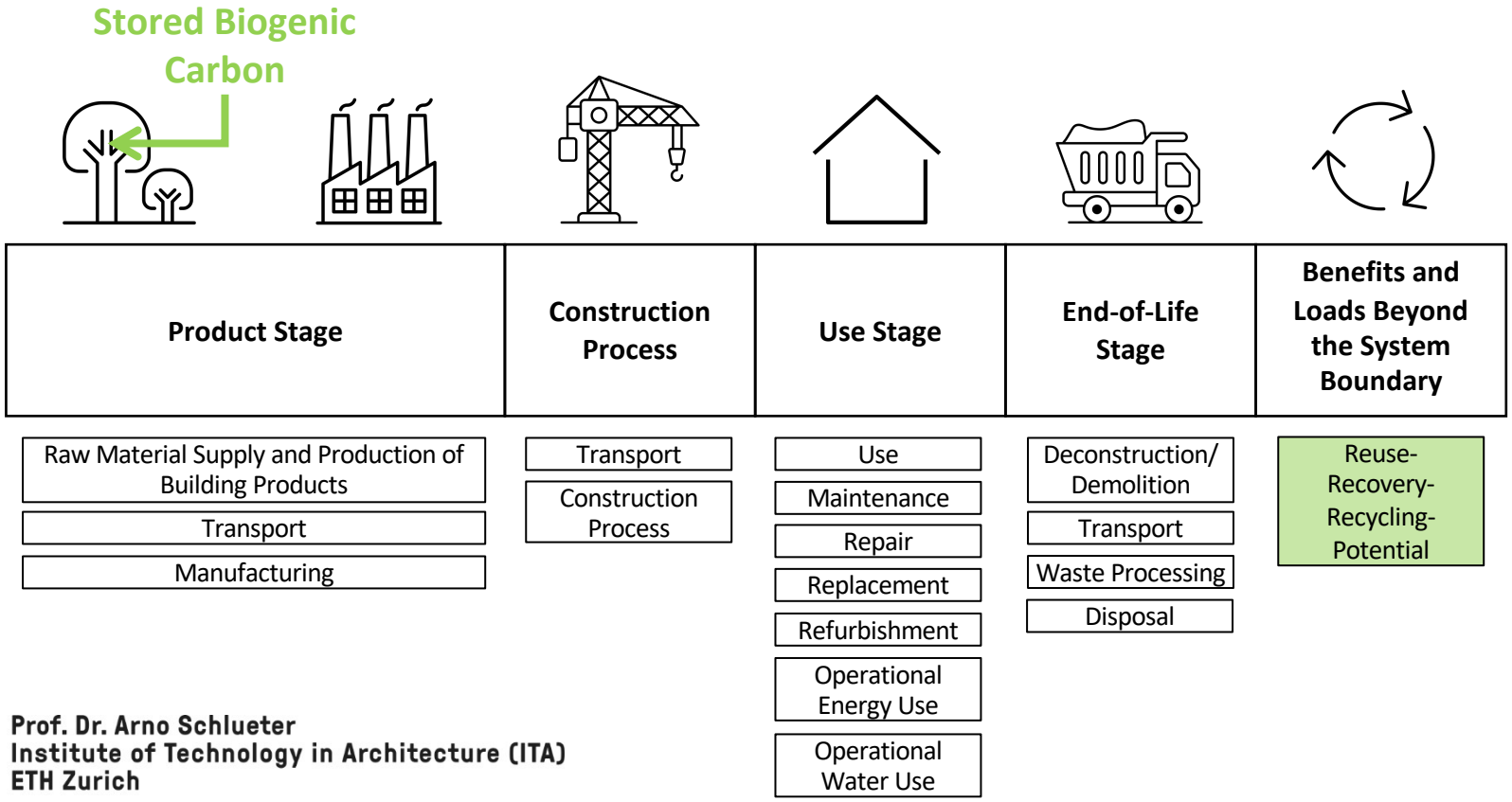
		Replacement	Disposal	
		Refurbishment		
		Operational Energy Use		
		Operational Water Use		

