Fleet-based LCA applied to the building sector – Environmental and economic analysis of retrofit strategies

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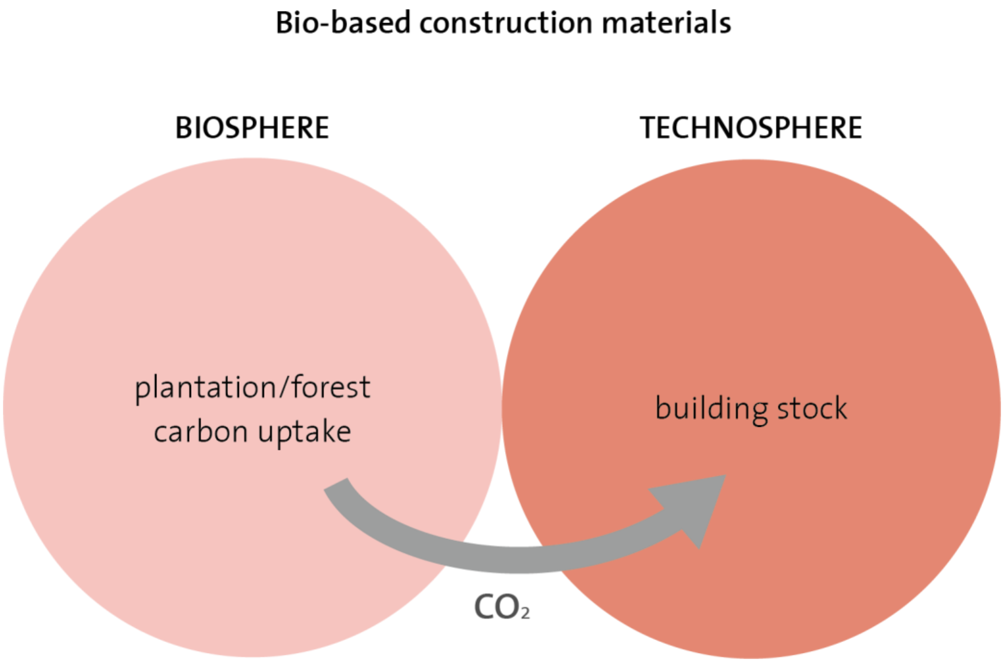
Source: Drone view of Lisbon city center. https://www.pond5.com/artist/dimid_by#1/2063

Motivation

- Paris agreement: limit increase to 1.5°C until 2050
  - 40% reduction of CO_2 emissions by 2030 compared to 1990
- This is expected to be achieved by means of incentive-based regulations and voluntary actions
- Building stock is major cause of final energy and GHG emissions consumption
- Renovation of buildings represents 17% of primary energy savings potential in EU
- In Portugal 70% of buildings built before 1990, when first regulation regarding thermal comfort was published
  - In 2010, 35% of the buildings needed major retrofit and 3% presented a high level of degradation



Bridging the gap between embodied and operational energy

- Disconnection between direct and indirect emissions in existing literature
- To achieve climate targets we need to find a way to bridge these two → Bio-based materials are a possibility
- Carbon sequestration can offset direct impacts (in terms of GHG)
- There are existing bio-based retrofit solutions (e.g straw, hemp, cork), with similar thermal performance to conventional materials

Research questions

How can we improve the understanding of **renovation dynamics** at the urban scale to achieve climate targets?

Which **materials** are better?

And what is the potential of **bio-based** materials?

➡ To answer these questions a new tailored methodology is needed.

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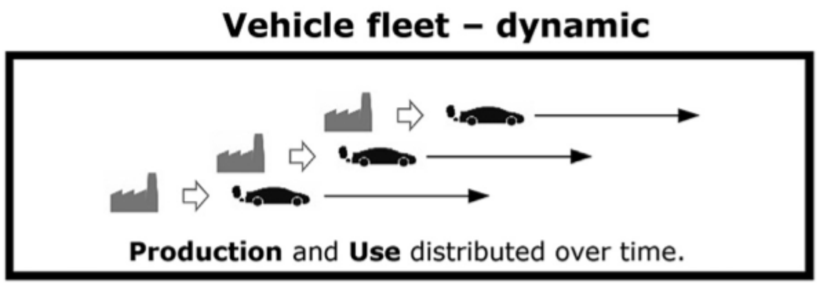
Method



Source: Garcia R. and Freire F. 2017. A review of fleet-based life-cycle approaches focusing on energy and environmental impacts of vehicles. Renew. Sustain. Energy Rev. 79 935–45.

