



Keynote lecture

Environmental labels in the building sector

Methodologies, benchmarks and indicators for the decarbonization of buildings

Prof. Francesco Asdrubali, Roma Tre University, Italy
Thursday, 29th June 2023



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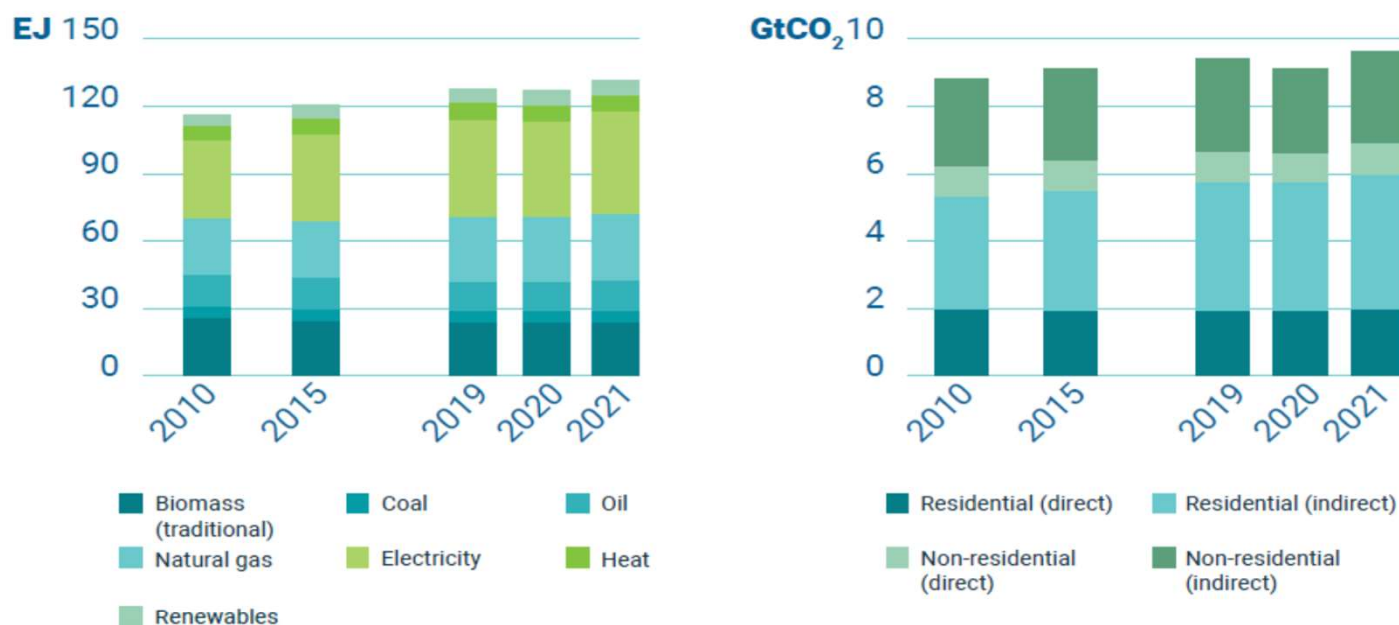
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Introduction

The impact of the building sector

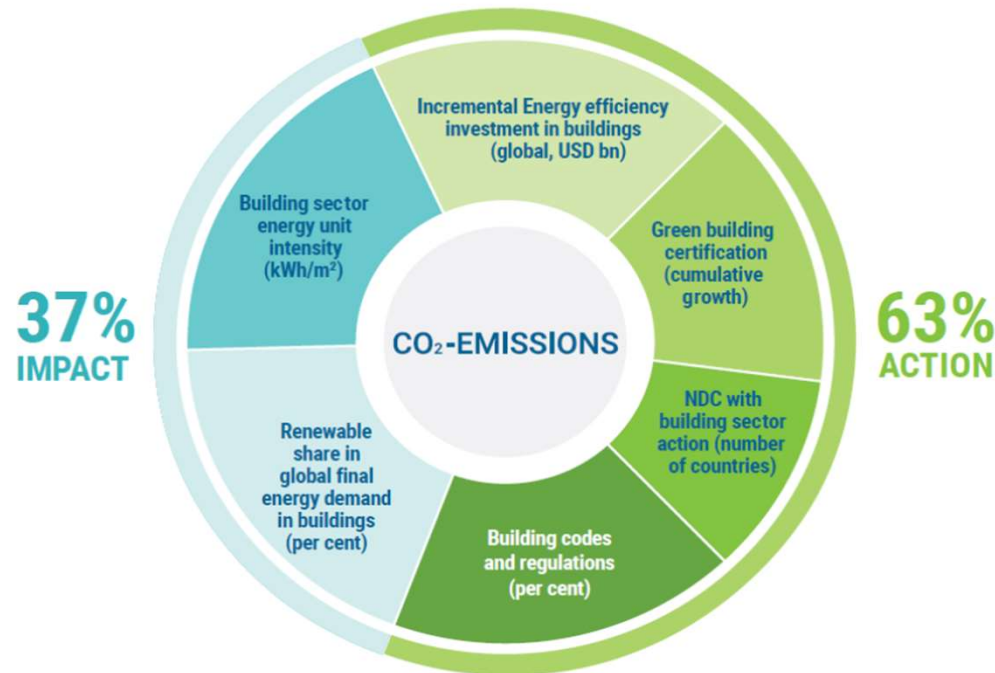
Figure 3. Energy consumption in buildings by fuel, 2010-2021 (left) and CO₂ emissions in buildings 2010-2021 (right)



Source: International Energy Agency (2022). Tracking Clean Energy Progress. Paris.

Global Buildings Climate Tracker index

Figure 8. Composition of the Global Buildings Climate Tracker showing its elements and their weight



Source: Adapted by the Buildings Performance Institute Europe (BPIE) 2022.

The decarbonization of the building stock is “not on track” to reach the goals of the Paris Agreement. In 2021, the buildings decarbonization index is only at 8.1 points out of 100 while it should be at over 17.1 points out of 100

Global building certification programmes

REGION	COUNTRY	RATING
Europe	Austria	DGNB Austria
	Croatia	DGNB Croatia
	Denmark	DGNB Denmark
	France	HQE
	Germany	DGNB
	Ireland	Home Performance Index
	Italy	GBC Home, Historic Building, Quartieri, Condomini
	Latvia	BREEAM-LV
	Netherlands	BREEAM-NL, DGBC Woonmerk
	Norway	BREEAM-NOR
	Russia	OMIR
	Spain	DGNB Spain, VERDE
	Sweden	BREEAM-SE, Miljöbyggnad, Miljöbyggnad iDrift, CEEQUAL, NollCO ₂
	Switzerland	Minergie, SNBS, DGNB Switzerland
	United Kingdom	BREEAM, EDGE
Oceania	Australia	Green Star
	New Zealand	Homestar, NABERSNZ, Carbon zero

Source: Adapted by authors from WorldGBC 2022.