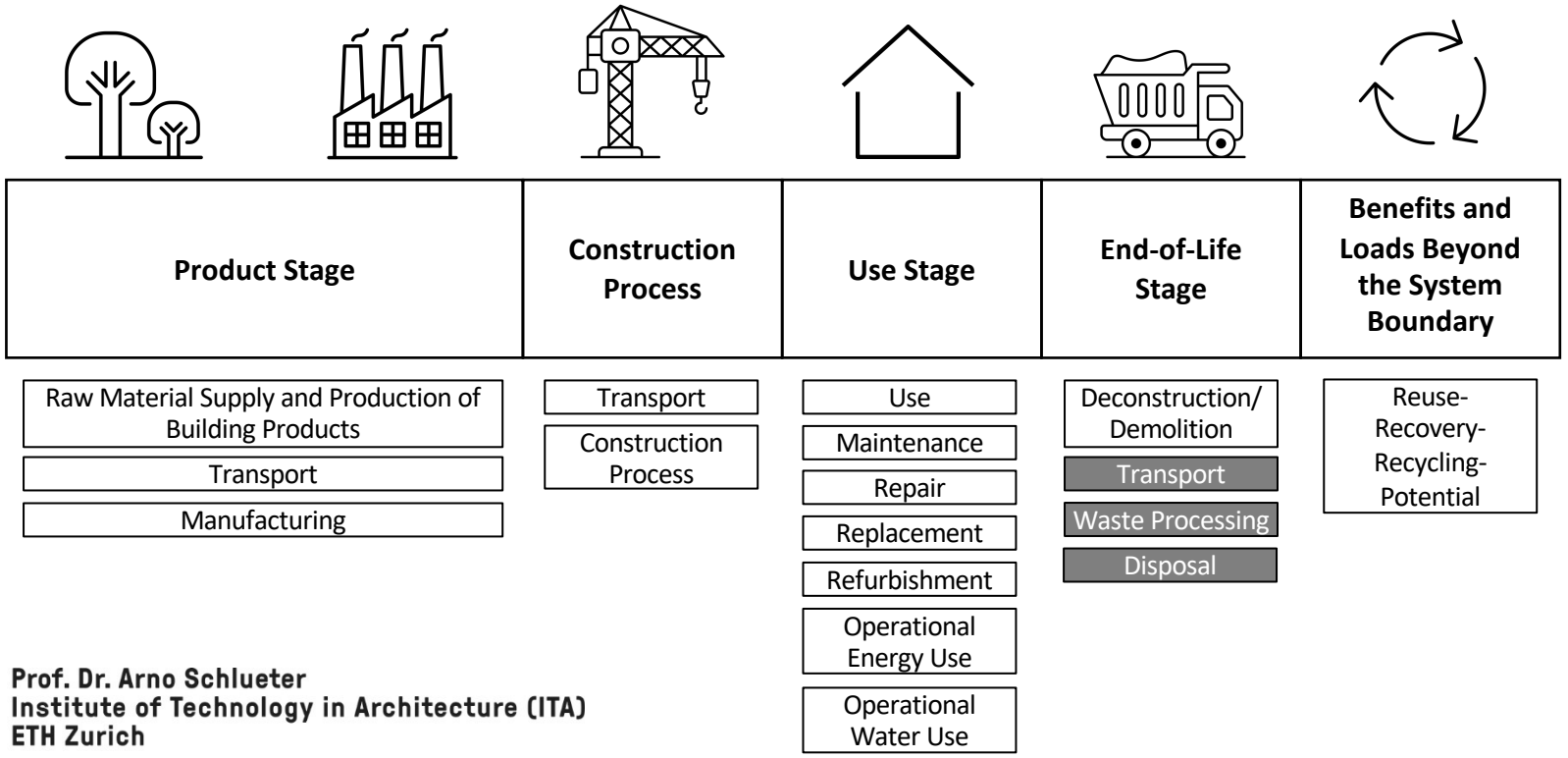
Life Cycle Stages – Stored Biogenic Carbon

- Carbon in biogenic materials that has been extracted from the atmosphere by plant growth and is not re-emitted again for the time it is stored



Life Cycle Stages – End-of-Life Emissions

- Occur when the building is deconstructed, and the materials are disposed of
- Are subject to great uncertainty as they are far in the future



How to Calculate

$$I_{upfront} = \sum_{material} Q_{material} * f_{material\,upfront}$$

$$I_{operational} = \sum_{source} E_{source} * f_{source}$$

$$I_{end\,of\,life} = \sum_{material} Q_{material} * f_{material\,end}$$

$$C_{stored} = \sum_{material} Q\_material * c_{material}$$

I is impact (e.g., GHG emissions)
Q is material qantity (e.g., kg or m2)
E is Energy (e.g., kWh)
C is Carbon (kg C)
f is impact factor (e.g., kgCO2eq/kg material)
c is specif carbon content (e.g., kgC/kg material)