Fleet-based LCA

- Alternative to product-centered approach
- Deals with effects distributed over time
- Integrates LCA and a fleet model to describe stocks and flows of a class of products
- Analysis of introducing alternative technologies
- Allows for capture of technological improvements over time and changes in background processes

Case study – Alvalade neighborhood

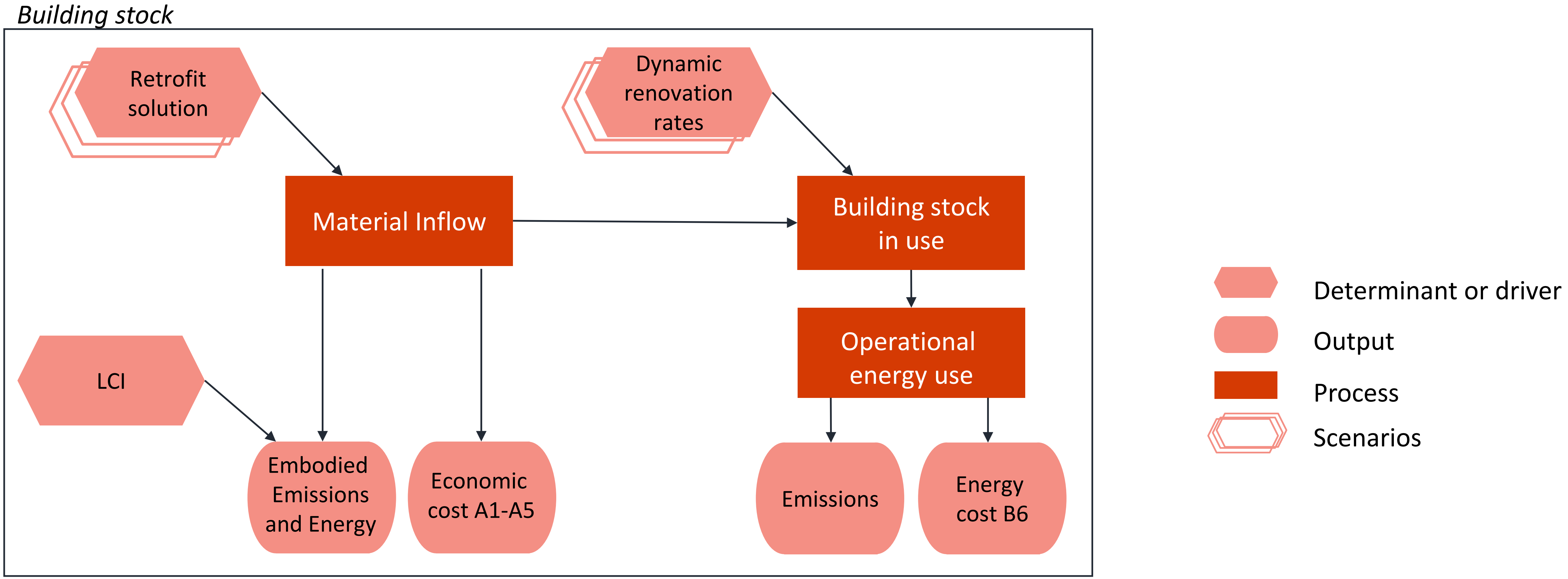
- Alvalade neighborhood was built between the 1940s and 1960s, promoted by an urban expansion plan of the Lisbon municipality.
- A specific type of construction called “Placa”, mixed masonry-reinforced concrete, is particularly prominent.
- In total 230 buildings were identified in the neighborhood to be a typical “Placa” building.

  → total of 124’577 m^2 opaque façade area

Included LC stages for analysis of environmental impacts and costs

	Product stage	Transport to building site	Installation into the building	Energy use for heating and cooling
LC stage	A1-A3	A4	A5	B6
Environmental Impact	one time			impact during 30 years
Cost	one time “economic” investment cost for renovation			energy cost during 30 years

embodied (A1-A3, A4, A5) · *operational* (B6)



Framework

Bottom-up building stock model

Declared unit: whole opaque façade area of all buildings under study

LCA: GWP, PE-NRe, ADP, EP, ODP, POCP

LC stages: Cradle to gate (A1-A5) and B6

Economic costs from cradle to gate (A1 – A5)

Energy costs of heating and cooling needs (B6) during 30 years

Scenario analysis

Technology scenarios

Retrofit with an external insulation composite system (ETICS) applied to a single wall, with:

I. No retrofit

Compared to:

II. Extruded Polysterene (EPS)

III. Insulation Cork Board (ICB)

U-value	EPS	ICB	No retrofit
[W/m²K]	0.38	0.42	2.41

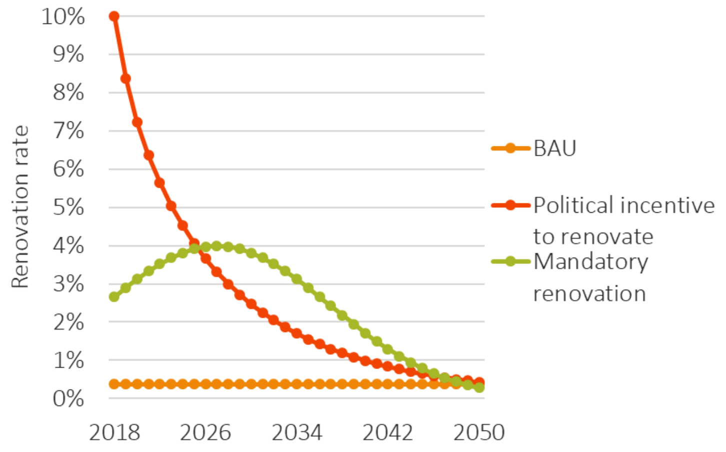
Dynamic renovation rates

Describes the next 30 years, with:

i. Business as usual (constant 0.4%)