Table 4. Global building certification programmes²¹

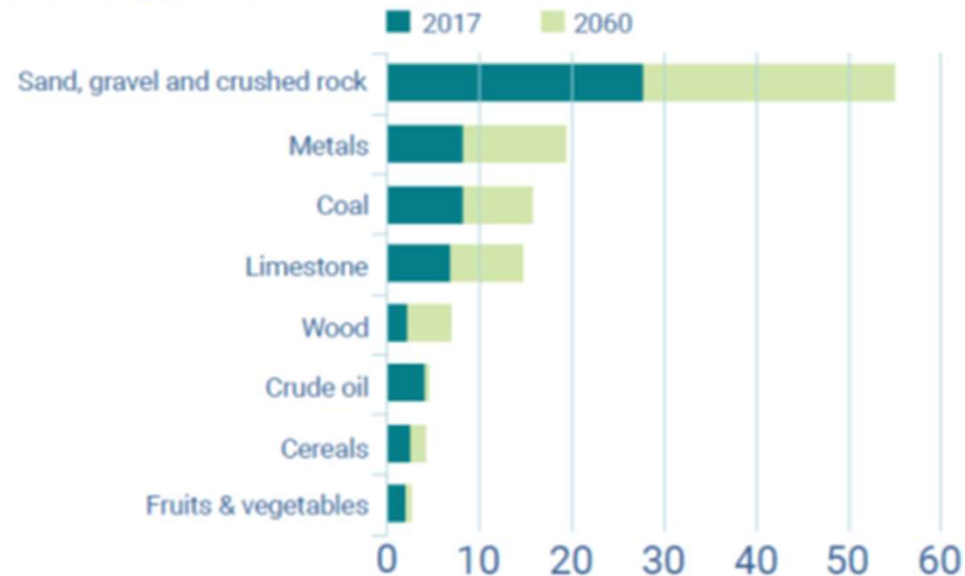
REGION	COUNTRY	RATING
Africa	Egypt	Green Pyramid Rating System
	Kenya	Green Mark
	South Africa	Green Star SA, Net Zero/ Net Positive
	Tunisia	EcoBat
	Uganda	Green Star Uganda
Americas	Brazil	GBC Brasil CASA, GBC Brasil Condomini, GBC Zero Energy
	Colombia	Casa (Colombia), ICONTEC
	Guatemala	Casa Guatemala
	United States of America	LEED, ILFI Zero Energy and Zero Carbon, Parksmart, PEER, RELi, SITES, TRUE, WELL
Asia	China	Assessment Standard for Green Building of China
	Hong Kong	BEAM Plus
	India	IGBC, GRIHA
	Indonesia	Greenship
	Japan	CASBEE
	Lebanon	ARZ rating system
	Malaysia	Green Building Index
	Pakistan	Pakistan Green Building Guideline (PGBG) BD+C
	Philippines	BERDE, Advancing Net Zero (ANZ/PH), PHILGBC Health and Well-being Tool for Buildings
	Saudi Arabia	saaf (Saudi Green Building Forum)
	Singapore	Green Mark, Singapore Green Building Product/Services Certification
	South Korea	Korea Green Building Certification
	Sri Lanka	GreenSL
	Turkey	B.E.S.T – Residential and Commercial Buildings Certificate
	United Arab Emirates	PEARL (Abu Dhabi), TARSHEED
	Vietnam	LOTUS

Resource consumption and construction materials

Figure 25. Construction materials are set to dominate resource consumption in fast-growing developing economies, with building material-related emissions projected to increase by 3.5 to 4.6 Gt CO₂eq/year by 2060

Construction materials dominate resource consumption

Consumption in gigatonnes



Source: OECD 2019. Adapted from 'Global Material Resources Outlook to 2060: Economic Drivers and Environmental Consequences' (OECD 2019).

Buildings decarbonization and life-cycle thinking

Figure 26. Whole-life and systems-thinking approach to enable multiple stakeholders at each decision point



Source: Adapted from Programme for Energy Efficiency in Buildings 2022.

Green building rating tools



A great variety of tools



Diffusion of green building rating tools

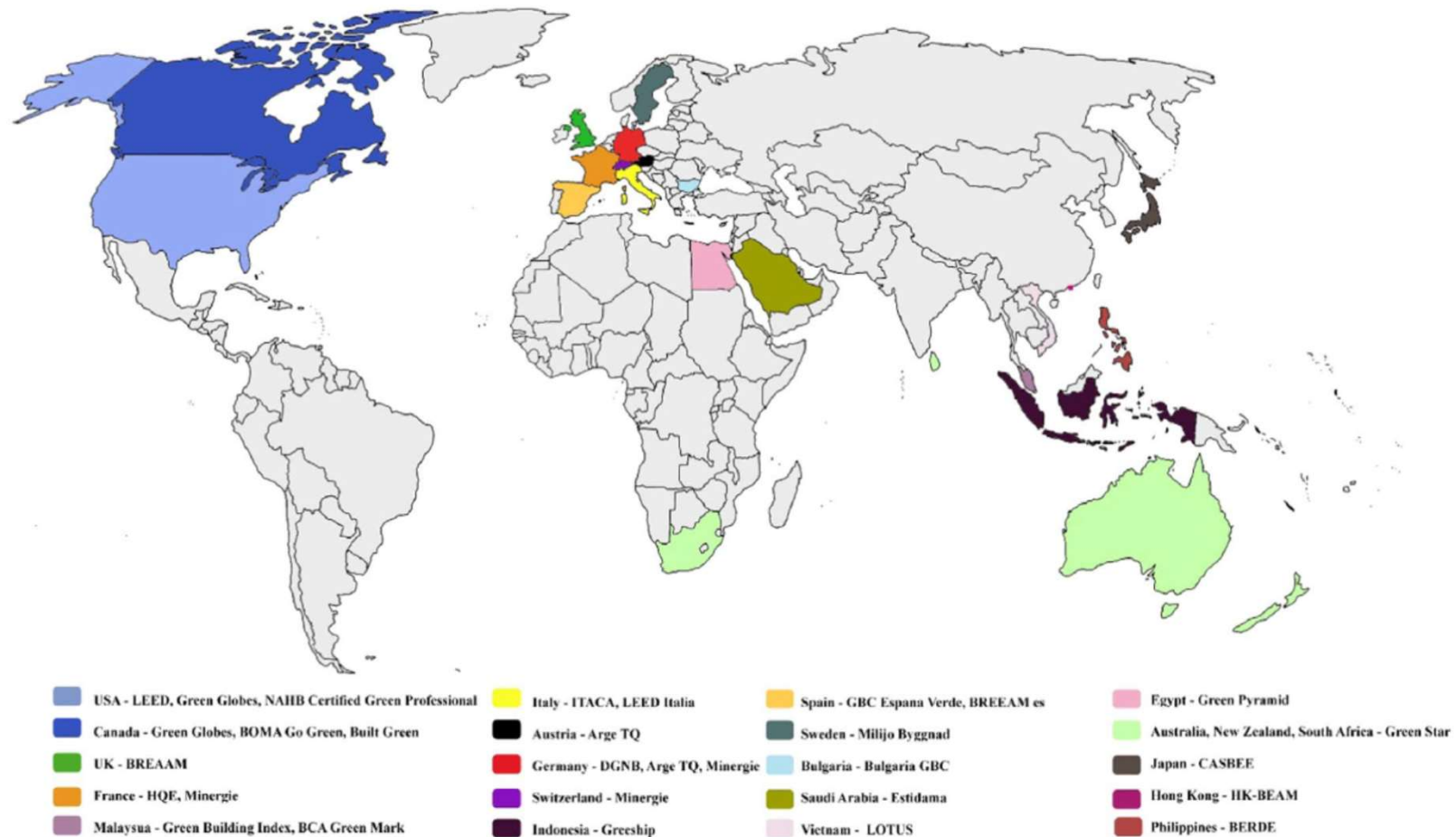
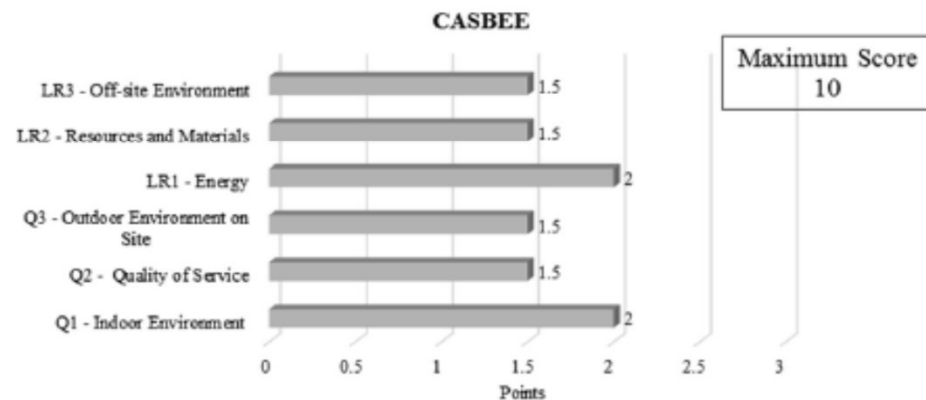
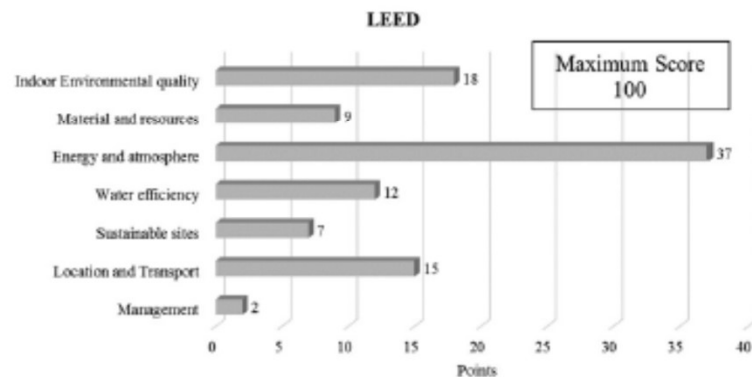
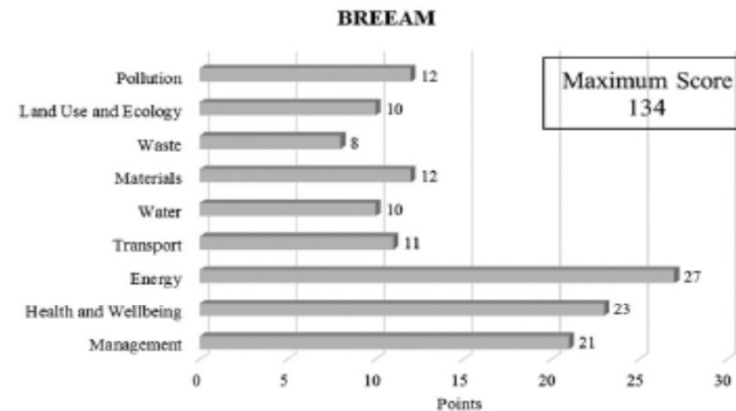
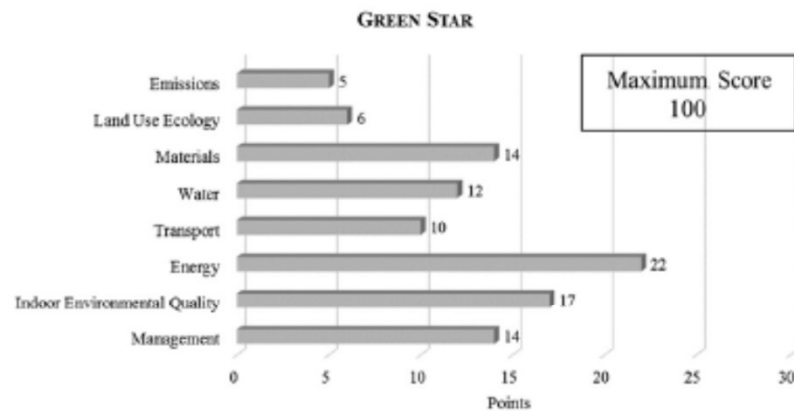