Where to Find Data

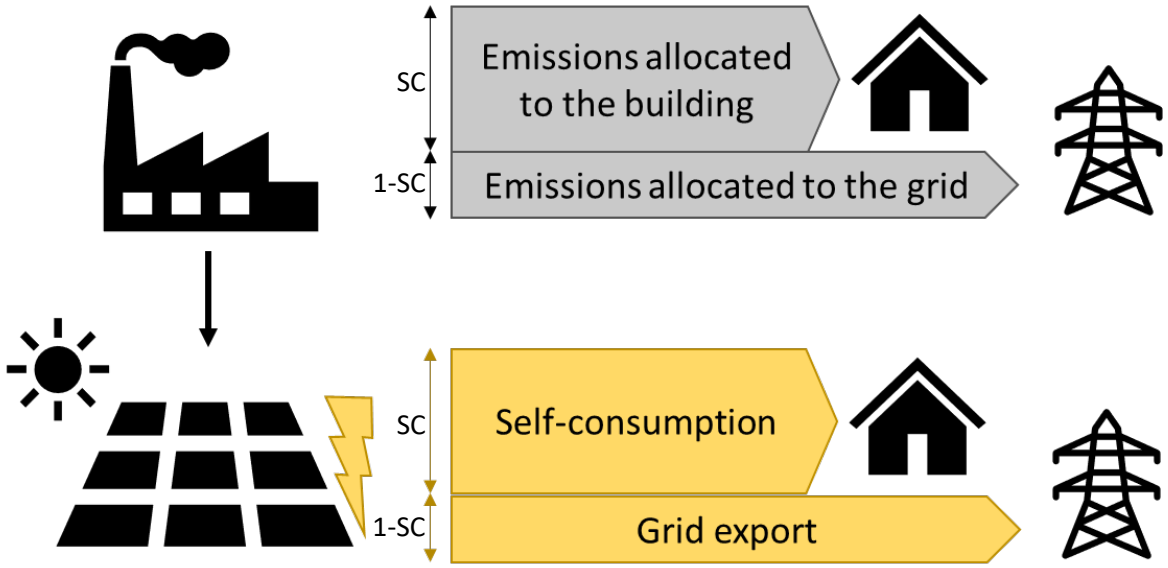
	KBOB	ökobaudat
Latest version	2022	2021
Organization	Swiss Federal Office of Energy	Federal Ministry for Housing, Urban Development and Building
Country	Switzerland	Germany
Cost	Free of charge	Free of charge

Available Tools

- KBOB Excel tool
- Ökobaudat online tool
- BOMBYX (connects with KBOB)
- Simapro
- One Click LCA
- OpenLCA
- Brightway

PV Allocation

- Electricity generated on site can be fed into the power grid.
- The embodied emissions of the PV are allocated “pro rata” according to the electrical energy consumption
- The production of PV electricity can have benefits outside the system boundary