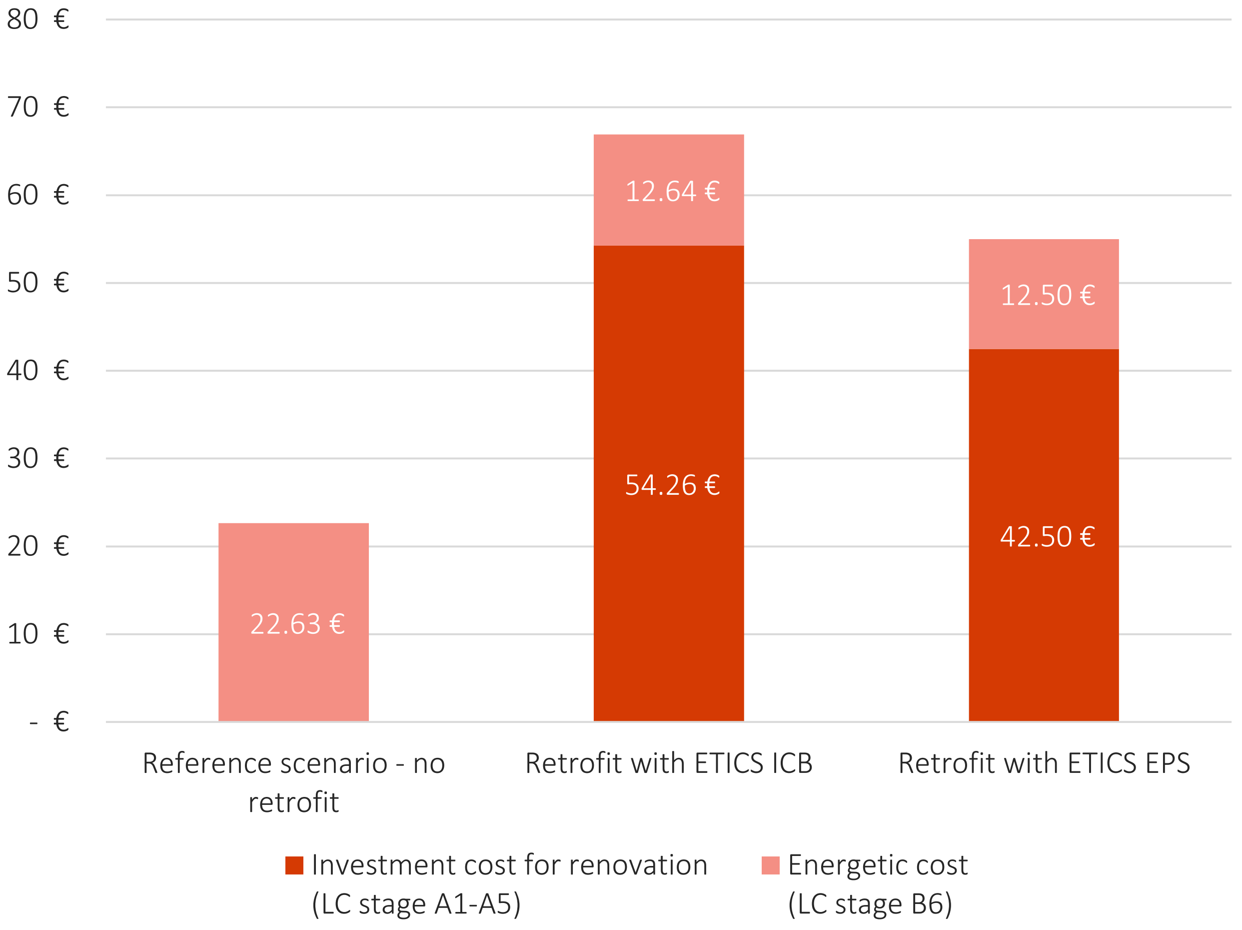
ii. Public incentive to promote renovation (Weibull probability density function)

iii. Legislation to make renovation mandatory (Normal distribution)



