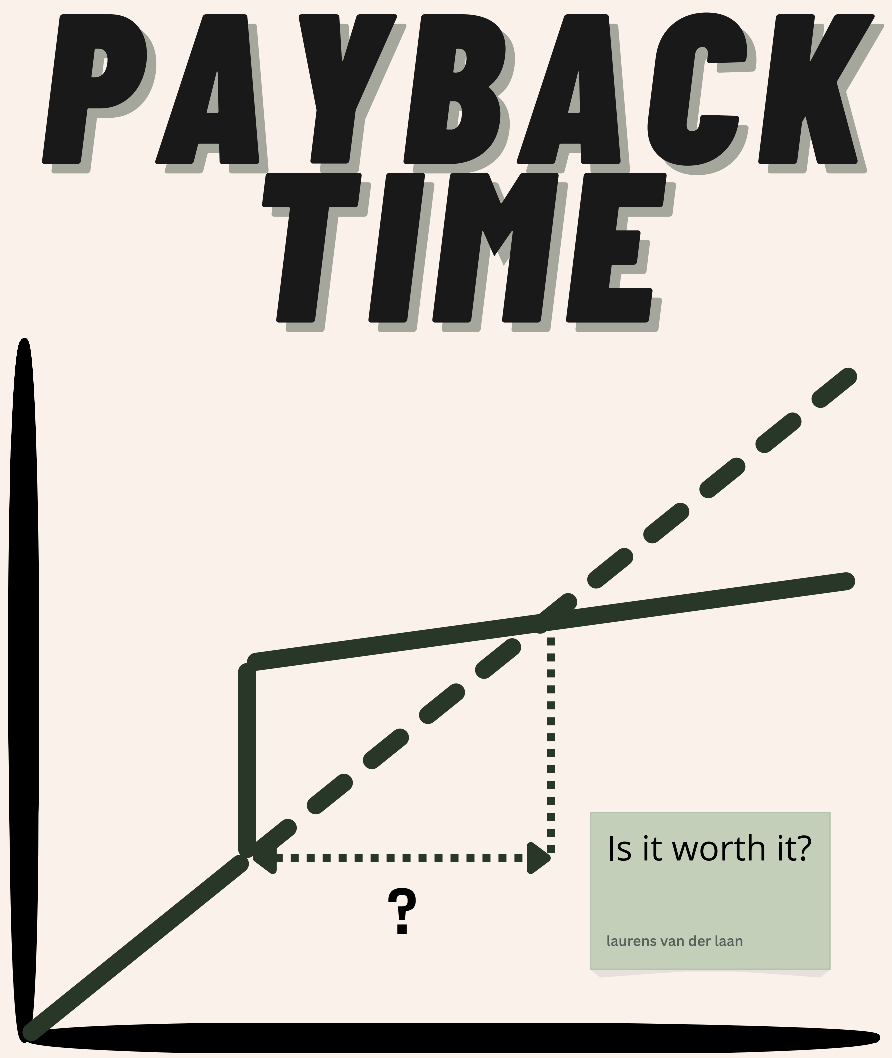
TU DELFT

EVALUATING THE ENVIRONMENTAL PAYBACK TIME OF ENERGY IMPROVEMENT MEASURES FOR SMALL OFFICE BUILDING RETROFITS IN THE NETHERLANDS

by Laurens van der Laan

MANAGEMENT IN THE BUILT ENVIRONMENT

OVERVIEW



SUMMARY

Focus: Analysing the environmental exploitation of retrofitting small office buildings

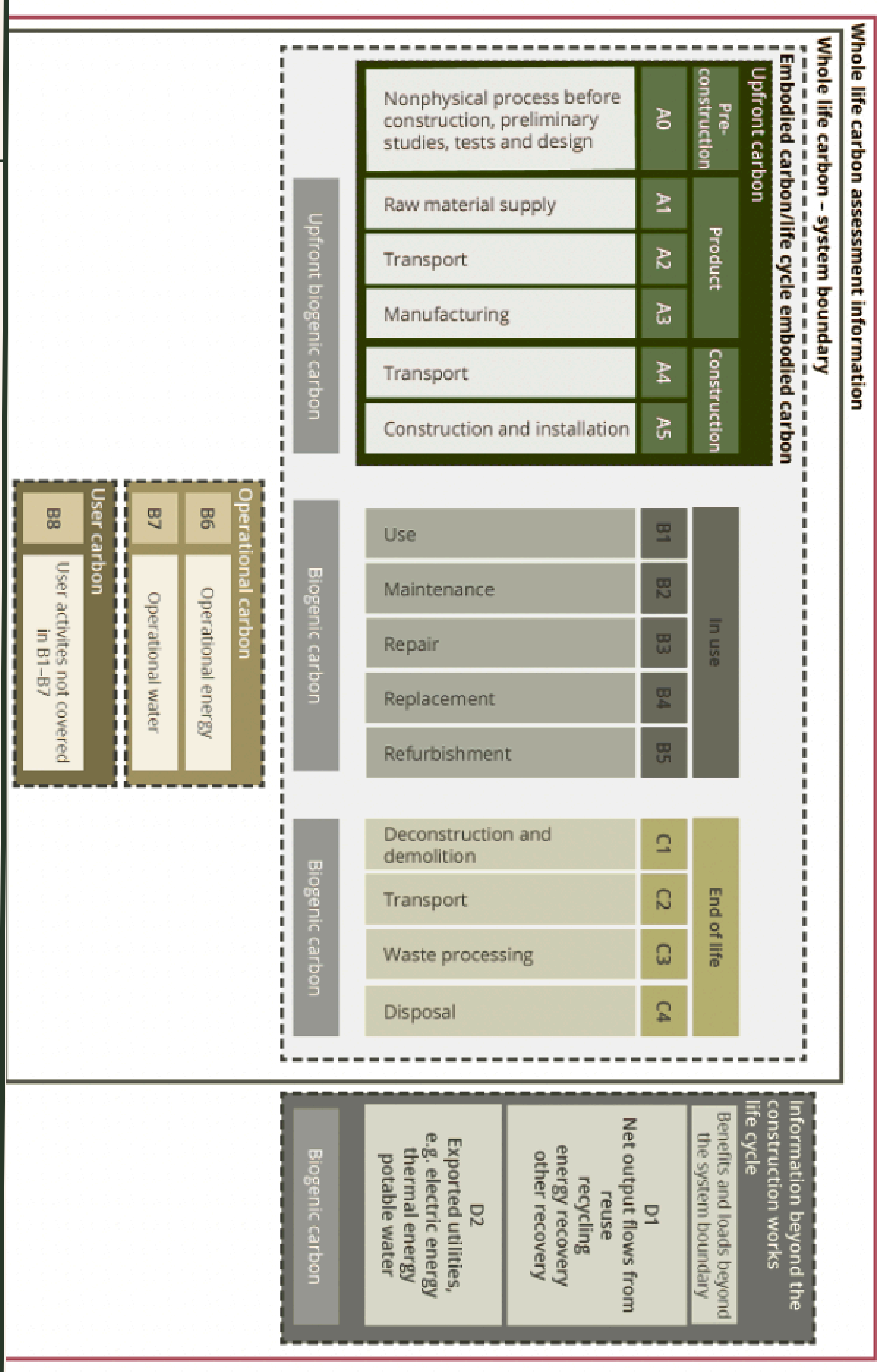
Goal: Find out the payback time

How: through a simulation-based approach, this research experimented with various retrofit scenarios using Vabi(simulation software) and the WLCA framework.

WHAT IS IT?

- Retrofit
- EIMS (Energy Improvement Measures)
- Whole life carbon (WLC)
- Operational carbon (Opex)
- Embodied carbon (Capex)
- Payback time
- Paris proof building

Environmental exploitation

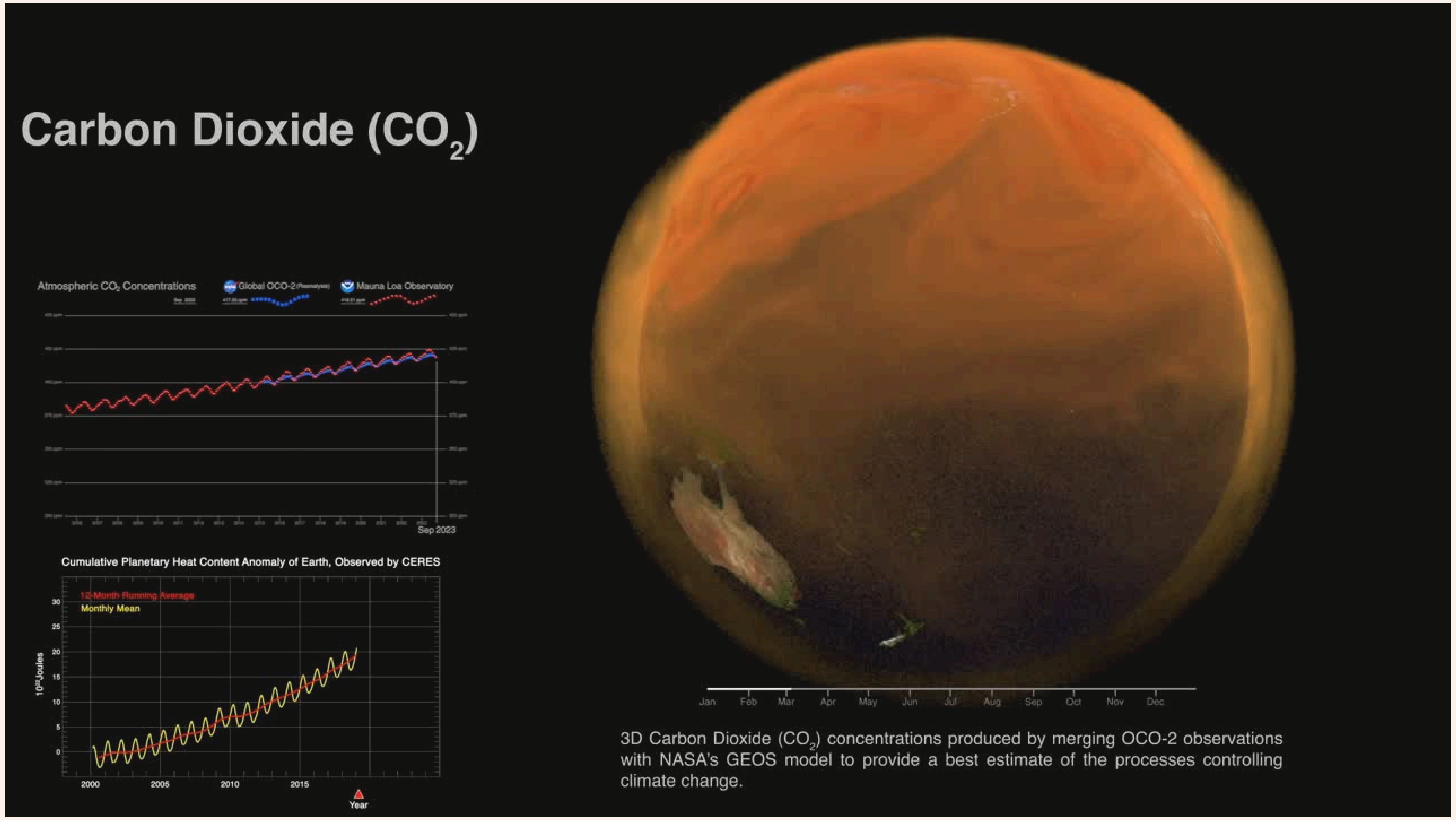


WLC framework(source: RICS, 2023)