$$I_{PV\ self} = I_{PV\ total} * SC$$

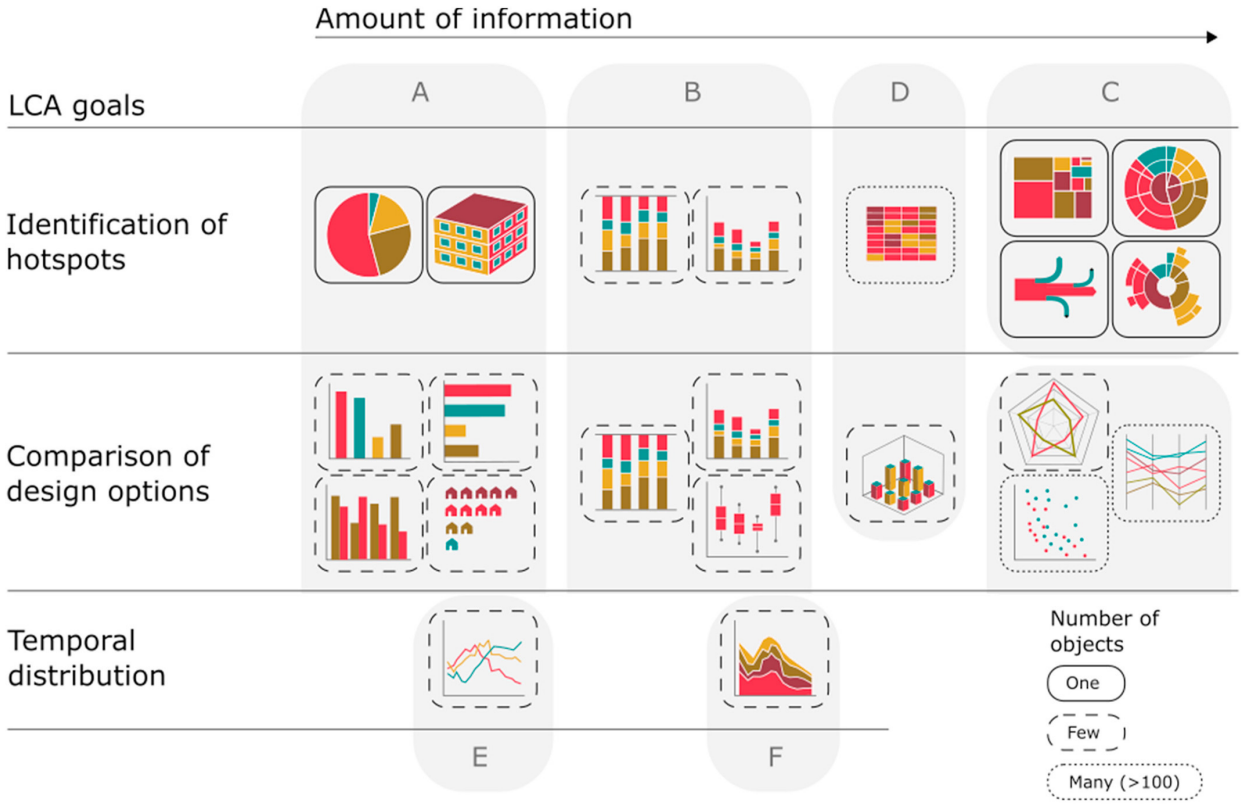
$I_{PV\ self}$: Emissions/Impact of PV allocated to the building
$I_{PV\ total}$: Total emissions/impact of installed PV
SC: Self consumption

Discussing Net-Zero

- GHGs released into the atmosphere are offset by removal from the atmosphere (Paris Agreement: Net-Zero by 2050)
- For buildings, this means that embodied and operational emissions are offset, but:
  - this can only be achieved by considering expanded analysis boundaries and by relying on decarbonization predictions,
  - the implementation of long-term carbon storage and capture is not currently reliable due to with technical and economic challenges,
  - carbon stored in biogenic materials cannot per se be counted as “negative” because it might be released at the end of the life cycle,
  - accounting requires working with quantities of the same unit, which is not the case for biogenic carbon in buildings, i.e. $kgC/m^2 \neq kgCO_2\text{-}eq/m^2$.

Visualization

- Identification of hot-spots:
  - Emissions per material
  - Emissions per building element
  - Emissions per building system
  - Upfront vs. operational emissions
- Comparison of design options
- Temporal distributions