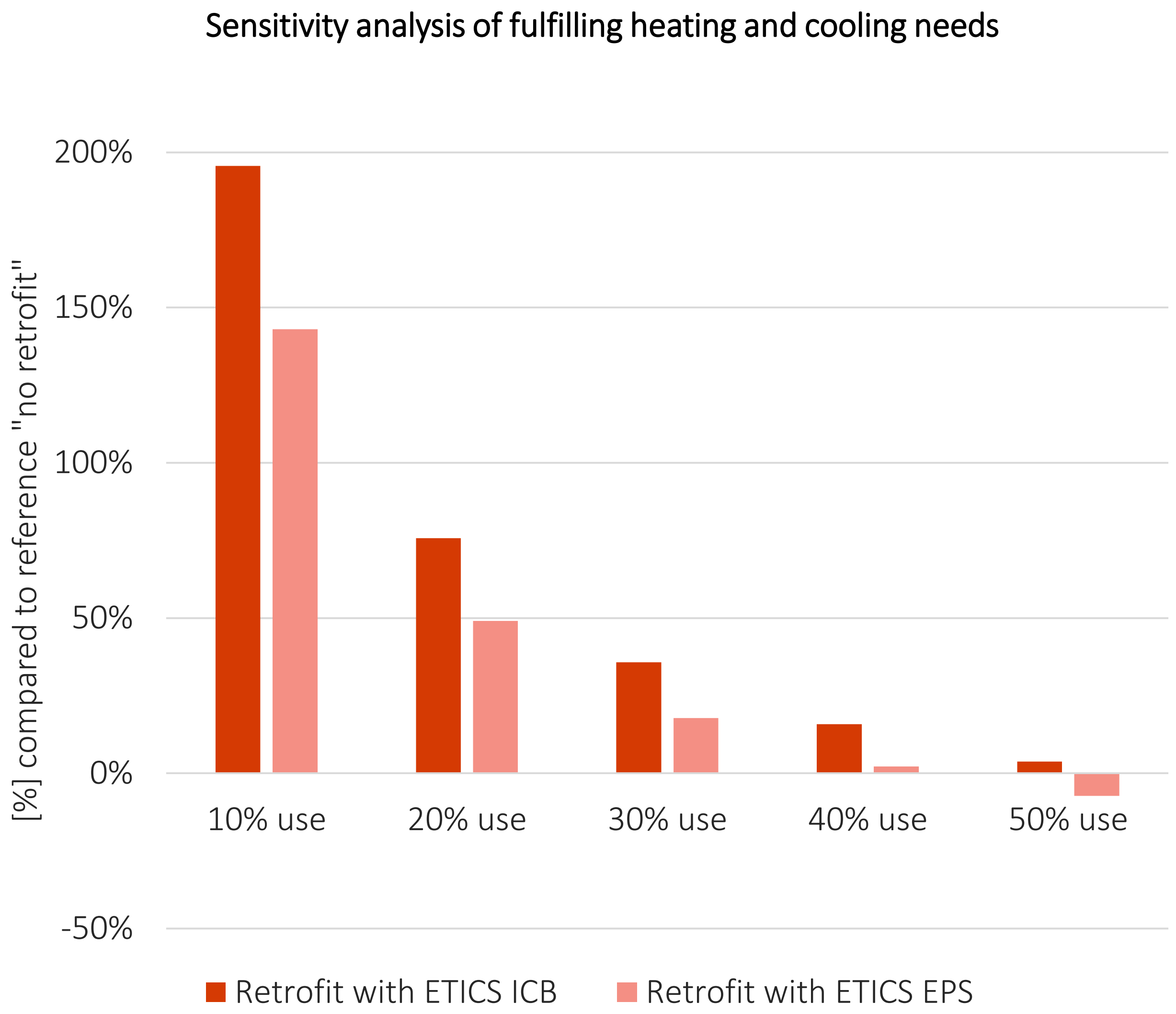
Results – Costs

Renovation investment cost and energetic cost for 1 m^2 of wall after 30 years of use



Costs

- Economic costs for LC stages A1-A5
  - EPS has cheaper acquisition cost than ICB (i.e. product manufacturing, transport to site, installation)
- Energy costs for LC stage B6
  - For default value of fulfilling 10% energy needs
  - Discount rate 3%
  - Based on current cost of 1 kWh of electricity (excl. VAT)