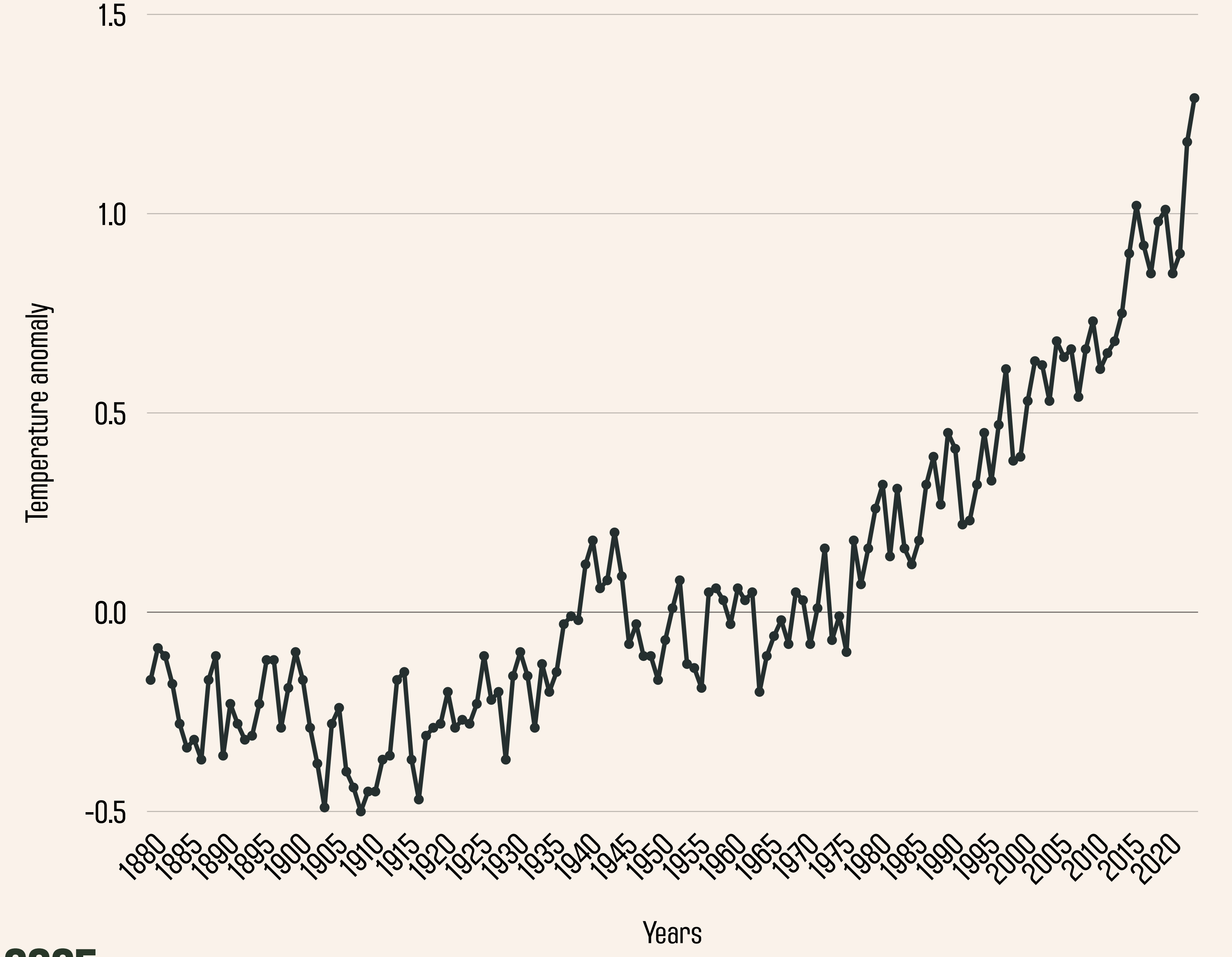
INTRODUCTION

- ESG → CSRD
- Mandatory EPC label C (Energy label)
- EPDB IV
- EU ETS2
- Emission-free buildings by 2050
    - Net zero Carbon
    - Net zero Energy
- “Paris proof buildings”
- Shift from energy to carbon reduction

CO_2 AND TEMPERATURE



Global Atmospheric Carbon Dioxide (source: Weir, 2023)



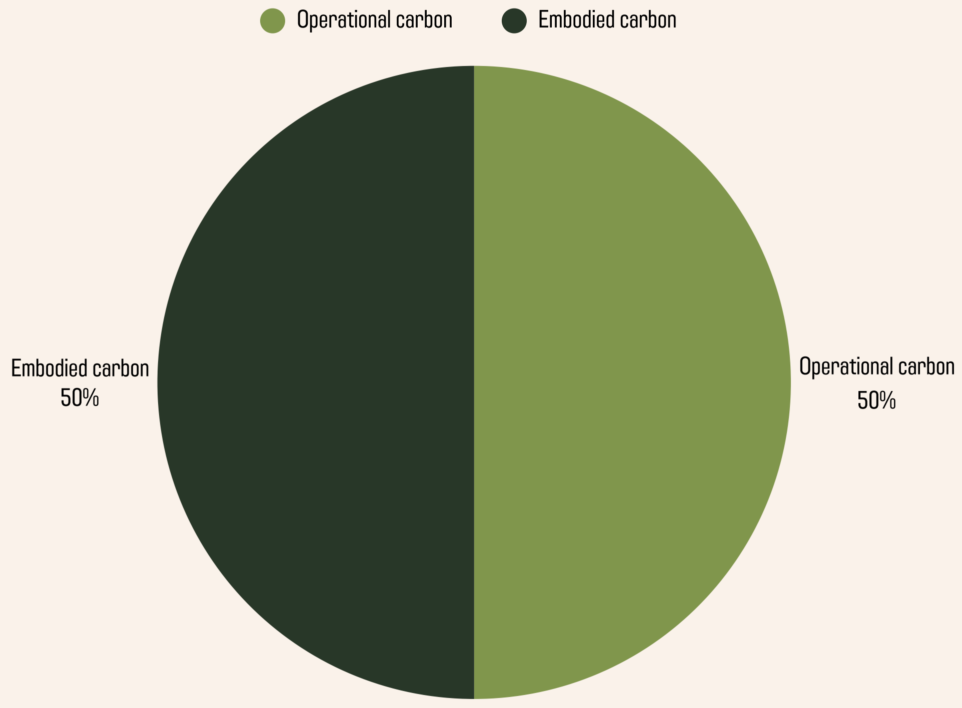
PROBLEM

01

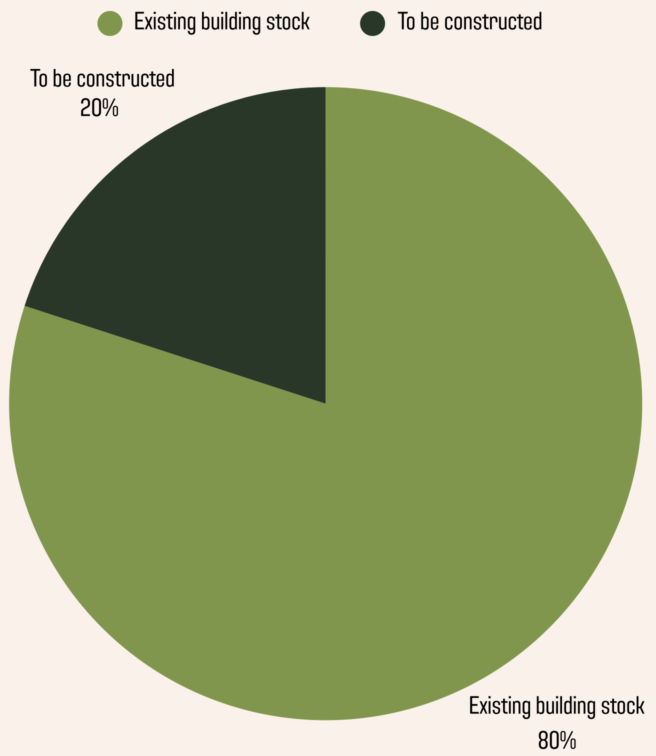
Reduce GHG emissions from built environment
→ to reach Paris climate agreement
Increasing pressure due to:
→ EPC label C - EPBD IV - EU ETS 2 - CSRD

Wide range of EIMs/retrofit has been discovered
→ but comes at the cost of embodied carbon → 11% of global and up to 50% of building emissions

Focus was operational energy and emission reduction
→ Shifted to embodied emissions of new construction
→ Now focus on renovations



Operational vs Embodied carbon in 2035 (source: Eleuterio, 2024)



Building stock off 2050 (source: Eleuterio, 2024)

PROBLEM

02

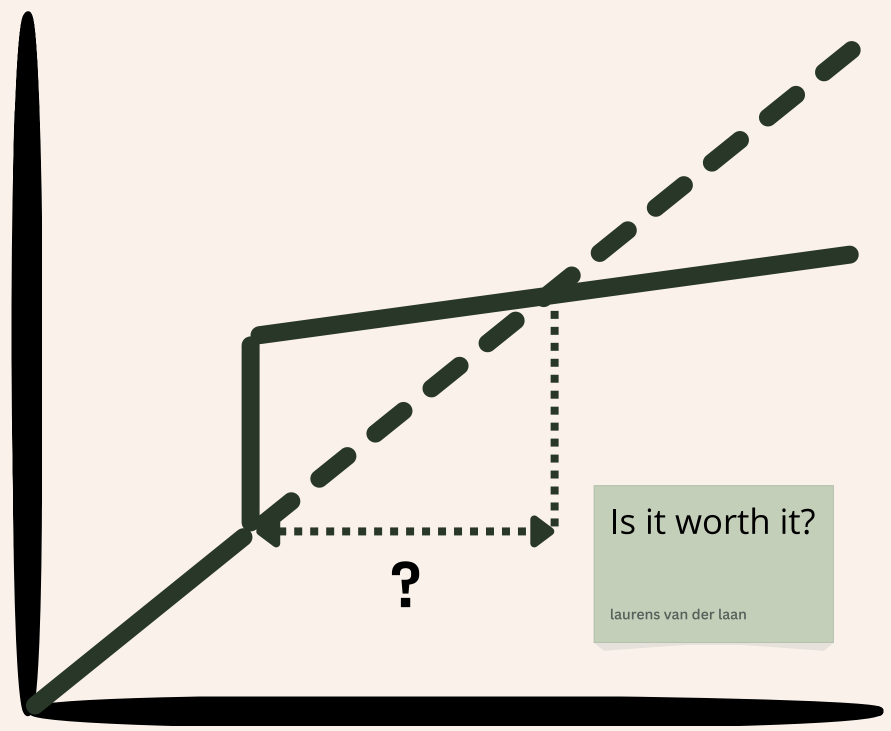
Existing studies focus on large office-, and residential buildings, outside of the Dutch context

Increasing regulatory and environmental pressure

→ Research neccesary in:

- Environmental exploitation
- Payback time

of retrofitting small office buildings



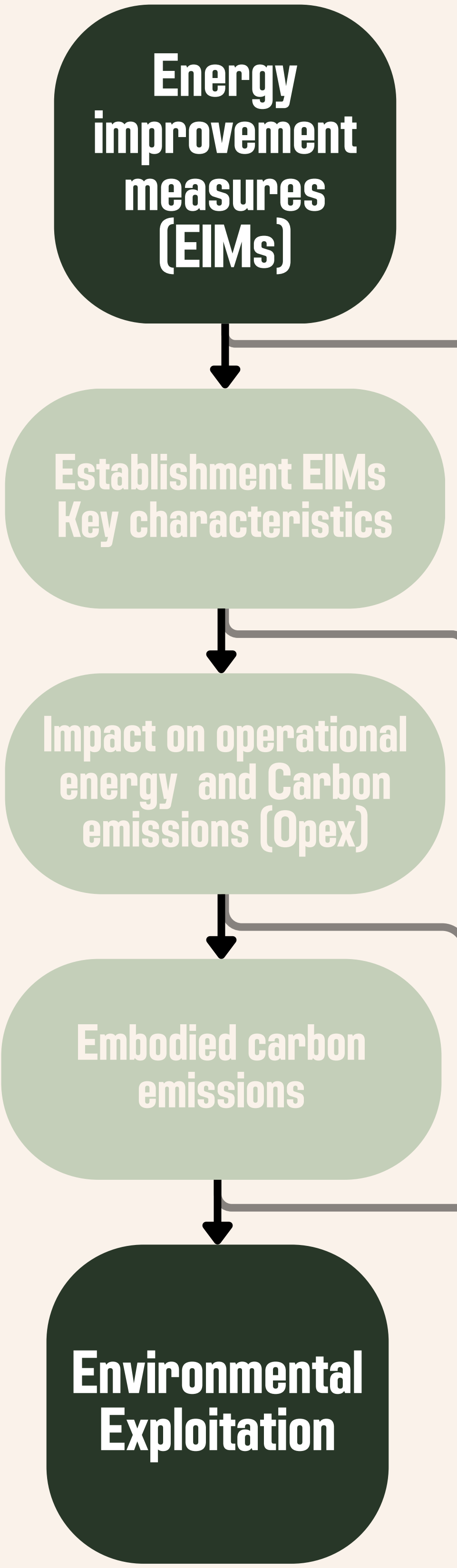
RESEARCH AIM

What happens with the Capex and **Opex,** when certain EIMs are implemented through retrofit packages focusing on reducing the Opex?