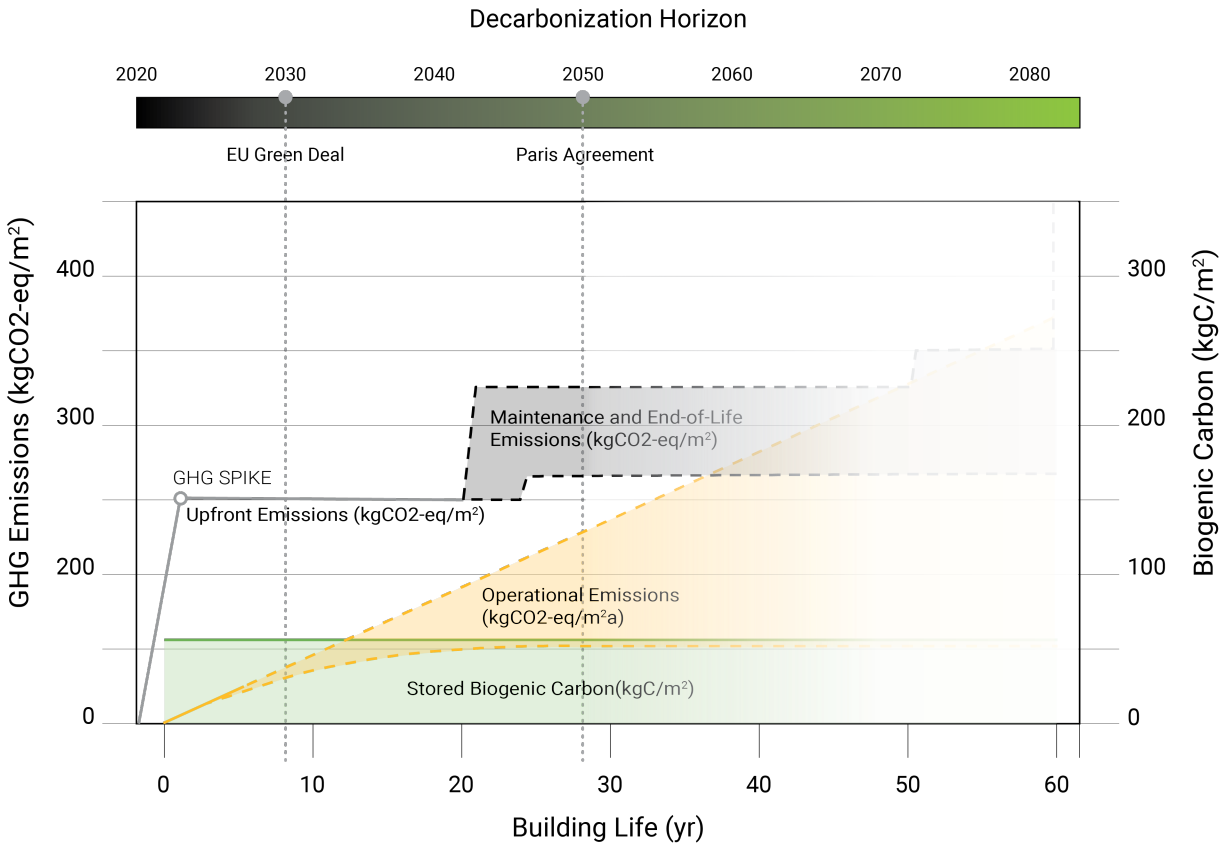


Adapted from Hollberg et al., 2021

Visualization – GHG Emissions Timeline (GET)

- Upfront Emissions in $kgCO_2$-eq/m^2
- Operational Emissions in $kgCO_2$-eq/(m^2a)
- Stored Biogenic Carbon in kgC/m^2
- End-of-life Emissions in $kgCO_2$-eq/m^2

- Calculation
- Assumption



Conclusion

- Because of the impact of the built environment on the climate, it is critical to quantify GHG emissions over the building life cycle, especially upfront emissions.
- The interpretation of the time dependency of buildings, e.g., 100 years, is a sensitive area and keeps causing discussions.
- In combination with life cycle costing of buildings, emissions accounting can save emissions as well as costs.

Appendix – How to Use KBOB and ökobaudat Databases

Upfront GHG Emissions – KBOB

	Ökobilanzdaten im Baubereich						
ID-Nummer	BAUMATERIALIEN Hinweis: Anzeigen der herstellerspezifischen und herstellerregionenspezifischen Daten durch Anklicken der '+' am linken Rand.	Rohdichte/ Flächen-masse	Bezug	Treibhausgas-emissionen			Biogener Kohlenstoff
				Total kg CO_2-eq	Herstellung kg CO_2-eq	Entsorgung kg CO_2-eq	im Produkt enthalten kg C
00	**Vorbereitungsarbeiten**	-					
07.005	Holzwolle-Leichtbauplatte, zementgebunden	400	kg	**0.536**	0.499	0.036	0.138
07.023	Konstruktionsvollholz	436	kg	**0.290**	0.245	0.044	0.450
07.008	Massivholz Buche / Eiche, kammergetrocknet, gehobelt	675	kg	**0.153**	0.114	0.039	0.451
07.008.01	Massivholz Buche / Eiche, kammergetrocknet, gehobelt, Produktion Schweiz	675	kg	**0.123**	0.084	0.039	0.451
07.007	Massivholz Buche / Eiche, kammergetrocknet, rau	675	kg	**0.136**	0.097	0.039	0.451
07.007.01	Massivholz Buche / Eiche, kammergetrocknet, rau, Produktion Schweiz	675	kg	**0.110**	0.070	0.039	0.451
07.006	Massivholz Buche / Eiche, luftgetrocknet, rau	705	kg	**0.121**	0.082	0.039	0.413