Note: Based on total economic cost for LC stages A1-A5 and energetic cost for B6

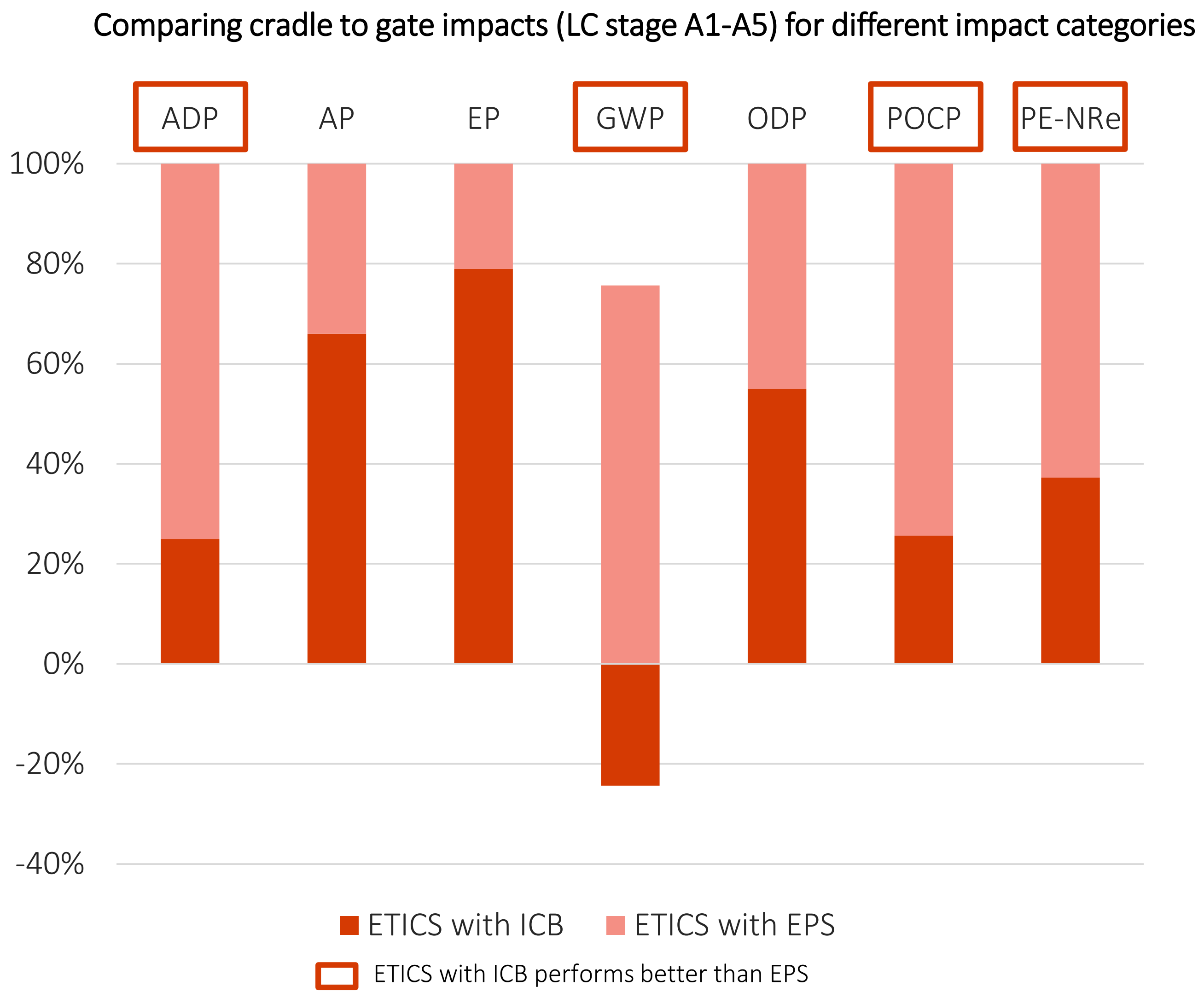
Sensitivity analysis of heating and cooling needs

- In many cases more than 10% of heating and cooling needs need to be fulfilled
  – e.g. home office, private practice, elderly and families with young children use their house more
- With more realistic needs (40-50%) the two ETICS solutions become economically competitive with the alternative of not renovating