Fig. 1. A global map of Green Building labelling systems.

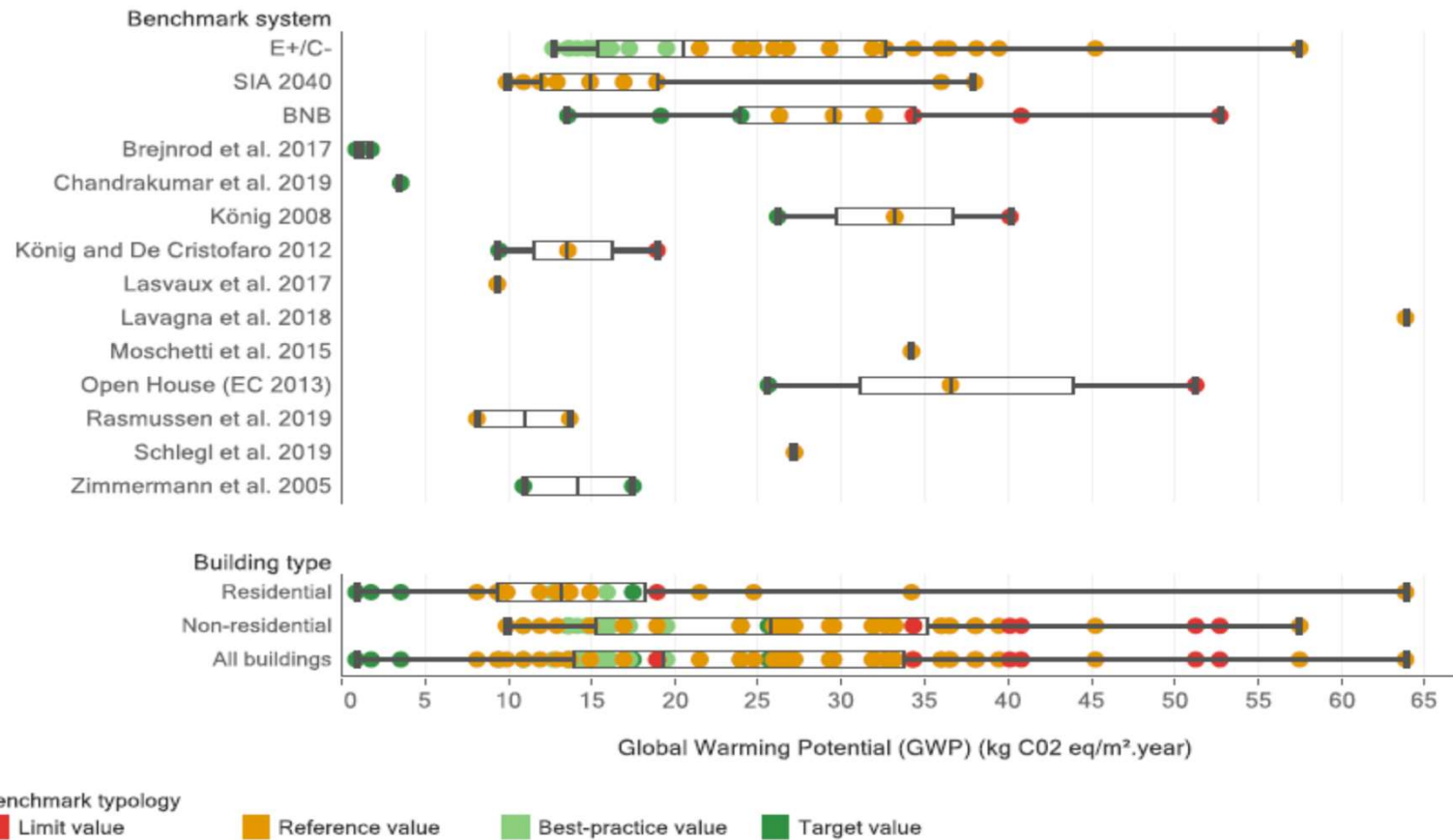
Green building rating tools areas and points



B. Mattoni, C. Guattari, L. Evangelisti, F. Bisegna, P. Gori, F. Asdrubali: "Critical Review and Methodological Approach to Evaluate the Differences Among International Green Building Rating Tools". Renewable & Sustainable Energy Reviews (2018) 82(1), 950-960.