Follow up: Embodied carbon (Capex) investment that can be divided by the reduction in operational carbon/year (Opex), **this results in:** environmental payback time

Conclusion:
Is it also worth it for small office buildings to implement EIMs?
What are the payback times?
Complies Capex with Co2 material-related emissions per m2?

MAIN- & SUBQUESTIONS



1.What energy improvement measures are commonly implemented in office buildings, and what are their key characteristics?

2.How do these energy improvement measures impact energy usage and operational carbon emissions (Opex)?

3. What is the amount of CO_2 that is invested as a result of implementing the energy improvement measures (Capex)?

Main question:

"What is the environmental payback time of energy improvement measures for small office buildings retrofits in the Netherlands?"

METHODOLOGY

Experimental approach building a case study of three sizes

- **Gathering energy improvement measures**

Desk research
List with most implemented measures
Determin realistic scenarios
Create retrofit packages

- **Simulation through Vabi**

Create models of Office buildings
Run energy simulations
Calculate energy use
Calculate operational emissions

- **WLCA (RICS) and Ökobaudat (EPD)**

Determine WLCA as an assessment method
Set preconditions and determine scope
Create list with data of all EIMs from EPDs
Calculate the invested embodied carbon

SIZES, SCENARIOS AND VARIANTS

- **Size**

100m²
200m²
500m²

- **Scenarios**

Baseline scenario
Scenario 2 (Hybrid)
Scenario 3 (Full electric)
Scenario 3+ (Renewable Energy)

- **Variants**

Metalstud lining wall (Metalstud - Non Biobased)
- CW100 profiles with Glasswool

Timber frame lining wall (HSB - Biobased)
- Timber frame with Wood fibre insulation

→ Scenarios

BASELINE SCENARIO

- **Base**

Represents the Values of a pre-2000s office building
→ 79% of office stock was build before 2000
Natural gas boiler (HR107)
Radiator heating
Natural ventilation
Bad insulation

		Baseline scenario 1	
		Rc value (m2 K/W)	
Facade		2.9	
Glass		0,5	
Roof		3.3	
Floor		0,3	
			Thickness (MM)
External wall type	Outside	Masonry brick	90
		Mineral wool	80
		Brick	140
	Inside	Plaster	2
Roof type	Outside	EPDM	20
		PUR Isolation	80
	Inside	Concrete floor	180
Floor type	Outside	Concrete floor	300
		Chape (sand cemen	70
	Inside	Floortiles	20
Window type		Wooden frame & HR Glass	
Internal Walls		Not included in this study	
Space Conditioning		Natural gass boiler (HR107)	
		Multisplit Cooling	
Heat and Air distribution system		Radiators	
		Natural ventilation System A	
Reneweble Energy		Absent	
Lighting		500LUX	
		50/50 TL&LED	
		Power 9,5W/m2	
Solar shading		Absent	

SCENARIO 2 + 3(+)

- ## Scenario 2 (Hybrid)

HR107 gasboiler + Heatpump (Air-water)

Envelope upgrades

Solar shading

Mechanical Ventilation

- ## Scenario 3(+) (Full electric)

Heatpump (Air-water)

Floor heating (Low temperature)

Renewable energy → PV panels

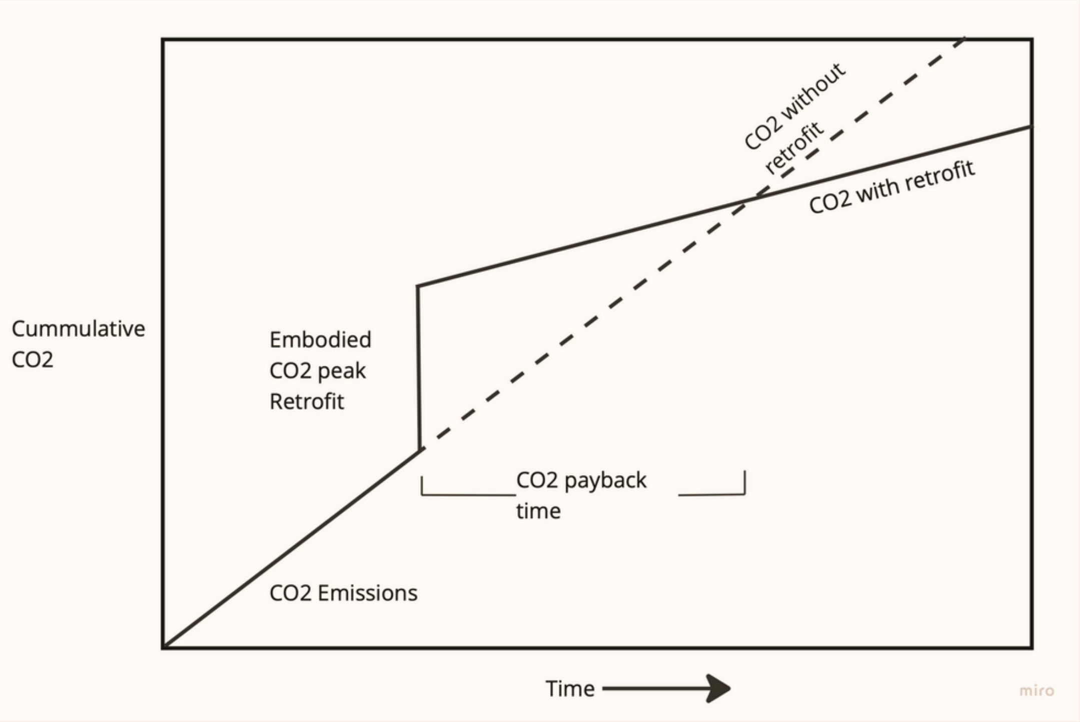
		Scenario 2 (Hybrid)			Scenario 3 (Fully electric)	
		Rc value (m2 K/W)			Rc value (m2 K/W)	
		Facade	5,6		Facade	5,6
		Glass	1,1		Glass	1,1
		Roof	7		Roof	7
		Floor	3,3		Floor	3,3
		Thickness (MM)			Thickness (MM)	
External wall type	Outside	Masonry brick	90	Outside	Masonry brick	90
		Mineral wool	80		Mineral wool	80
		Brick	140		Brick	140
		Flexible woodfiber + Timber framework and board material	163		Flexible woodfiber + Timber framework	163
	Inside	Plaster	2	Inside	Plaster	2
Roof type	Outside	EPDM	20	Outside	EPDM	20
		PUR Isolation	100		PUR Isolation	100
		PUR Isolation	80		PUR Isolation	80
	Inside	Concrete floor	180	Inside	Concrete floor	180
Floor type	Outside	PUR Isolation	80	Outside	PUR Isolation	80
		Concrete floor	300		Concrete floor	300
		Chape (sand cement	70		Chape (sand cemer	70
	Inside	Floortiles	20	Inside	Floortiles	20
Window type		Wooden frame & HR++ Glass			Wooden frame & HR++ Glass	
Internal Walls		Not included in this study			Not included in this study	
Space Conditioning		Hybrid setup Natural gass boiler (HR107) + Air-Water Heatpump Ventilation type D -Balance ventilation -WTW unit Multisplit Cooling			Heatpump Air-Water xKW - COP 4 Ventilation type D -Balance ventilation -WTW unit Multisplit Cooling	
Heat and Air distribution system		Radiators (Low temperature) Airducts for ventilation			Floorheating 200mm (Low temperature) Airducts for heating	
Reneweble Energy (Scenario 3+)		Absent			PV panels Monocrystalline silicon 1650x1000 mm Power: WP 400	
Lighting		500LUX 100% TL&LED Power 4W/m2			500LUX 100% TL&LED Power 4W/m2	

PROCESSING RESULTS (PAYBACK TIME)

- Embodied carbon invested / yearly reduction in operational emissions = payback time in years
- Using which modules ->
  - Module A1-5 and C were used to calculate the payback times
- Comparing material-related emissions/m2 to Paris-proof threshold
  - Determine if the investment was too big

Paris Proof grenswaarden	materiaalgebonden kg CO_2-eq. per m²			
	2021	2030	2040	2050
Woning (eengezinswoning)	100	63	38	23
Woning (meergezinswoning)	100	63	38	23
Kantoor	125	79	47	28
Retail vastgoed	125	79	47	28
Industrie	100	63	38	23

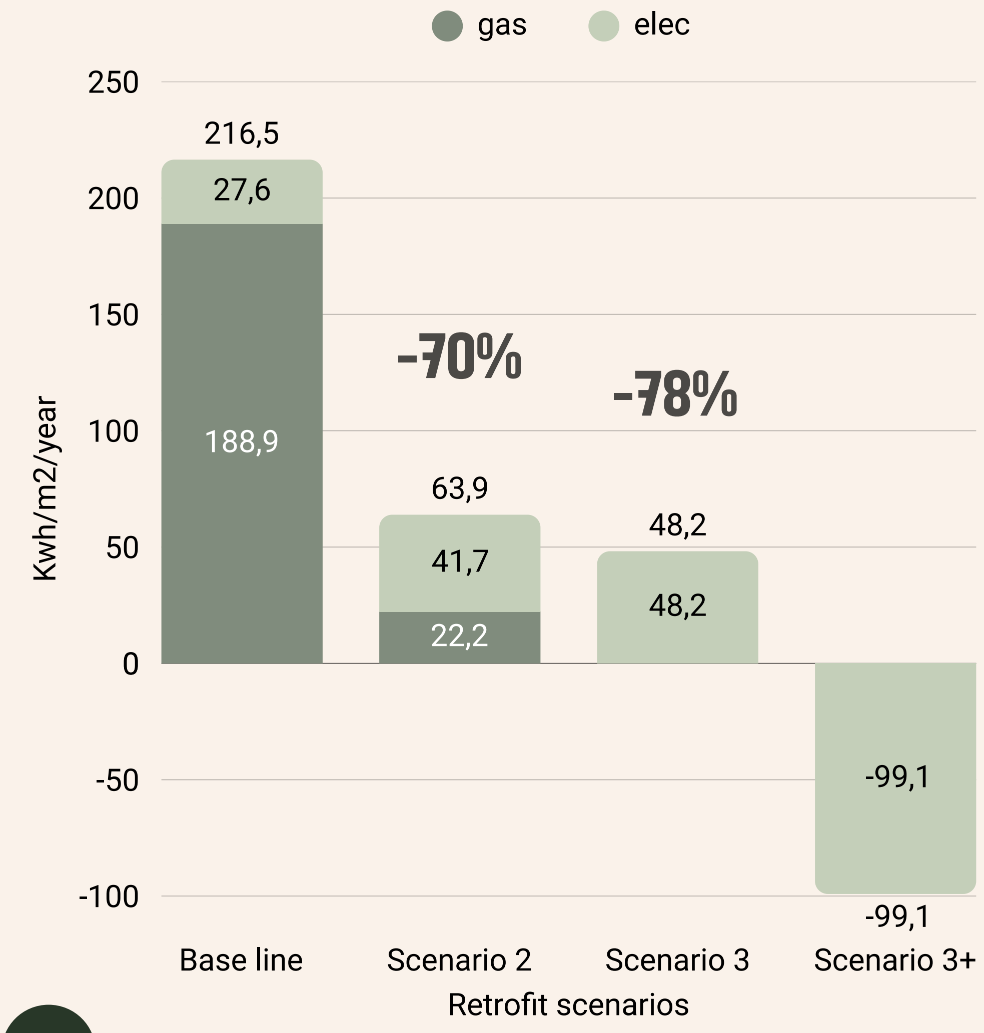
Materiaal gebonden emissies (source: DGBC 2024)