Results – Environmental Impacts

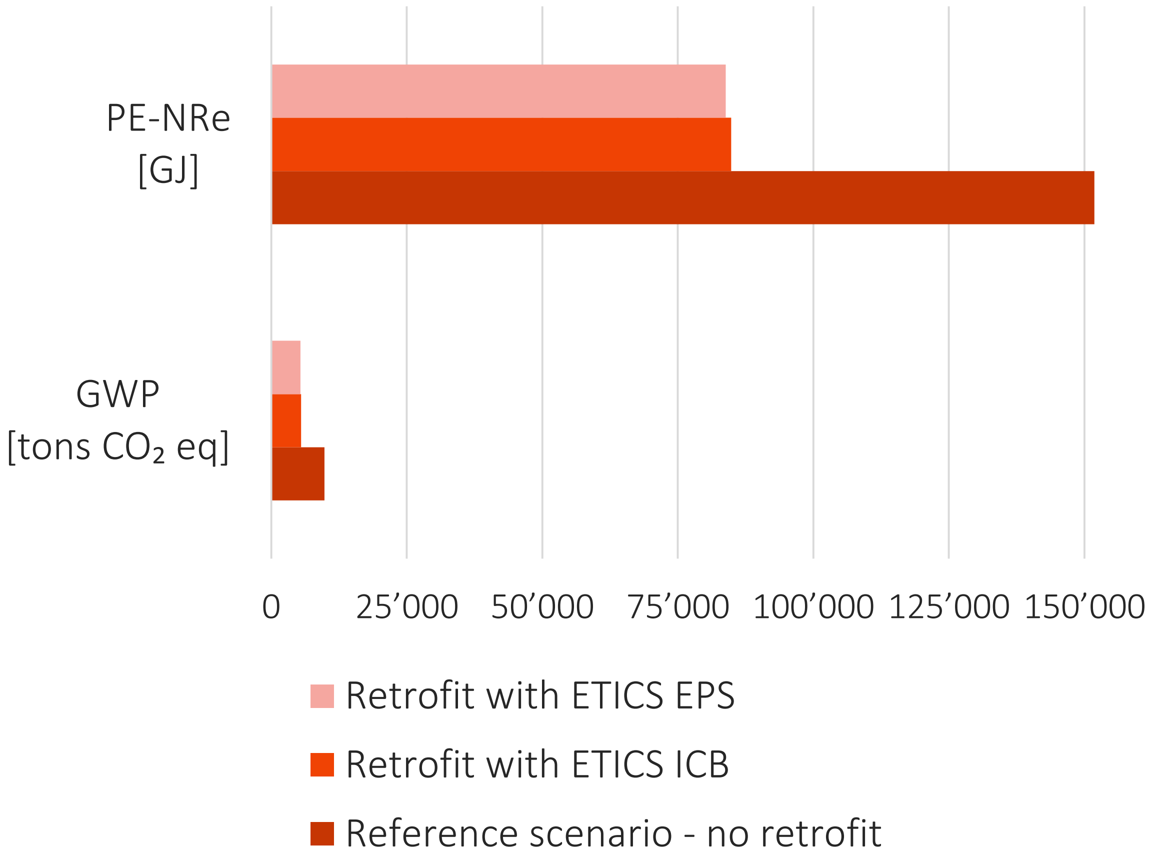
Renovation all at once

Impacts from cradle to gate



- Hypothetical case that everything is renovated at one moment in time
- Both ETICS are 0.08 m thick
- Alternative “no renovation” has 0 impacts
- Negative GWP for ICB thanks to biogenic carbon capture

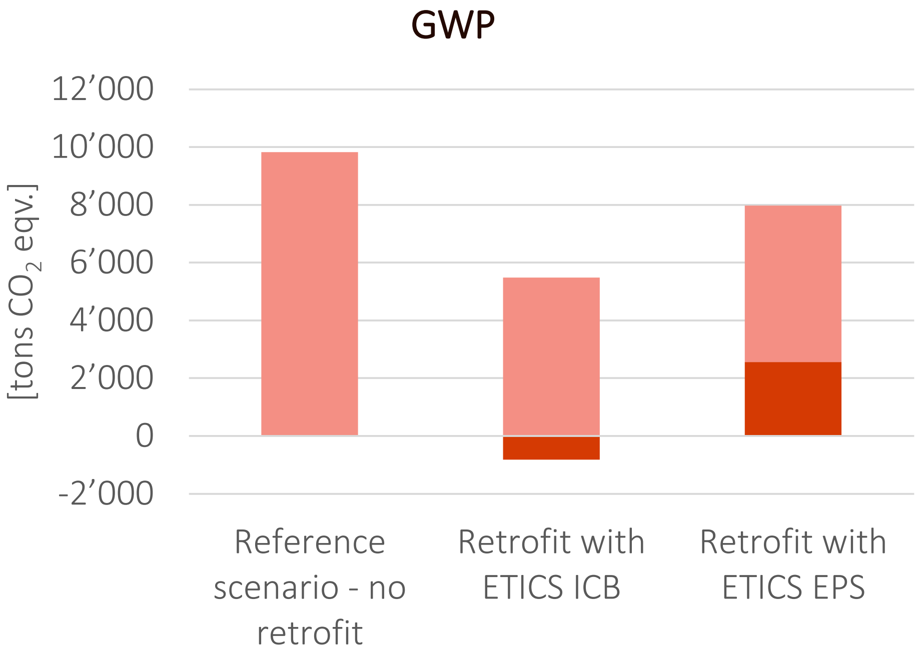
Impacts arising from heating and cooling during 30 years (LC stage B6)