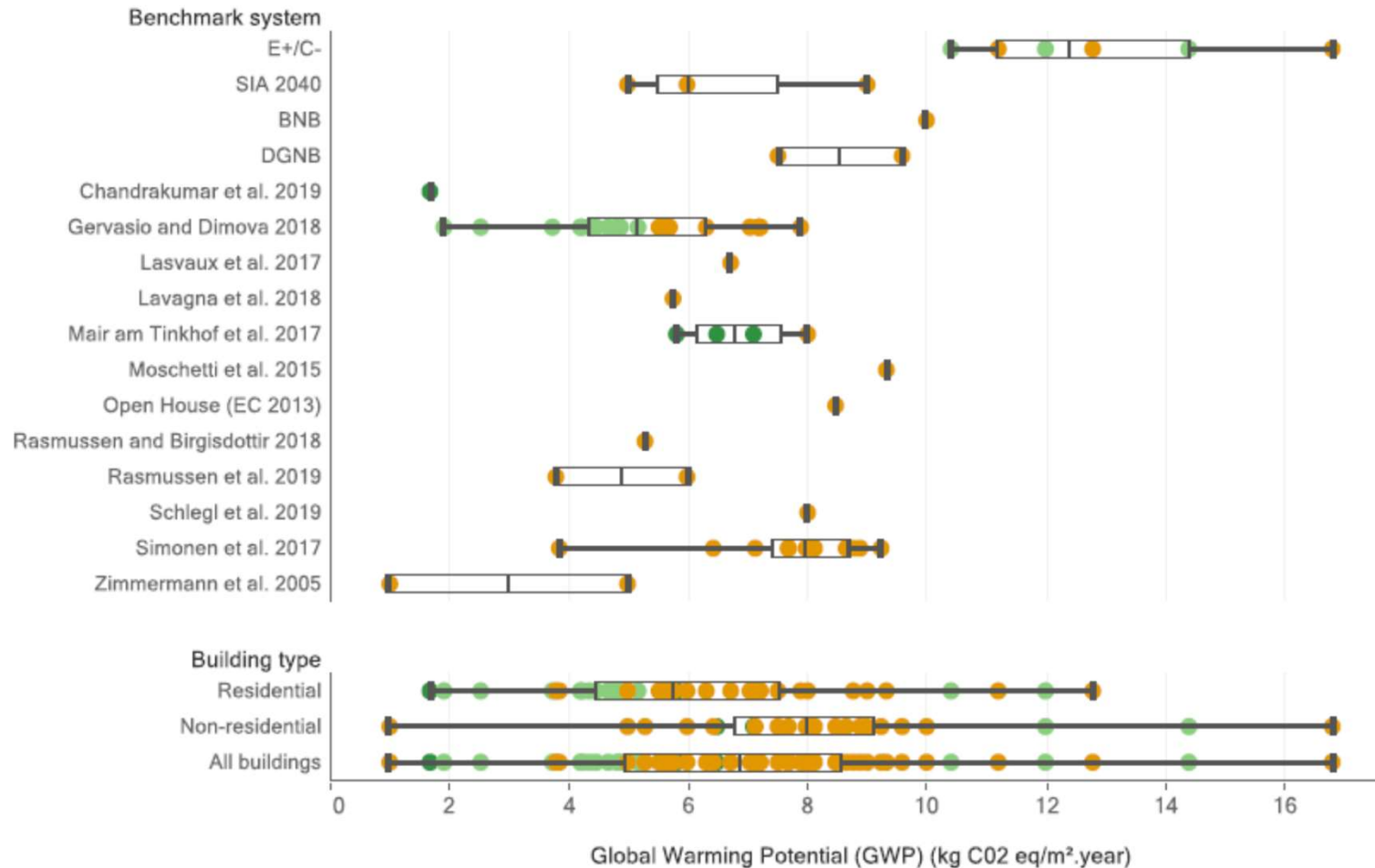
Environmental benchmarks for buildings

Full life cycle impacts



- D. Trigaux, K. Allacker, W. Debacker. Environmental benchmarks for buildings: a critical literature review, The International Journal of Life Cycle Assessment volume 26, pages1–21 (2021)

Embodied impacts



- D. Trigaux, K. Allacker, W. Debacker. Environmental benchmarks for buildings: a critical literature review, The International Journal of Life Cycle Assessment volume 26, pages1–21 (2021)

- Various benchmarks based on LCA have been developed as part of regulations, labelling systems, sustainability rating tools and research studies.
- The review of 23 existing benchmarks show a very high variability due to differences in benchmark approach, scope, system boundaries, applications.
- For global warming, the statistical values for the full life cycle impacts (embodied and operational) range from about 15 up to 35 kg CO₂ eq/m² year
- D. Trigaux, K. Allacker, W. Debacker. Environmental benchmarks for buildings: a critical literature review, The International Journal of Life Cycle Assessment volume 26, pages1–21 (2021)

LCA in the building sector

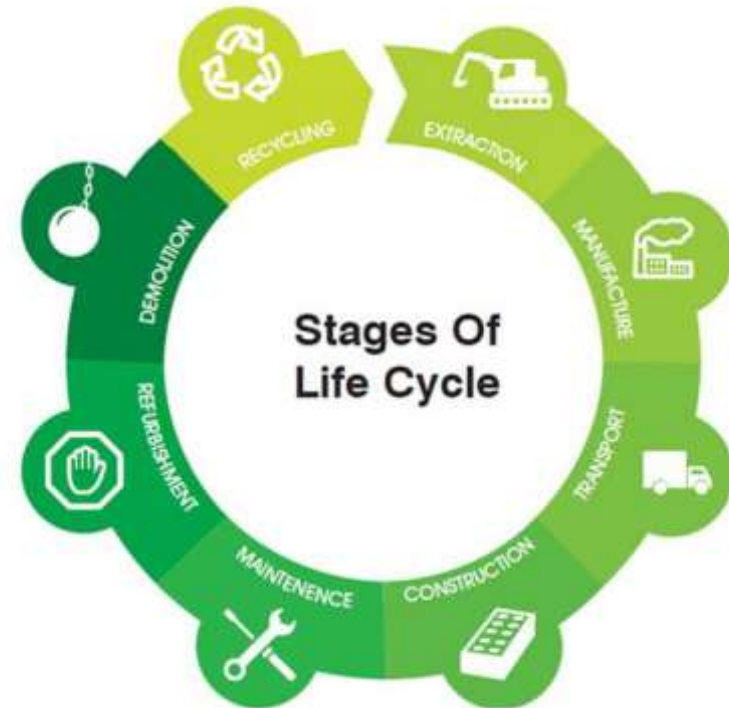
Life cycle approach in the building sector



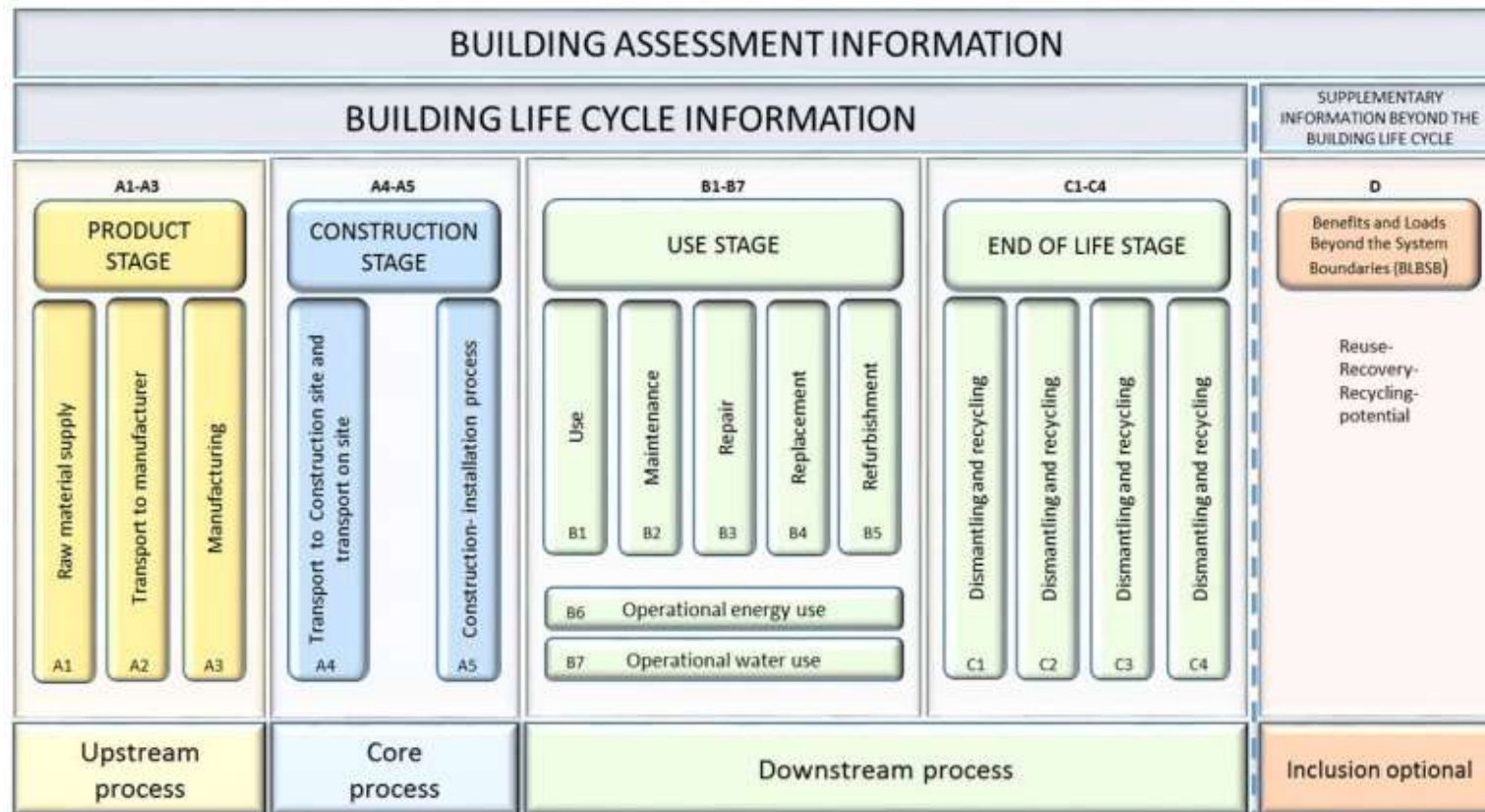
Potential Burden Shifting

The shift of burdens is the transfer of the environmental impacts caused by the use of operational energy to the materials and energy systems embodied in the building

In NZEB buildings there is a transfer of the environmental burdens from the use stage to the construction, production and end-of life ones.