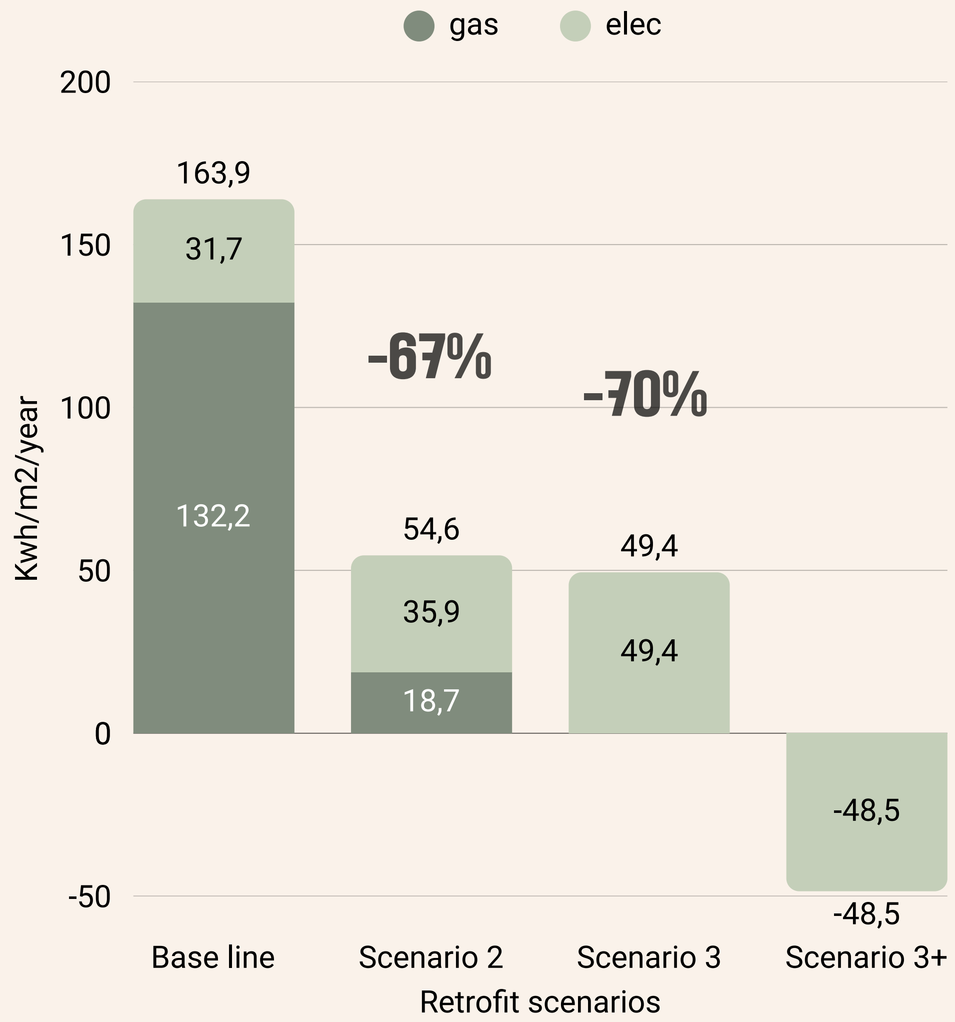
RESULT

Energy reductions

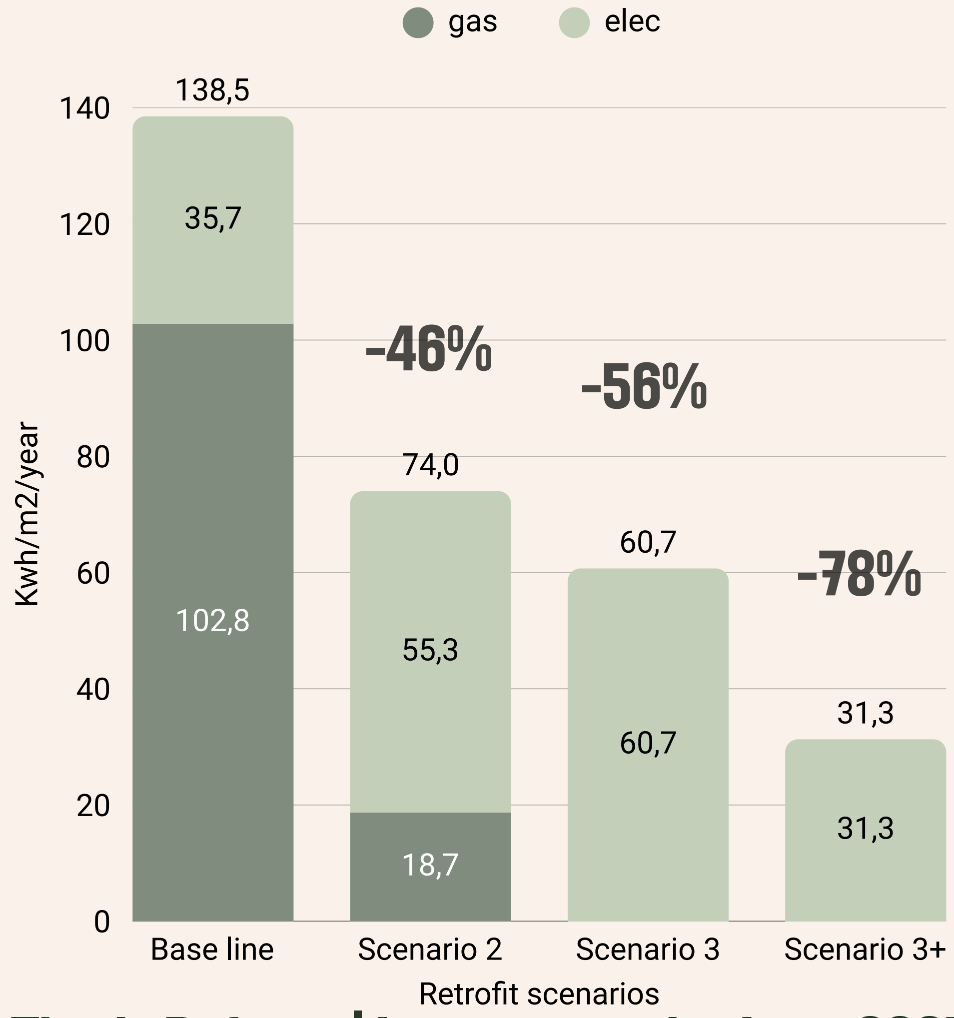
100m2



200m2



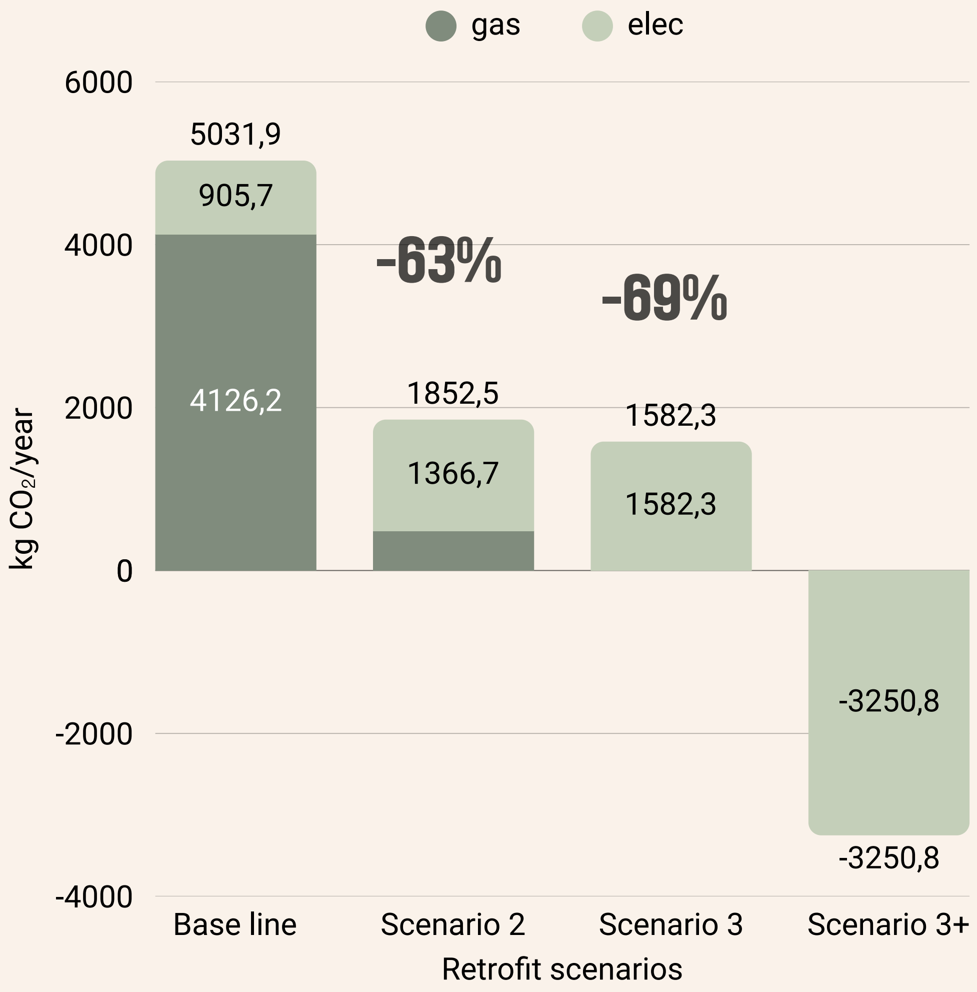
500m2



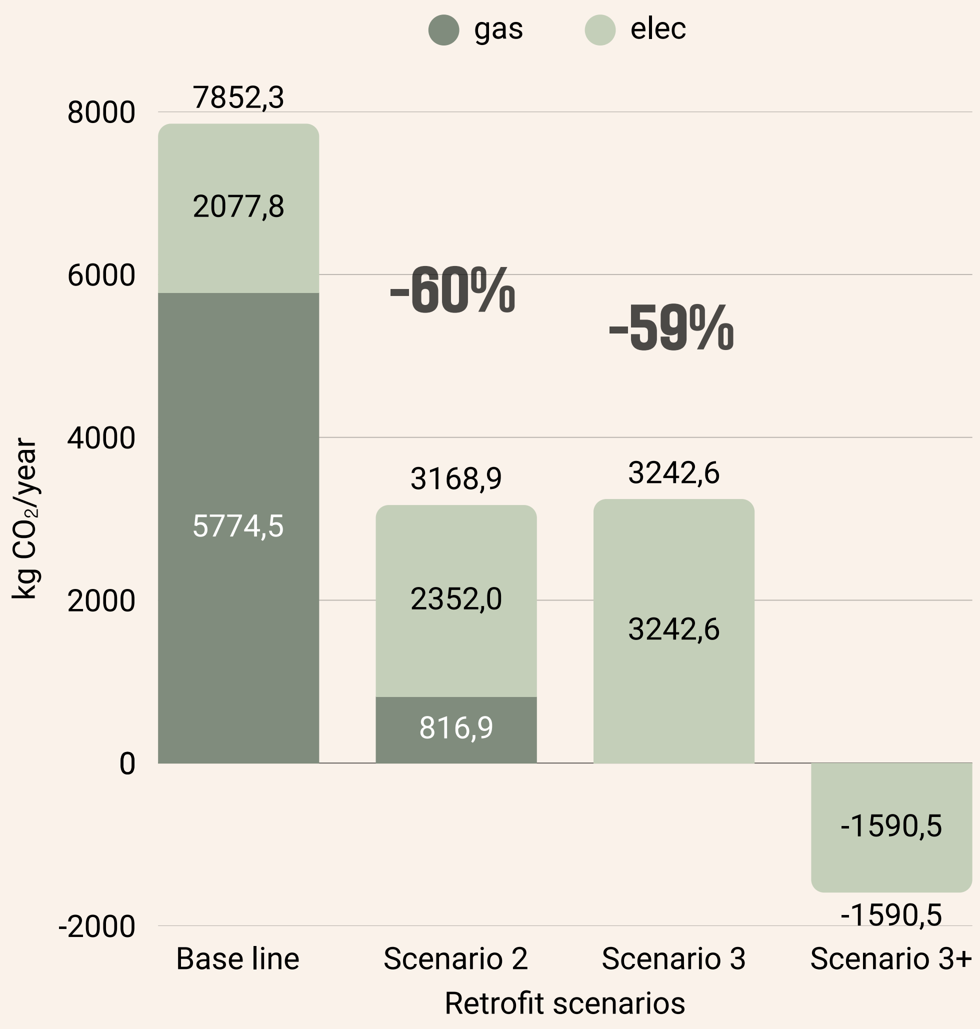
Operational CO_2 reductions

RESULT

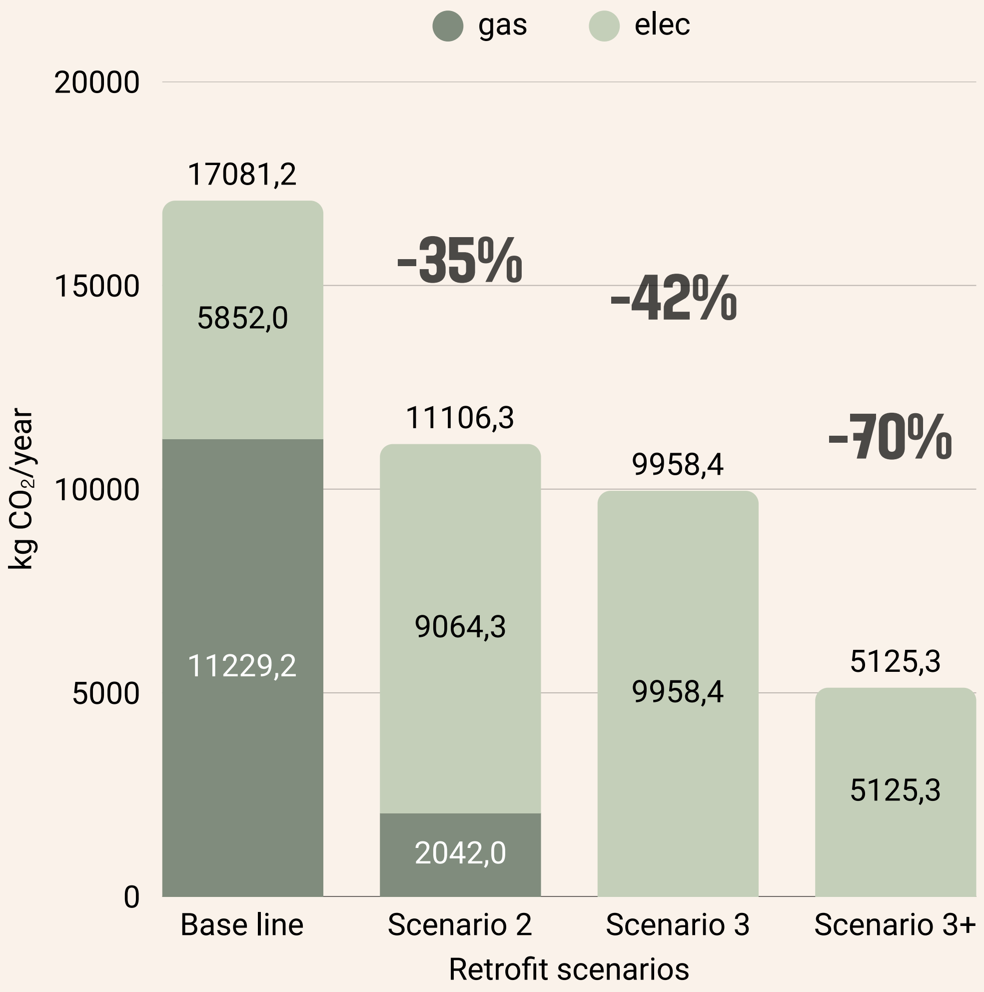
100m2



200m2



500m2

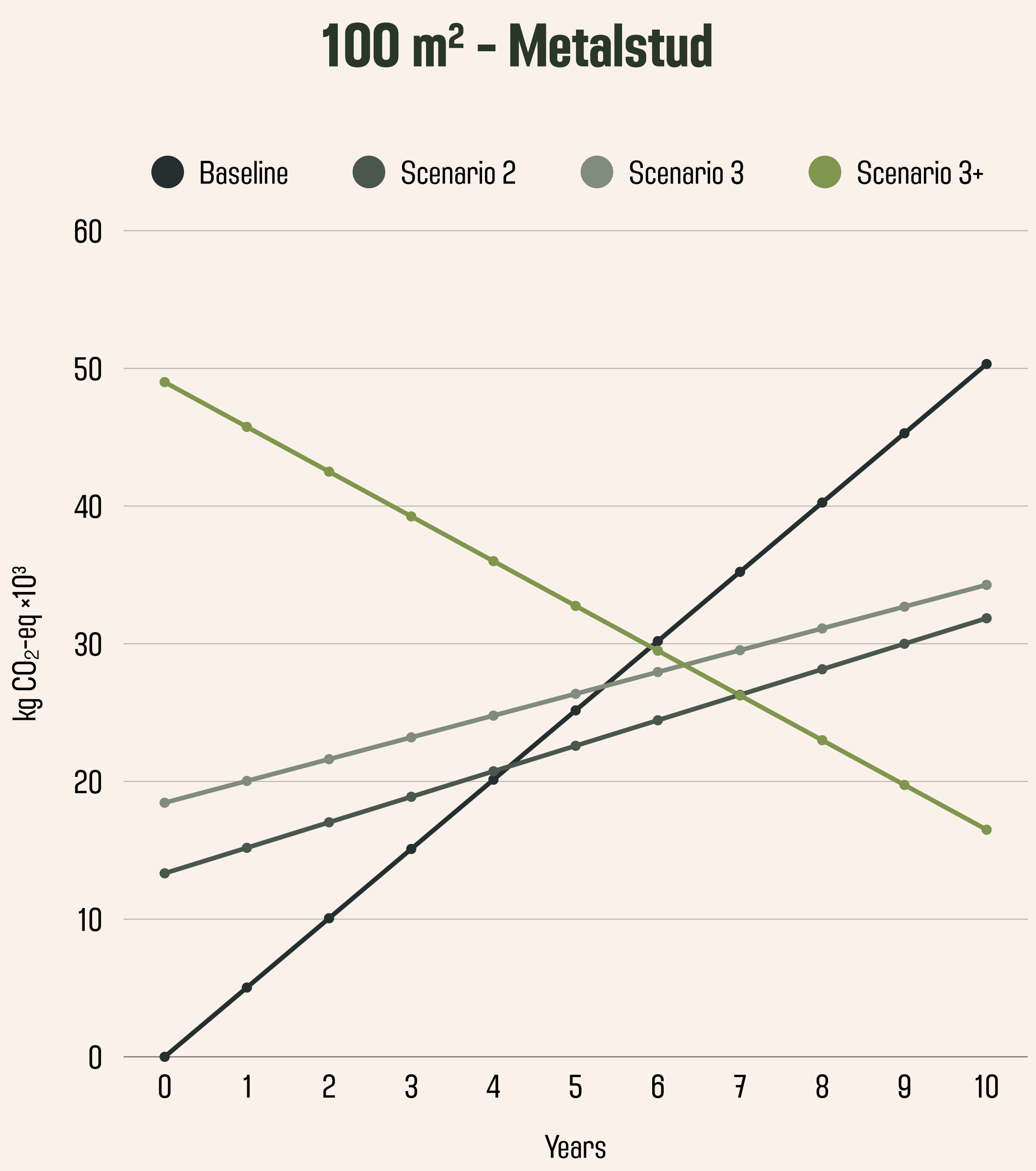


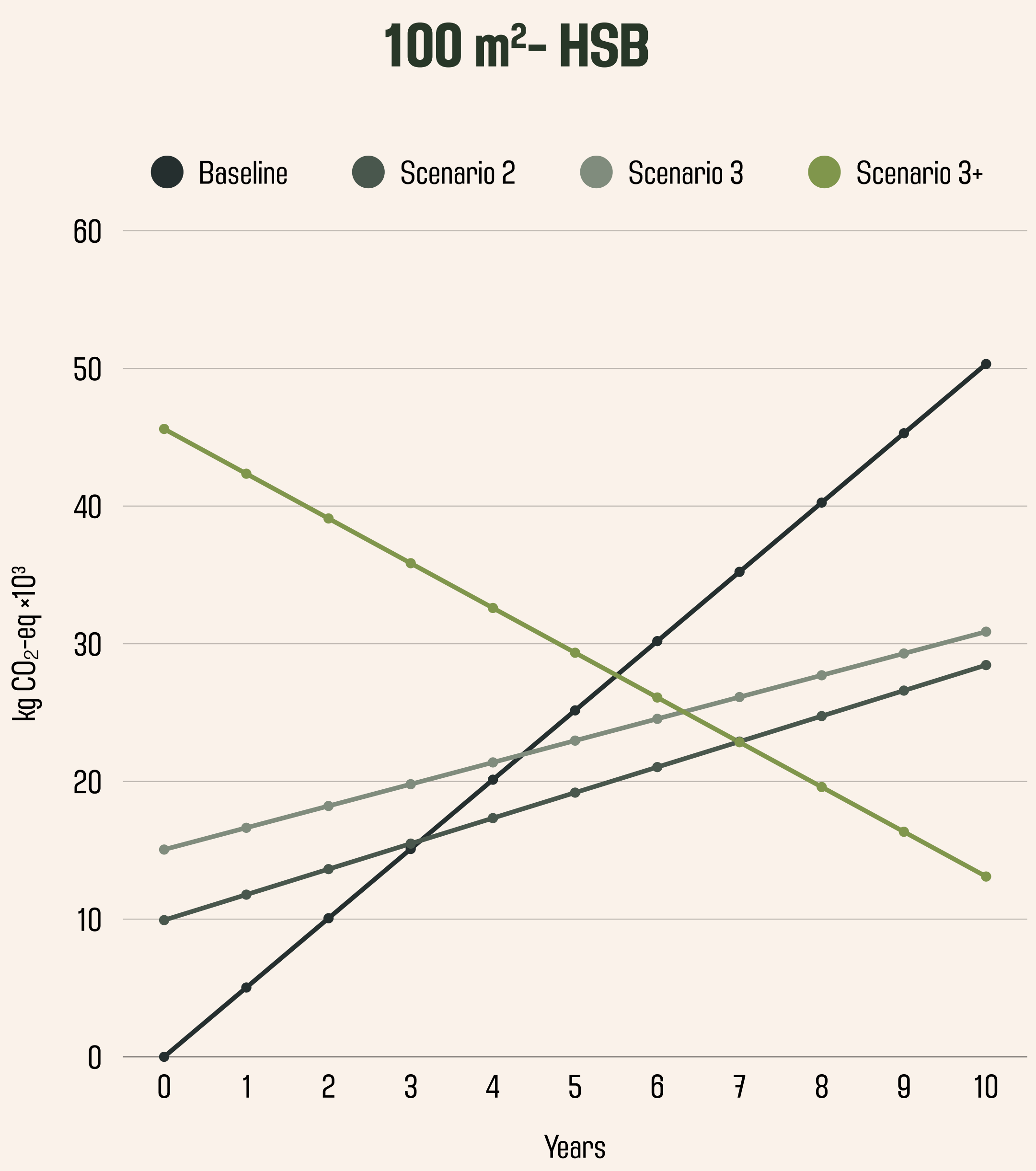
RESULT

Energy & Emission reductions

- Comparable with literature which reports 40-70% energy reduction for deep retrofits
  - → Literature also researched bigger buildings →
    - Smaller buildings → biggest energy reduction → in line with heat- and cooling loss
- The retrofits, in scenario 3+, all achieve the ‘Paris-proof’ A+++ label
  - Proving the retrofits achieve the wanted standards
- Smaller buildings have more surface-to-volume ratio for solar panels, meaning big buildings cannot always reach the required capacity in renewable energy on site
- Emission reductions mirror energy consumption trends, but are less high → due to energy mix & emission factors
- When difference in energy reduction is not big enough between SC2 and SC3 →
  - Increase in emission → Warning for electrification → emission factor worse than gas