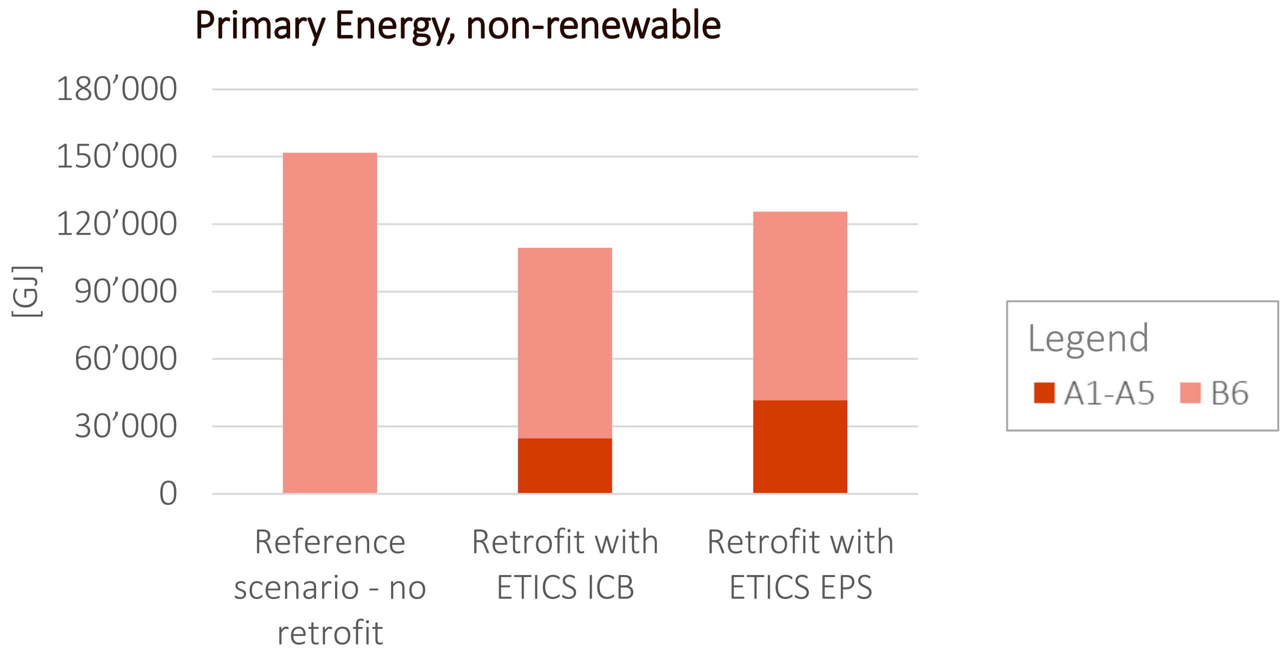


Heating and cooling during 30 years

- For operational energy use (B6) and 10% consumption of energy needed to fulfill the heating and cooling needs
  - “No retrofit” has highest impacts
  - ETICS with ICB and EPS show similar results