In order to consider the burden shifting an LCA approach is mandatory.



The Product Category Rules (PCR) indicate the LCA stages to be included in the analysis.

Output of LCA studies

- - **Cumulative Energy Demand (CED) method**: calculates **the amount of energy (MJ-eq)** used during the entire life cycle of the building.
- - **IPCC (International Panel on Climate Change) method**: classifies the different emissions according to their contribution to greenhouse effect; the indicator is Global Warming Potential (GWP), **the unit is kg CO₂-eq**.
- - **Eco-Indicator 99 method**: allows the evaluation of the emissions and the use of resources according to **11 impact categories** (carcinogenic substances, respiratory diseases, climate changes, ozone depletion, radiation that causes ionisation, acidification/eutrophication, ecotoxicity, land use, mineral resource depletion and fossil fuels), grouped into three damage categories:
 1. **damage to human health**, expressed as the number of years of human life lost or in suffering from diseases;
 2. **damage to the quality of ecosystems**, expressed as the loss of living species in a certain area over a certain period;
 3. **damage to resources**, expressed as the surplus of energy necessary for the further extraction of minerals and fossil fuels.

Embodied Energy: definition

- The initial Embodied Energy includes all phases from the extraction of the raw material until it is ready to be delivered from the manufacturer.
- The recurring Embodied Energy is the energy used in maintaining and repairing the building over its effective life (stages B2-B5).
- The total Embodied Energy considered in this study includes the energy uses in producing, transporting, installing and finishing the building materials and components during initial erection as well as renovation of the building.

Embodied Carbon: definition

- The initial Embodied Carbon includes the emissions produced during all phases from the extraction of the raw material until it is ready to be delivered from the manufacturer.
- The recurring Embodied Carbon is the CO₂ emissions spread in maintaining and repairing of the building over its effective life (stages B2-B5).
- The total Embodied Carbon considered in this study includes the sum of the emissions spread in producing, transporting, installing and finishing the building materials and components during initial erection as well as renovation of the building.

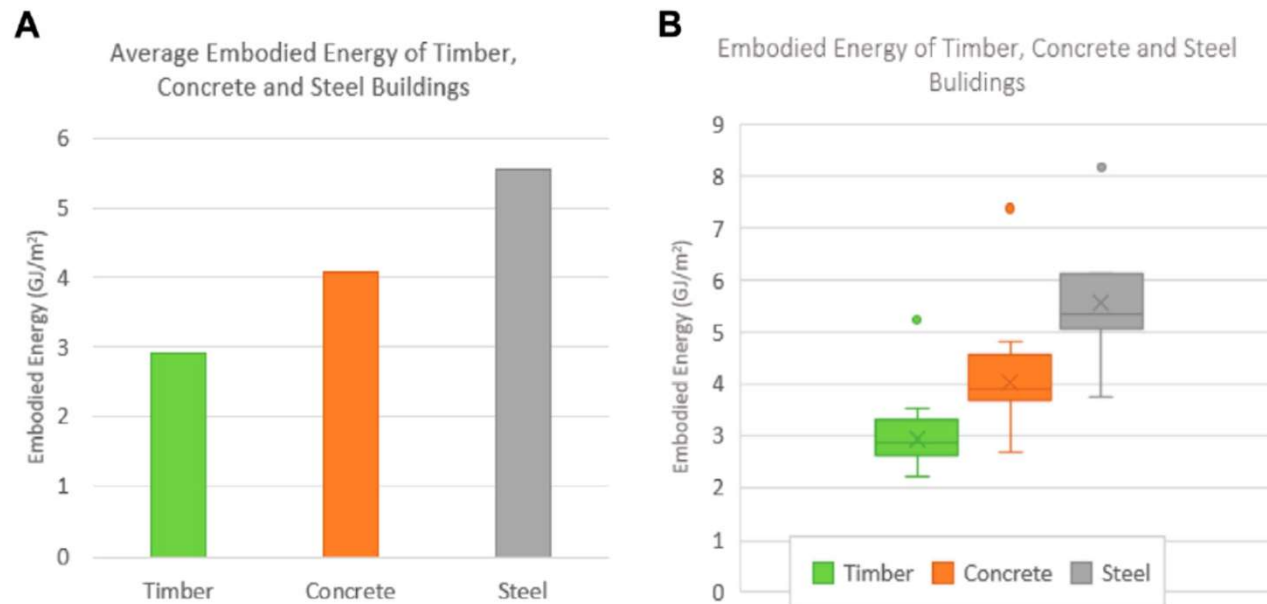


FIGURE 3
(A) Average embodied energy (B) Embodied energy.

Life cycle energy analysis of residential wooden buildings versus concrete and steel buildings: A review, Daniela Schenk and Ali Amiri, Front. Built Environ., Volume 8 - 2022
<https://doi.org/10.3389/fbuil.2022.975071>

In order to evaluate the environmental effectiveness of the NZEB retrofit of existing buildings two indicators are considered of interest:

The energy payback time (EPBT) is the ratio between the difference of initial Embodied Energy after and before the retrofit and the annual saved energy due to the retrofitting.

$$EPBT = \frac{E_i}{E_0}$$

The carbon payback time (CPBT) is the ratio between the difference of initial Embodied Carbon after and before the retrofit and the annual carbon reduction due to the retrofitting.

$$CPBT = \frac{M_i}{M_0}$$

EU Project “BRITA in PuBs” Bringing Retrofit Innovation to Application in Public Buildings

- The project permitted to evaluate the energy and environmental performance of a set of retrofit actions implemented in public buildings (see figure aside).
- Synthetic indexes, as energy payback times, were determined.



Stuttgart Filderhof



Hol Church



Plymouth City College



Vilnius University



Brno the "Brewery"



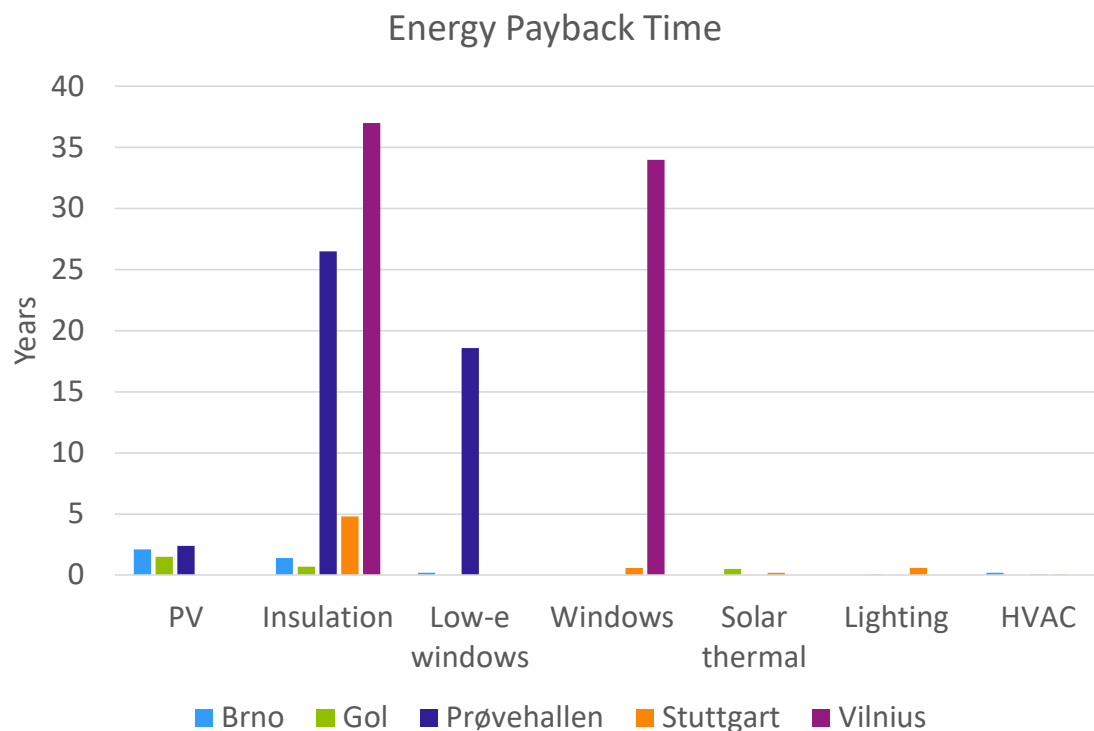
Proevhallen Cultural centre



Borgen Community Centre

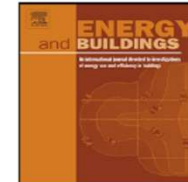
BRITA in PuBs project

- Sensibly higher payback times were found for the interventions regarding the insulation of the envelope and the substitution of windows.
- The payback of the PV is the lowest in all locations
- The paybacks are shorter than the useful life of the retrofit interventions.