Upfront GHG Emissions – ökobaudat

Kerninformationen des Datensatzes	
Ort	DE
Erläuterungen zur geographischen Repräsentativität	Für die Ökobilanzierung von Schicht-Massivholzplatten wurden Daten von 2 Werken berücksichtigt (Rüter & Diederichs 2012). Für alle in Rüter & Diederichs (2012) angeführten Vollholzprodukte wurden von 2009 bis 2011 insgesamt 178 Prozesslinien erfasst. Im Verhältnis zu den vom Statistischen Bundesamt gemeldeten Produktionsmengen im selben Zeitraum entspricht die erreichte Abdeckung von Vollholzprodukten aus Nadelschnittholz 38 %.
Referenzjahr	2021
Name	3- und 5-Schicht Massivholzplatte (Durchschnitt DE)
Biogener Kohlenstoffanteil	◦ Carbon content (biogenic): 219.94 kg ◦ Carbon content (biogenic) - packaging: ND kg

Indikator	Einheit	Rohstoffbereitstellun A1	Herstellung A1-A3	Transport A2	Herstellung A3	Einbau A5 Entsorgung Verpackung (Standardszenario)	Transport C2	Abfallbehandlung C3	Recyclingpotential D energetisch (Standardszenario)	Recyclingpotential D stofflich
Globales Erwärmungspotenzial - fossil (GWP-fossil)	kg CO2-Äqv.	42.54	156.4	25.14	88.69	0.8724	0.5367	12.14	-247.9	-11.17

Operational Emissions – KBOB

ID-Nummer	Ökobilanzdaten im Baubereich ENERGIE	Bezug Grösse	Einheit	Treibhausgas-emissionen kg CO_2-eq
41	**Brennstoffe**[1]			
41.001	Heizöl EL	Endenergie	kWh	**0.324**
41.002	Erdgas	Endenergie	kWh	**0.230**
41.003	Propan/Butan	Endenergie	kWh	**0.293**
41.004	Kohle Koks	Endenergie	kWh	**0.435**
41.005	Kohle Brikett	Endenergie	kWh	**0.398**
41.006	Stückholz	Endenergie	kWh	**0.023**
41.007	Holzschnitzel	Endenergie	kWh	**0.011**
41.008	Pellets	Endenergie	kWh	**0.028**
41.009	Biogas	Endenergie	kWh	**0.124**
	[1]Oberer Heizwert			
43	**Nutzwärme**			
43.013	Elektrospeicherofen (Strom CH)	Nutzwärme[2]	kWh	**0.127**
43.014	Elektrospeicherofen (Strom CH zertifiziert)	Nutzwärme[2]	kWh	**0.017**
43.001	Heizkessel Heizöl EL	Nutzwärme[2]	kWh	**0.343**
43.002	Heizkessel Erdgas	Nutzwärme[2]	kWh	**0.234**
43.003	Heizkessel Propan / Butan	Nutzwärme[2]	kWh	**0.289**
43.004	Heizkessel Kohle Koks	Nutzwärme[2]	kWh	**0.643**
43.005	Heizkessel Kohle Brikett	Nutzwärme[2]	kWh	**0.588**
43.006	Heizkessel Stückholz	Nutzwärme[2]	kWh	**0.033**
43.007	Heizkessel Holzschnitzel	Nutzwärme[2]	kWh	**0.021**
43.008	Heizkessel Pellets	Nutzwärme[2]	kWh	**0.038**
43.009	Heizkessel Biogas	Nutzwärme[2]	kWh	**0.127**

Before conversion

After conversion

Stored Biogenic Carbon – KBOB

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				Total kg CO_2-eq	Herstellung kg CO_2-eq	Entsorgung kg CO_2-eq	im Produkt enthalten kg C
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07.005	Holzwolle-Leichtbauplatte, zementgebunden	400	kg	**0.536**	0.499	0.036	0.138
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Stored Biogenic Carbon – ökobaudat

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End-of-Life Emissions – KBOB

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