RESULT





Payback times

SC 2 → HSB 3.12 and Metalstud 4.19 years

SC 3 → HSB 4.26 and Metalstud 5.35 years

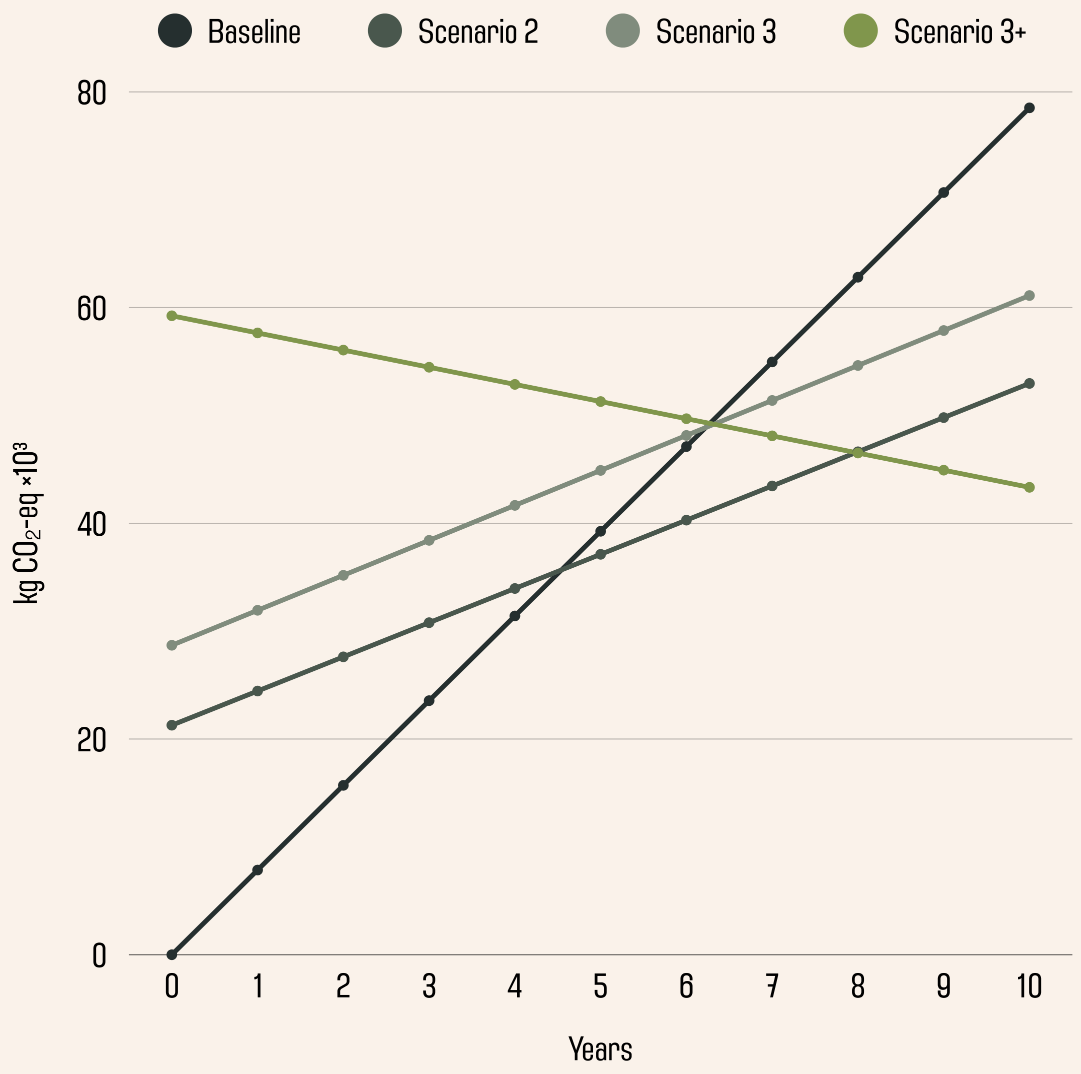
SC3+ → HSB 5.51 and Metalstud 5.92 years

SC3 to overtake SC2 after 19 years

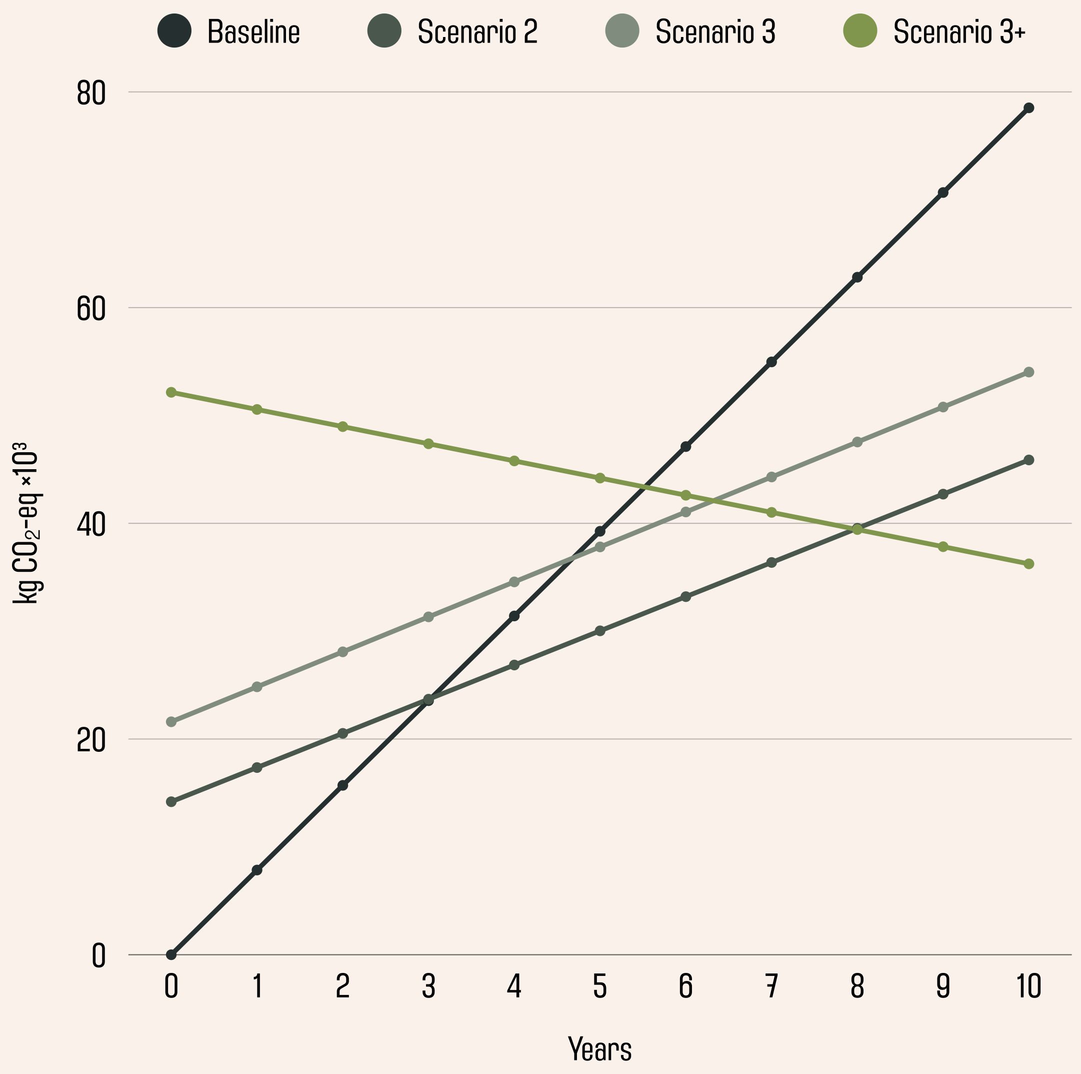
more than 3 times the amount of carbon is invested in SC3+compared to other scenarios -> only 125% and 110% longer payback time

RESULT

200 m² - Metalstud



200 m²- HSB



Payback times

SC 2 → HSB 3.03 and Metalstud 4.54 years

SC 3 → HSB 4.69 and Metalstud 6.22 years

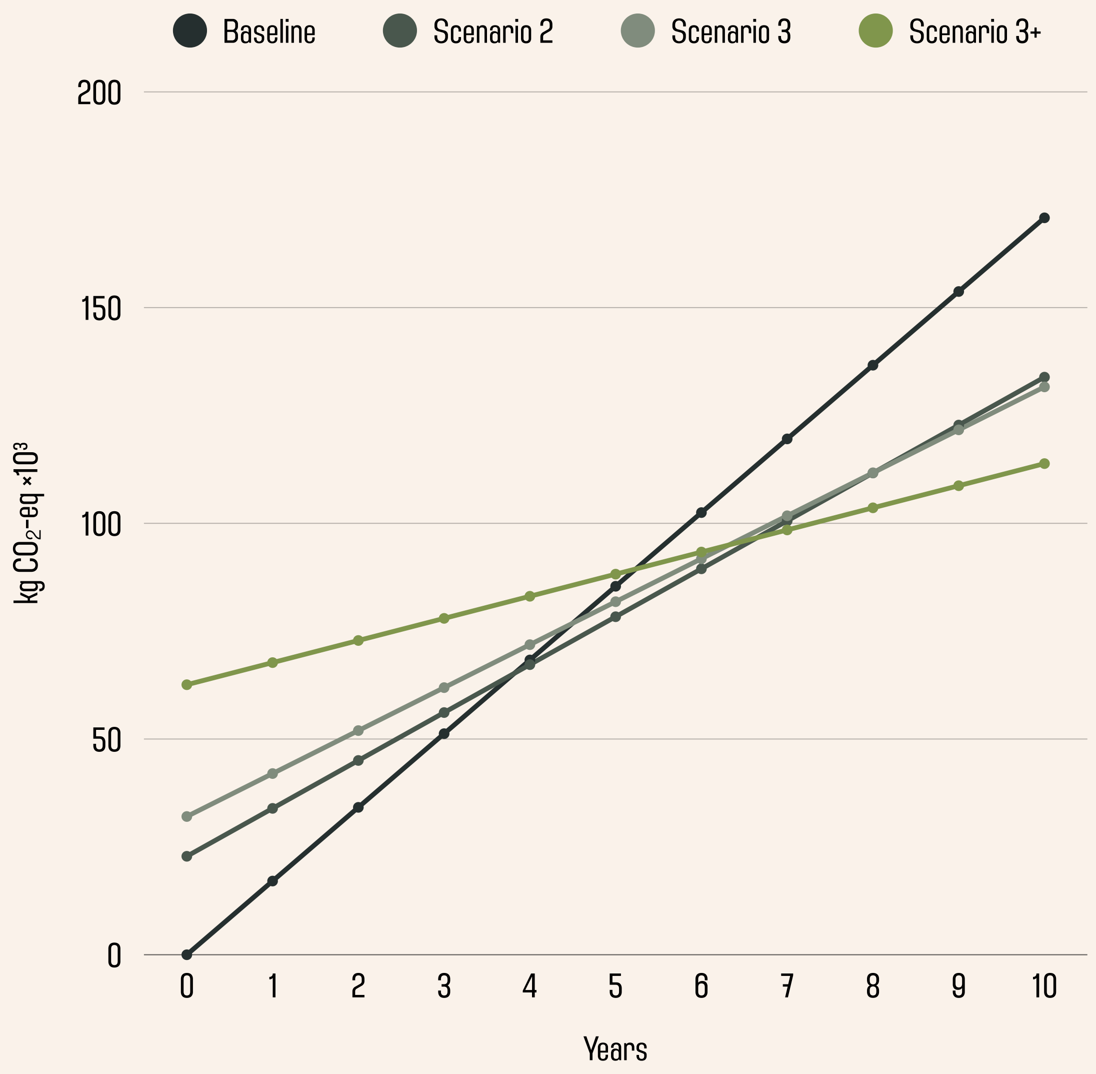
SC3+ → HSB 5.52 and Metalstud 6.27 years

SC3 is never better than SC2

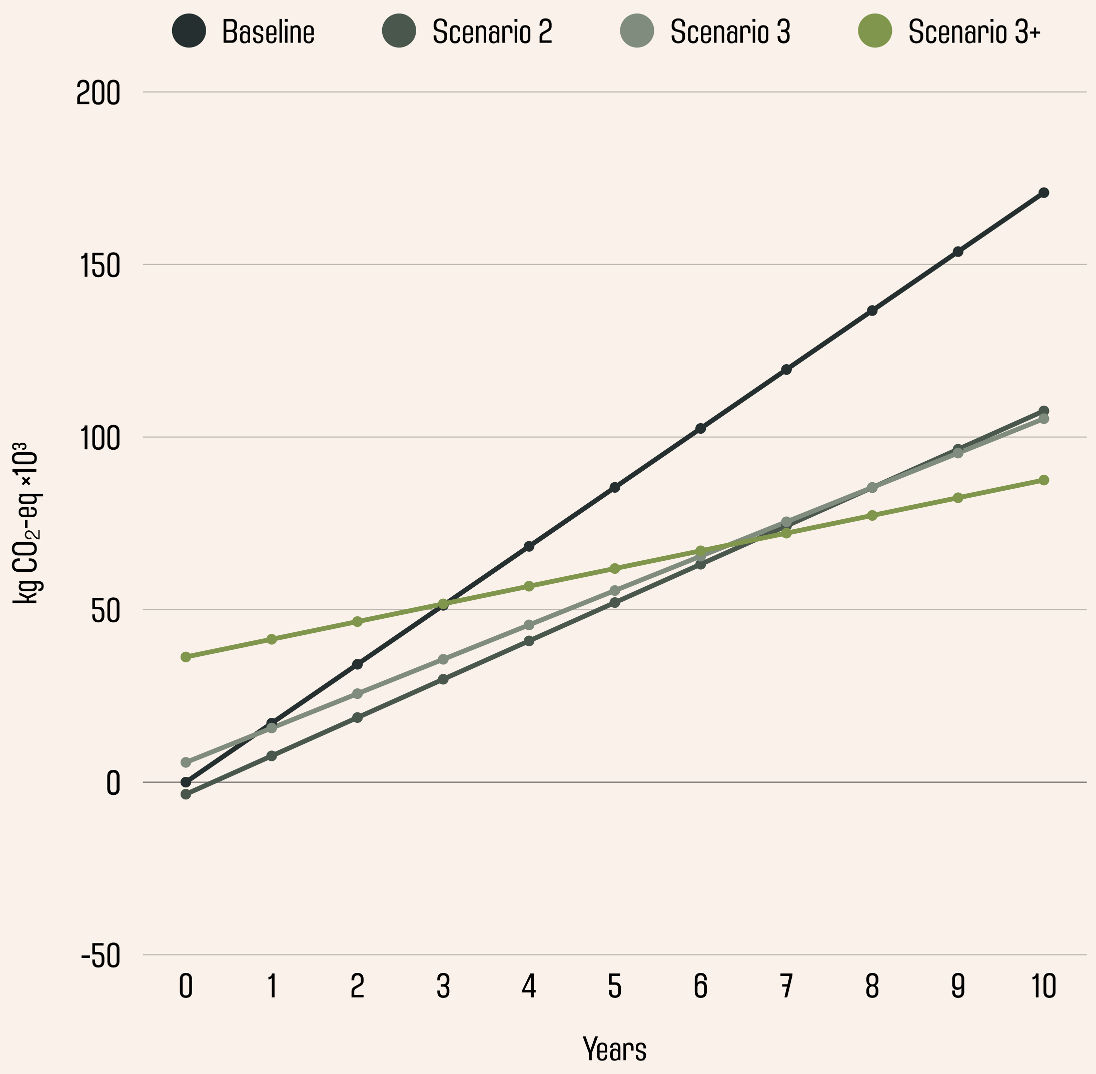
more than 2 times the amount of carbon is invested in SC3+compared to other scenarios -> only 117% and 101% longer payback time