Fulvio Ardente, Marco Beccali, Maurizio Cellura, Marina Mistretta, Energy and environmental benefits in public buildings as a result of retrofit actions. 2011. Renewable and Sustainable Energy Reviews.

LCA of conventional buildings



Life cycle analysis in the construction sector: Guiding the optimization of conventional Italian buildings



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^a University of Perugia, Industrial Engineering Department, Via G. Duranti 67, 06125 Perugia, Italy

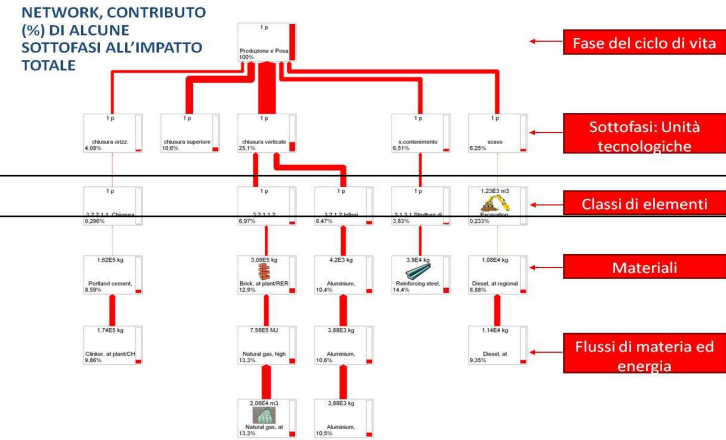
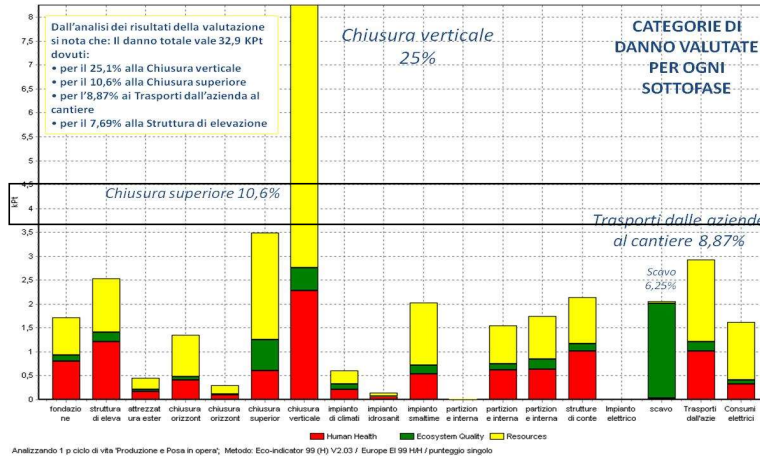
^b Brookhaven National Laboratory and Columbia University, New York, USA

Case study: LCA of three Italian conventional buildings

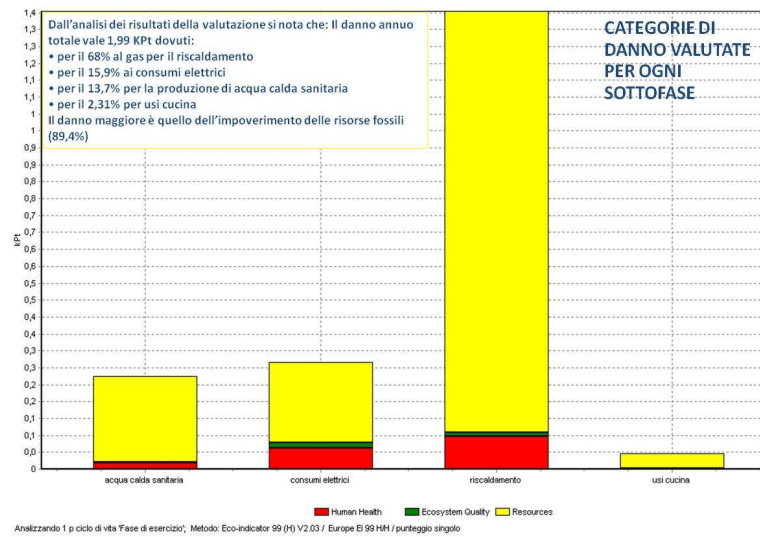


LCA RESULTS

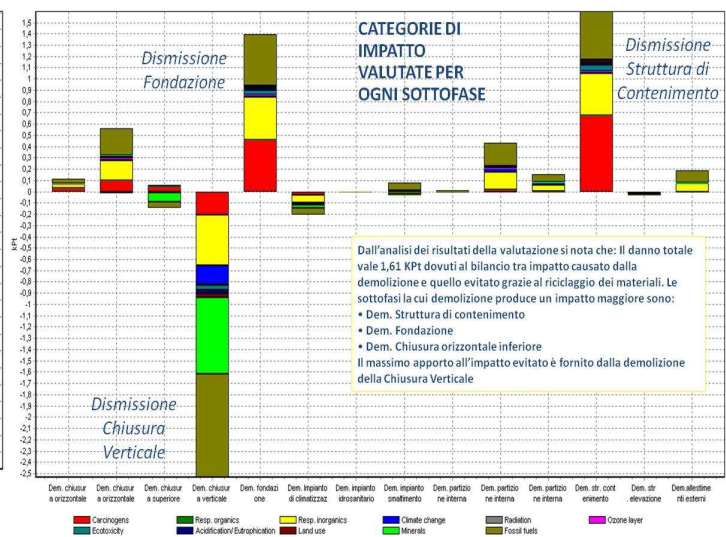
Construction



Operation



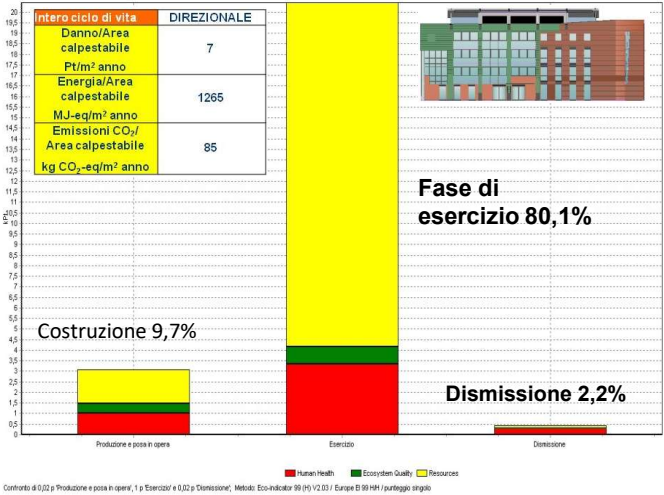
End of life



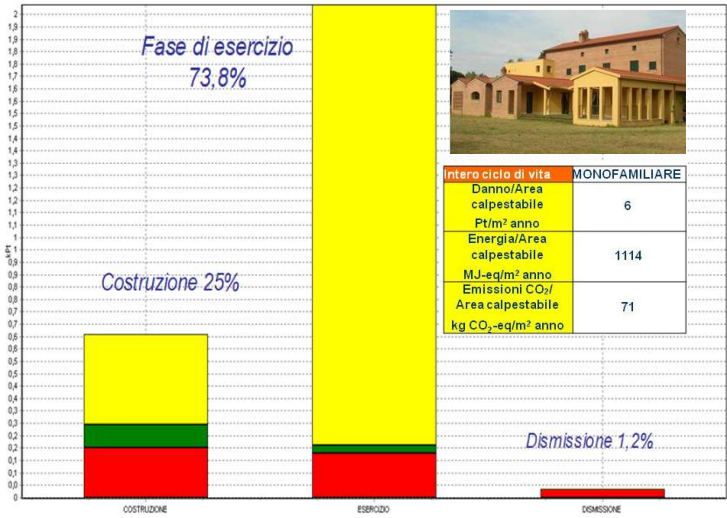
LCA RESULTS

Intero ciclo di vita Ecoinvent 99H/H	
EDIFICIO	
MONOFAMILIARE	Pt/anno 2695
PLURIFAMILIARE	7778
DIREZIONALE	22992