LC stages A1-A5 + B6



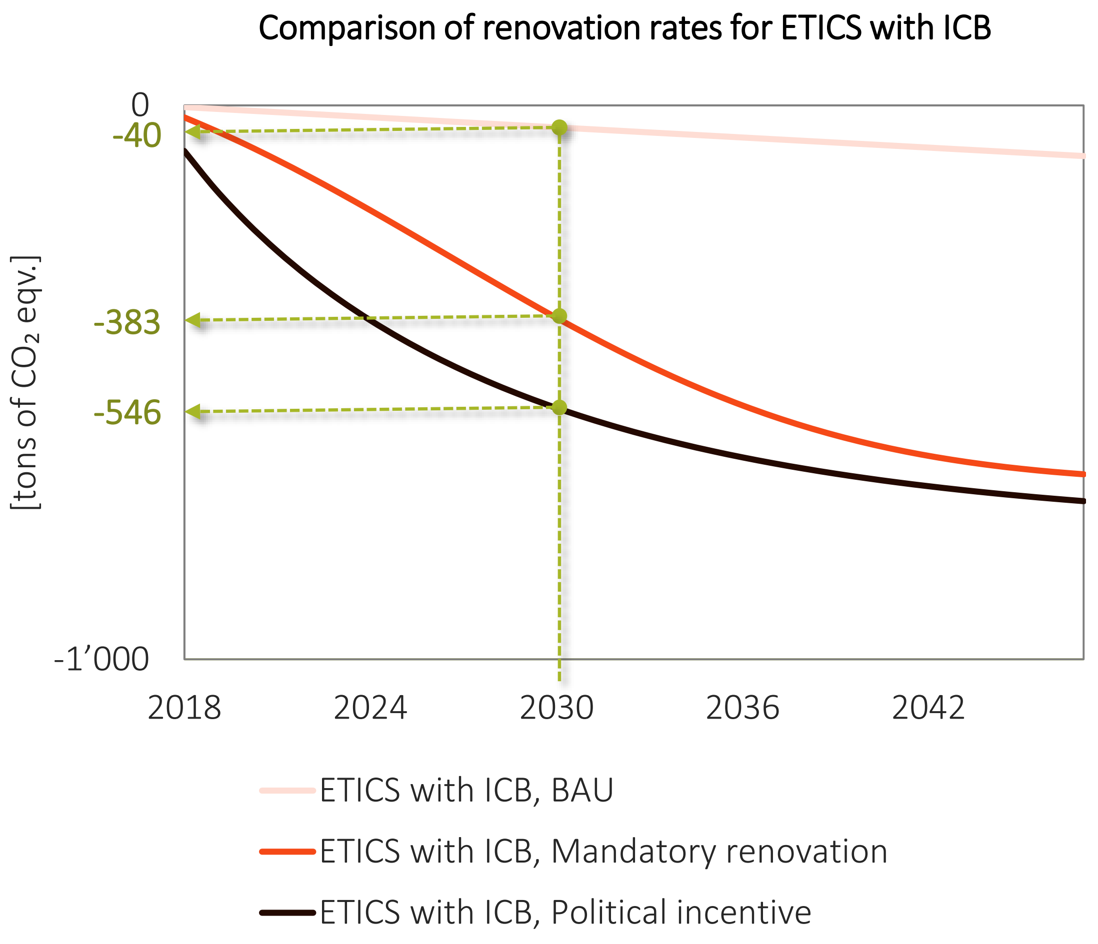


	Reference	Retrofit ICB	Retrofit EPS
Saving potential	0	53%	19%

	Reference	Retrofit ICB	Retrofit EPS
Saving potential	0	28%	17%

Results – Environmental Impacts

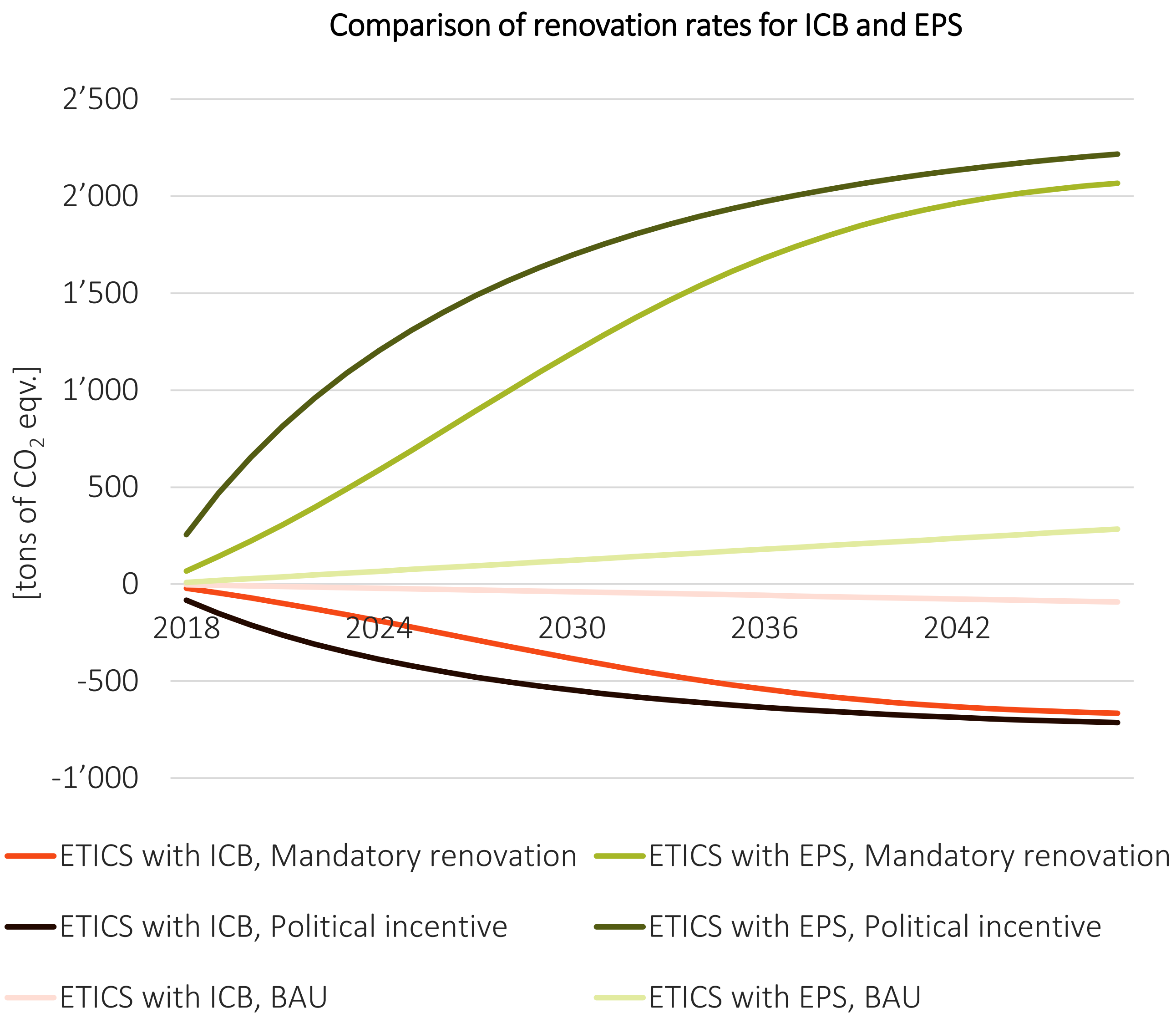
Dynamic renovation rates



Note: For cradle to gate (A1-A5)

Dynamic cumulative GWP

- For declared unit, ETICS with ICB
- Carbon storage over time thanks to bio-based material
- Compares policy scenarios for cradle to gate impacts
- Renovation is direct driver of emissions released over time
- First critical step towards Paris agreement is 2030



Dynamic cumulative GWP

– cont.

- Only bio-based material offers advantage of carbon sequestration
- ETICS with EPS has (positive) and comparable higher cradle to gate impacts

Conclusions

- Important to consider temporal profiles of emissions so that LCA results are a function of time and translate climate goals into action-making
  - Possible thanks to dynamic renovation rates
  - Political incentives are more promising to achieve improvements in the short to mid-term
- Bio-based material offers benefit of carbon sequestration
  - Thermal and cost performance are slightly worse than conventional retrofit material e.g. EPS, but small differences
  - Full potential regarding time line of Paris agreement was shown with this study
- Clear reduction of environmental impacts thanks to thermal retrofit
- Renovation, when considering a realistic consumption of energy for heating and cooling, is cost-competitive with the reference case

Limitations

- Simplified fleet-based LCA:
  - Needs a more refined building stock model that also allows to model EoL and replacement of buildings and elements. Including these temporal dynamics makes the fleet-based LCA particularly interesting but was not done here.
  - No changes in background process and no technological improvements over time were considered.
- Uncertainty of dynamic renovation rates
- Uncertainty of heating and cooling needs
  - Sensitivity analysis was performed
  - But, dynamics of operational energy needs should be included to account also for temporal variation of electricity production
- Monetization of environmental impacts should be discussed
- We need to dissect CO_2 eqv. for each sector, critical time steps and country

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Thank you.

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