RESULT

500 m² - Metalstud



500 m²- HSB



Payback times

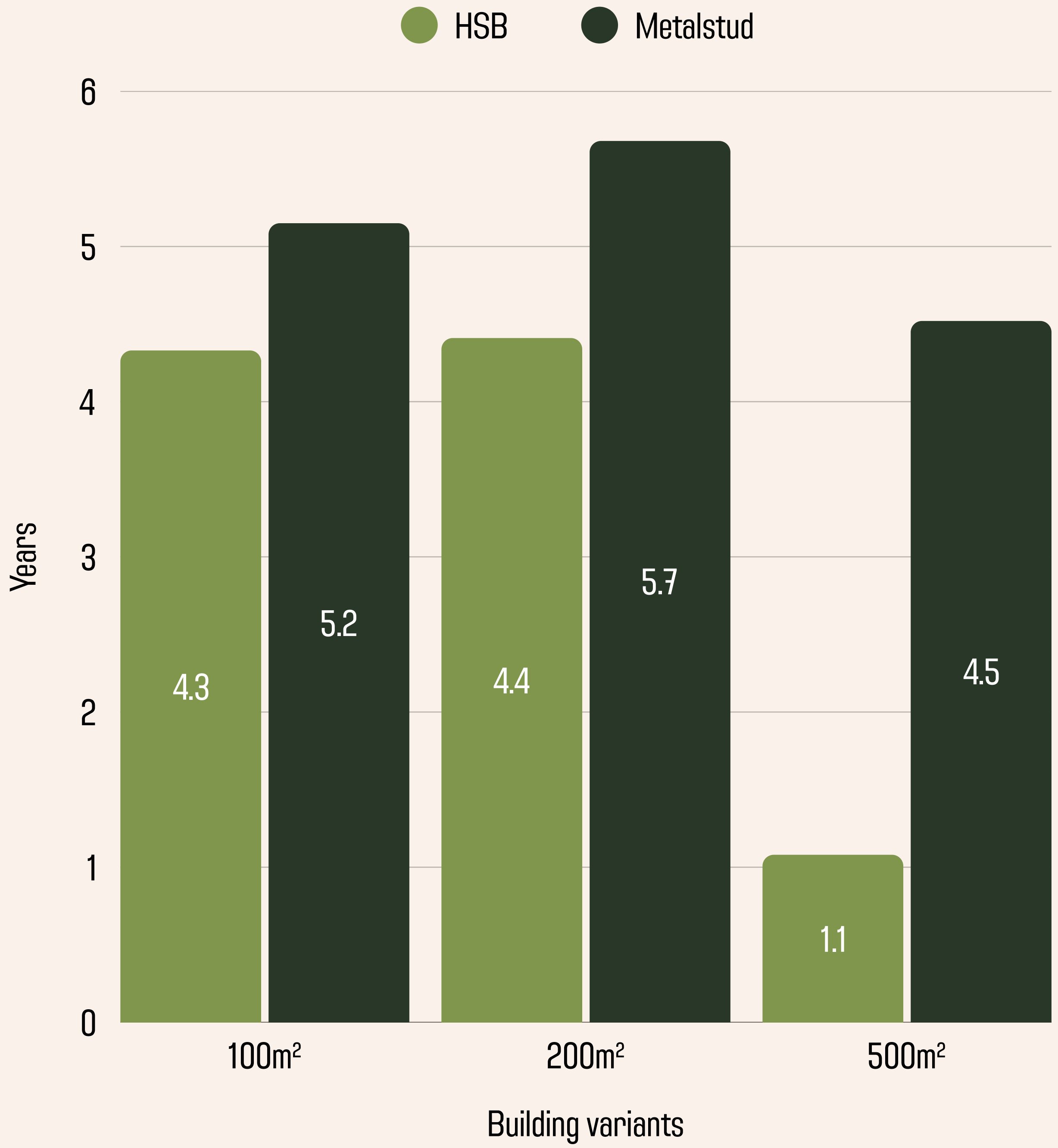
SC 2 → HSB -0.58 and Metalstud 3.82 years

SC 3 → HSB 0.80 and Metalstud 4.50 years

SC3+ → HSB 3.03 and Metalstud 5.24 years

Because of huge amount of biogenic storage of HSB and thus big share of PV panels in CO_2 → 379% longer payback time, and 116% for metalstud

RESULT



Average payback times

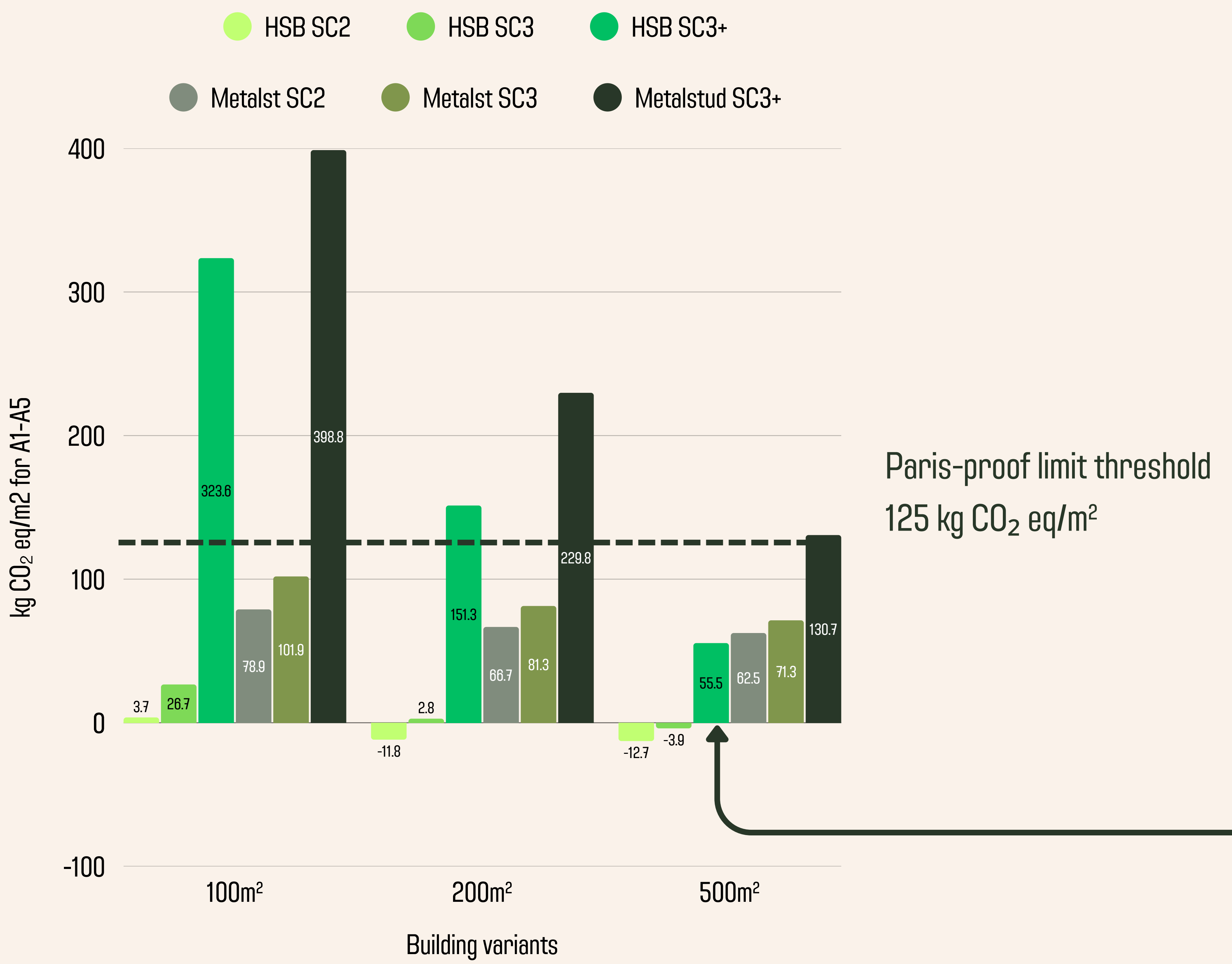
Studies revealed payback times: 2,9 - 6,5 years → confirmed

Depending on depth, system and material choice

Biogenic storage →

Impacts payback time drastically

No linear relationship between building size and payback → biggest building → shortest payback → scale effects, fixed systems less impactful in larger buildings → system size doesn't equally grow to building size



RESULT

Material-related emissions

Compared to literature →

Values reported in research for bigger buildings between 20 up to 185 kg CO_2 eq/m^2

→500m2 within these results

Strongly dependent on building size → scale effects

Material choice makes a big impact

SC3+ for HSB 500m^2 only scenario with renewable energy that stays under threshold

DISCUSSION

- **Material and scope selection**

Scope of retrofit measures in or decreases payback time by years
→ solar panels → up to 3 times the amount of the other EIMs combined

Material choice has big influence →
Example: 100m² of glass wool = ~300kg CO_2 eq emitted; 100m² of wood fibre = ~300kg CO_2 eq stored

Source of materials matters →
Example: Silicon solar panels made in China → emit up to 2 times the amount of kg CO_2 eq/kWh produced

DISCUSSION

- **Energy measurement and grid/system mix**

Grid decarbonisation impacts the operational carbon reduction → reducing the payback times of SC2, SC3 but increasing SC3+
→ next to material choice, grid mix has a significant impact

Although energy simulation (Vabi) is becoming more accurate → performance gap remains
→ However, experts and research contradict each other

Electrification doesn't always reduce CO_2 emissions proportionally due to current grid mix (electricity: 0.328 vs. gas: 0.22 kg CO_2/kWh)
→ Electrification → from an environmental standpoint → less attractive without renewable energy or better grid-mix in 100 and 200m²
→ Hybrid scenarios show shorter payback times → hybrid scenario more attractive for 100 and 200m² buildings
→ Payback time compared to full electric is 19 years for 100m² or does not exist for 200m²

DISCUSSION

- **Reliability of EPD and net possitive impact on climate**

Embodied carbon data quality varies across databases; this affects WLC accuracy
→ Limited and consistent data use can lower embodied emissions by 40.7%

Ökobaudat database complies with EN15804+A2 but has gaps (e.g. not all modules filled, generic system data).