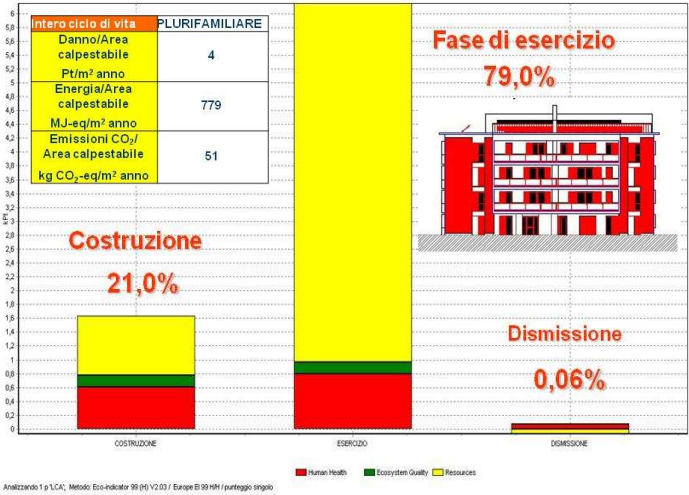
Office building



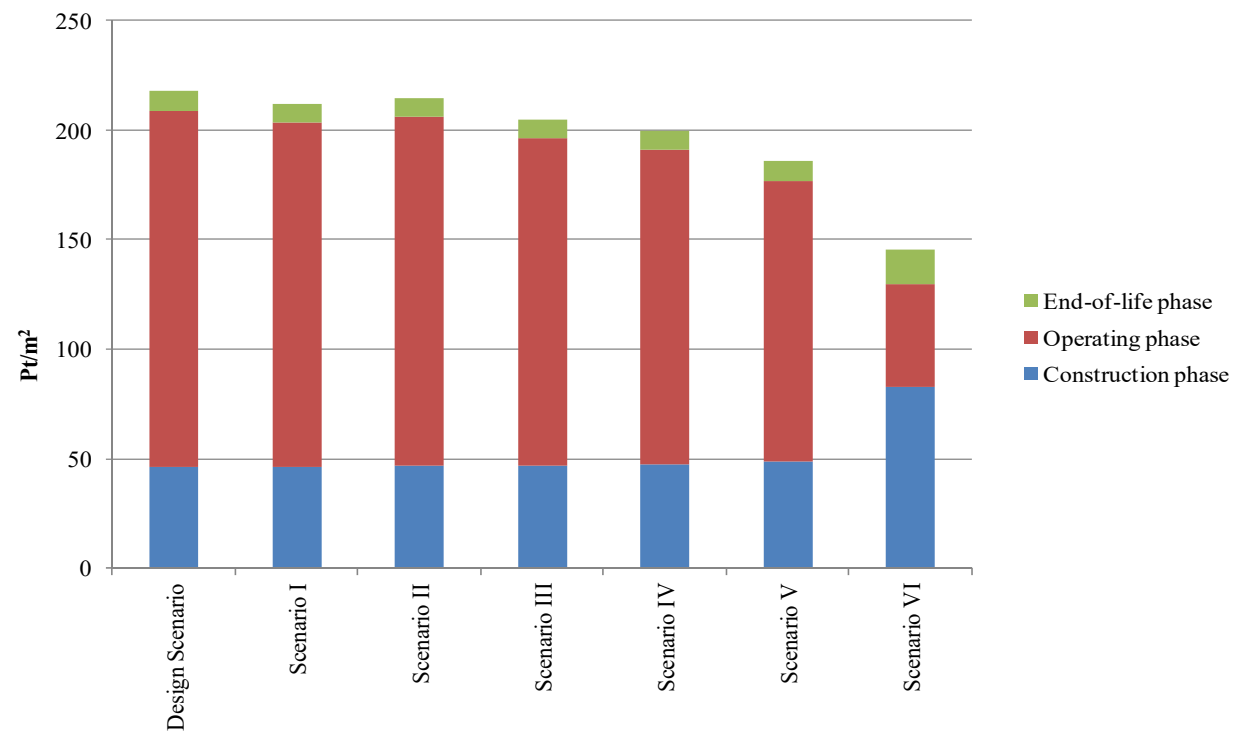
Detached house



Multi storey building



Optimization and retrofit: LCA approach



LCA of a NZEB building



Energy and environmental payback times for an NZEB retrofit

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^b Politecnico di Torino, Department of Energy, Corso Duca degli Abruzzi 24, 10129, Turin, IT, Italy

^c Niccolò Cusano University, Department of Engineering, Via don Carlo Gnocchi 3, 00166, Rome, IT, Italy



**Public school in Turin
(northern Italy)**



Methodology: LCA modelling

- The analysis follows the standards UNI EN ISO 14040 and UNI EN ISO 14044
- Ecoinvent database, included in SimaPro software, is employed
- Retrofit interventions lifespan is supposed to be equal to 50 years (as suggested by PCR)
- Transportations distances are all considered equal to 60 km
- End-of-life stage is not included
- Different maintenance frequencies were supposed:
 - Load bearing structures - 100 years
 - Windows - 35 years
 - Wall lining - 25 years
 - Wall coverings - 10 years
 - Services - 20 years

Methodology: Energy modelling

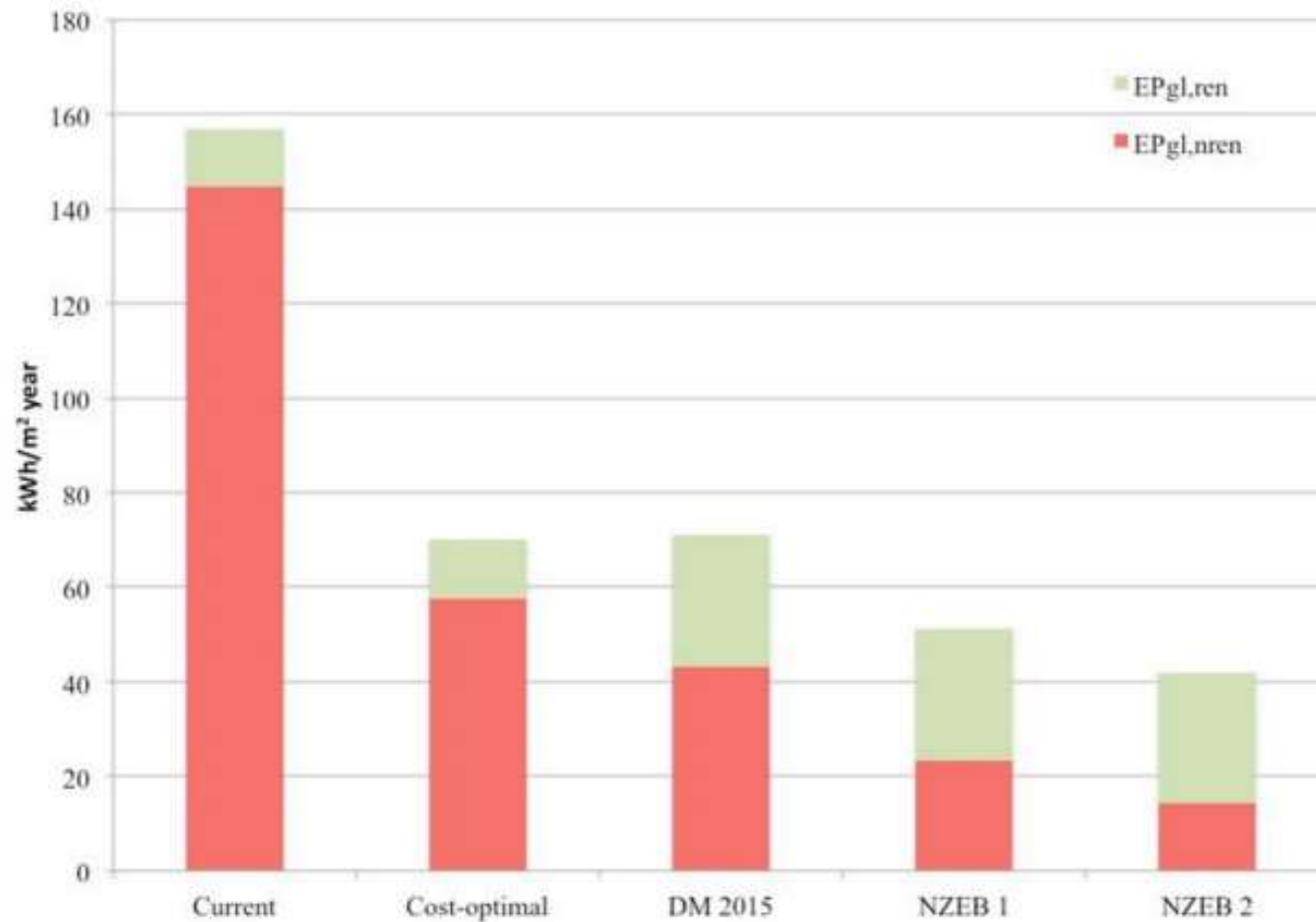
- The building is modelled with an energy simulation software following the technical specification of the Italian Standard UNI/TS 11300
- The model was calibrated starting from real occupation profiles and using standard climatic conditions.
- A standard climate was established to perform the retrofit scenarios so that the energy saving potential was not affected by specific weather data.