Deeper retrofits achieve higher higher operational reductions → but have longer payback time → means that net positive impact on climate begins later

DISCUSSION

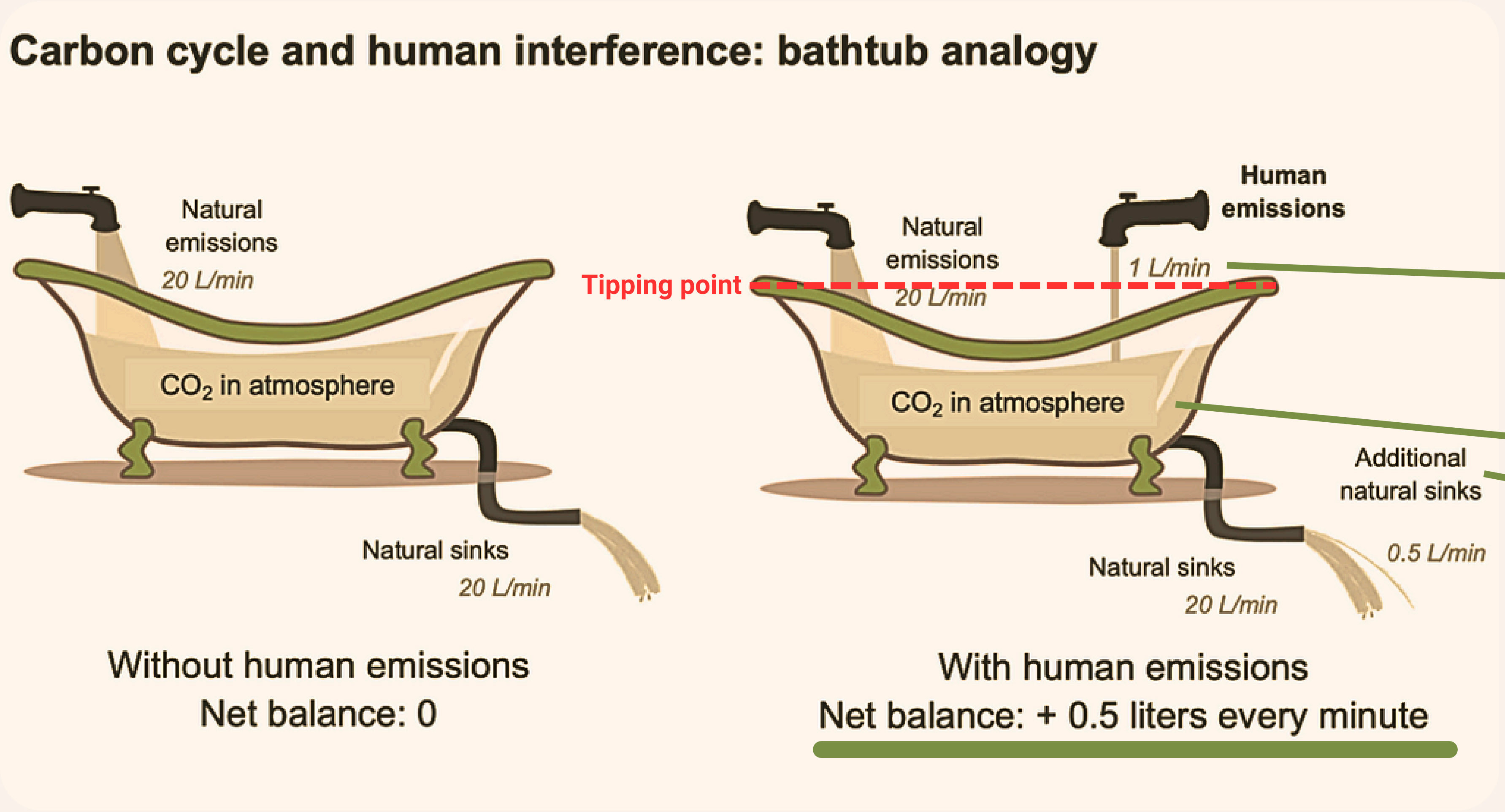
- **Net impact on climate**

Traditional carbon assessments focus on total emissions over the building's life cycle → However, recent research stresses that not only the amount, but also the time of when emissions occur is important
→ Emissions released now cause more cumulative change than those released later

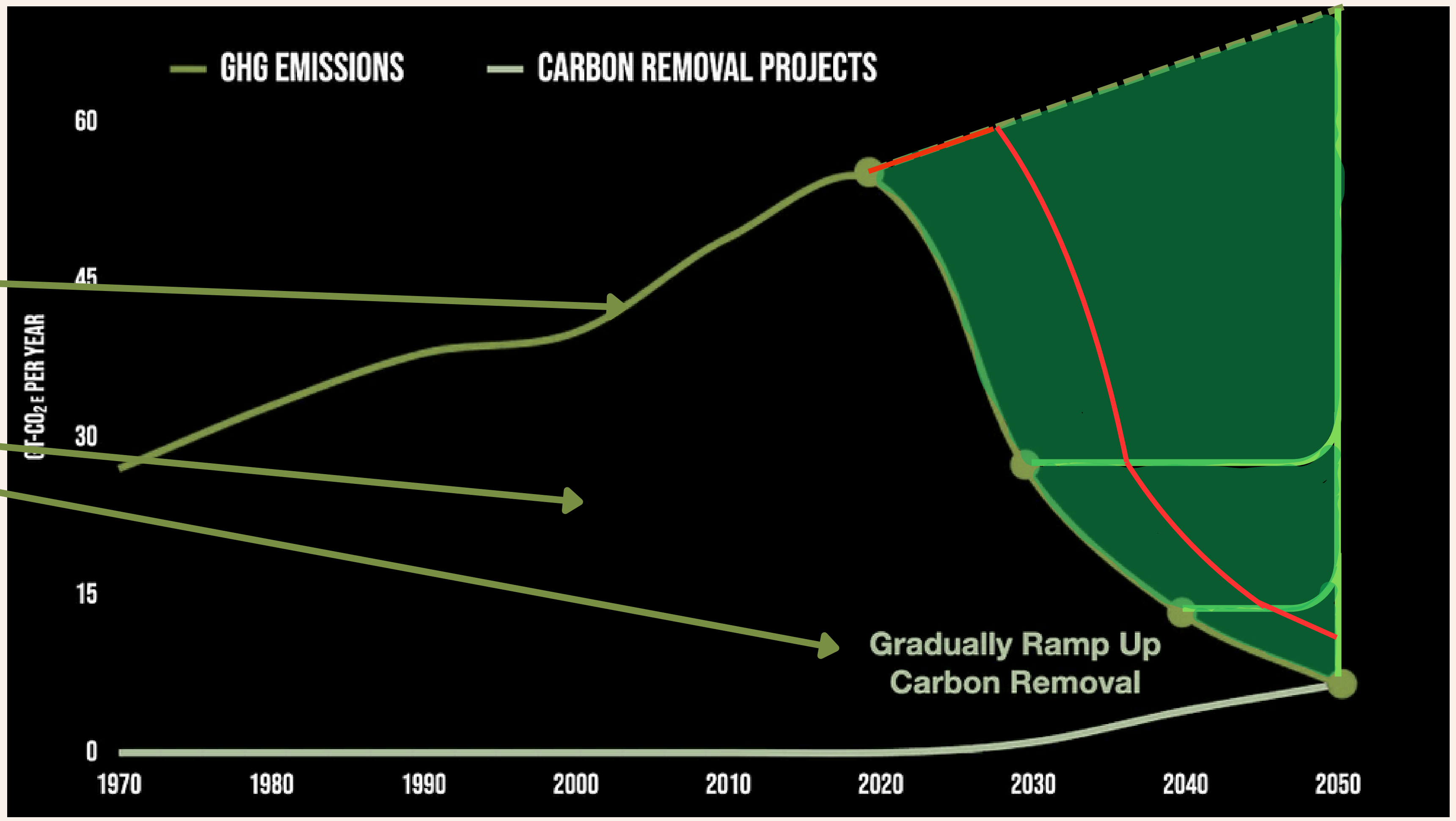
Therefore, high embodied carbon investments now may:
→ Worsen long-term climate trajectories
→ Delay climate goals, even if operationally efficient later

Lower embodied carbon strategies with shorter payback times:
→ May offer a more favourable net positive climate impact
→ Even if they reduce slightly fewer total emissions over the same period

DISCUSSION



Analogy Carbon cycle (source: KNMI, 2024)



Historical Greenhouse Gas Emissions (source: Foley, 2021)

CONCLUSION

Retrofit packages implemented were very effective at reducing energy (46 to 78%) and carbon emissions (35 to 70%)
→ however relationship between energy and operational emission reduction is not always linear

Full electrification is not always the right choice → if energy grid doesn't decarbonise and no access to renewable energy

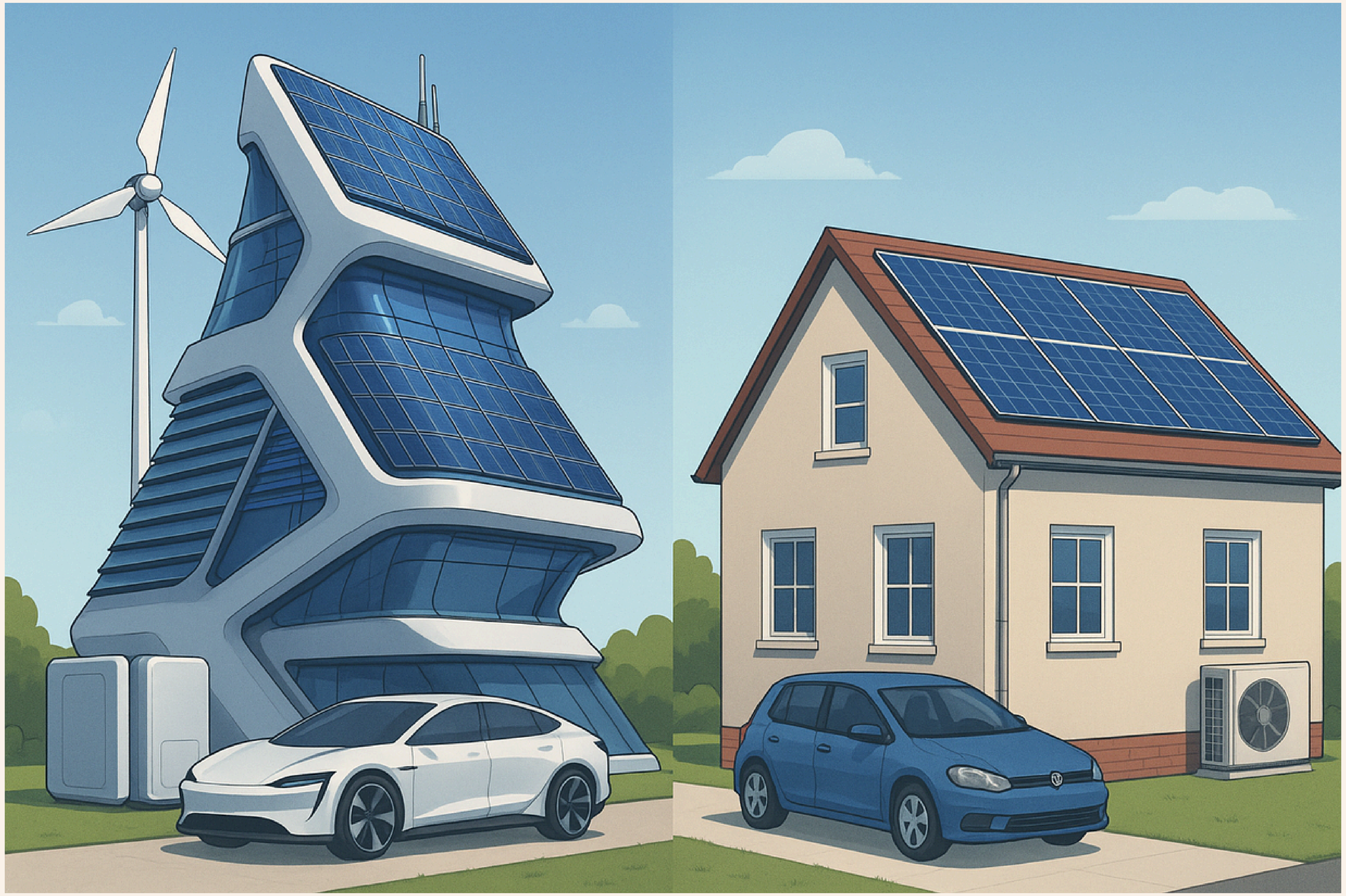
Material choice makes a big impact on embodied carbon → influencing payback time by multiple years

Payback times found in this research confirm the times from earlier research → varying from -0,58 years up to 6.27 years

For small buildings, it is almost impossible to reach Paris proof material-related emission standards.
→ however, for bigger buildings, it seems easier → linear line visible → scale effects

RECCOMENDATIONS

- Ensure consistency in EPD databases
- Promote biobased materials with carbon storage
- Include PV capacity in full-electric assessments
- Implement a phased retrofit strategy, net impact now
- Use carbon payback time in policy tools
- Account for the time value of carbon



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THANK YOU

by Laurens van der Laan

Mentors:
Herman van de Putte
Michaël Peeters
Jorg de Jonge

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