The retrofit solutions

Four retrofit scenarios were envisioned for the building used as a case study:

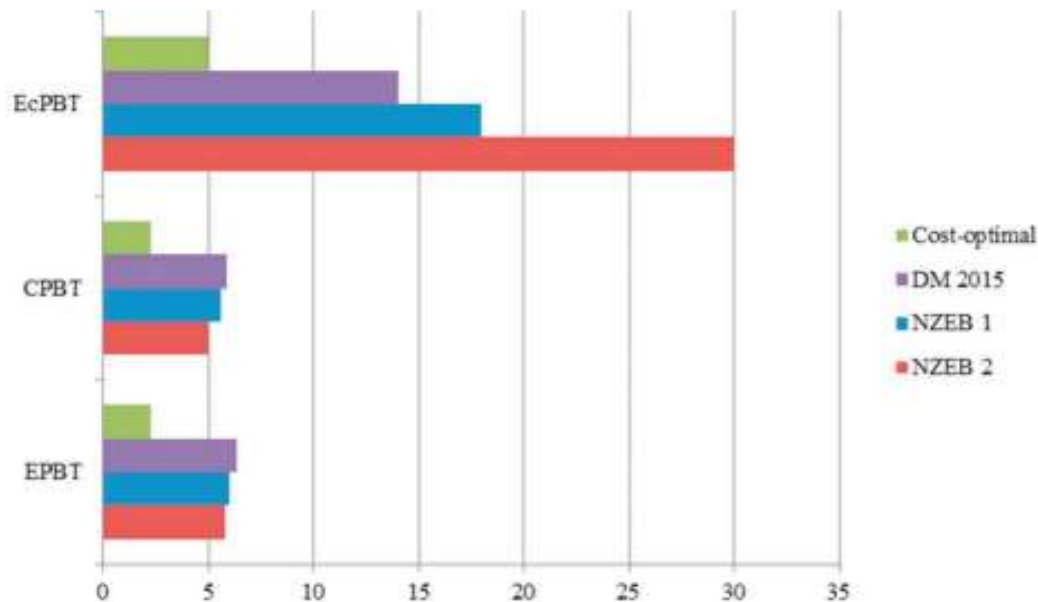
- a cost-optimal solution;**
- a retrofit intervention that allows the building to respect the current Italian legislation on energy efficiency (now called compliant with the DM 2015);**
- two retrofits to achieve the NZEB standard, as defined by the Italian legislation (called NZEB1 and NZEB2).**

The results



Overall specific energy consumptions for the different retrofit solutions.

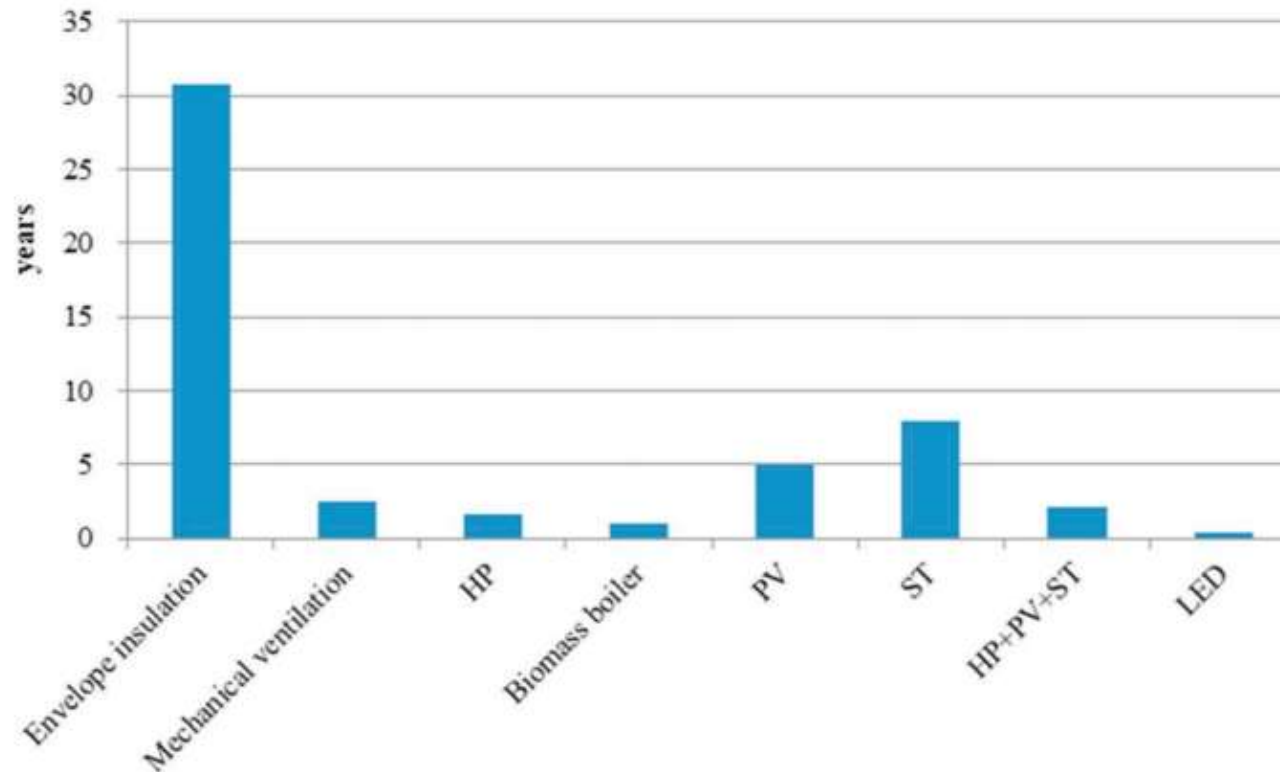
The results



LCA results and comparison between the economic and environmental payback times. The economic payback times are always higher than the environmental ones.

	EE (MJ)	EC (kg CO ₂ -eq)	Energy saving (MJ/year)	Carbon saving (kg CO ₂ /year)	EPBT	CPBT
NZEB 1	23 118 043.80	1 654 762.40	3 373 147.51	253 000.00	6.9	6.5
NZEB 3	22 826 407.94	1 534 762.40	3 460 936.46	259 000.00	6.6	5.9
DM	21 873 500.74	1 491 532.20	3 114 509.25	233 000.00	7.0	6.4
Cost-optimal	6 854 550.19	580 532.20	2 401 055.64	180 000.00	2.9	3.2

The results



Energy payback times for some retrofit interventions (HP: heat pump, ST: solar thermal, envelope insulation includes both opaque and transparent surfaces). Some interventions have lower payback periods. The values are comparable to other literature results.

Environmental labels

Environmental labels: a tool for buildings decarbonization

Three types (ISO series 14020):

- **Environmental labels - Type I – ISO 14024**
- **Environmental auto-declarations - Type II – ISO 14021**
- **Environmental Product Declarations (EPDs) - Type III – ISO 14025**

Environmental labels



Certificazioni di sostenibilità ambientale.

Type I : multicriteria approach

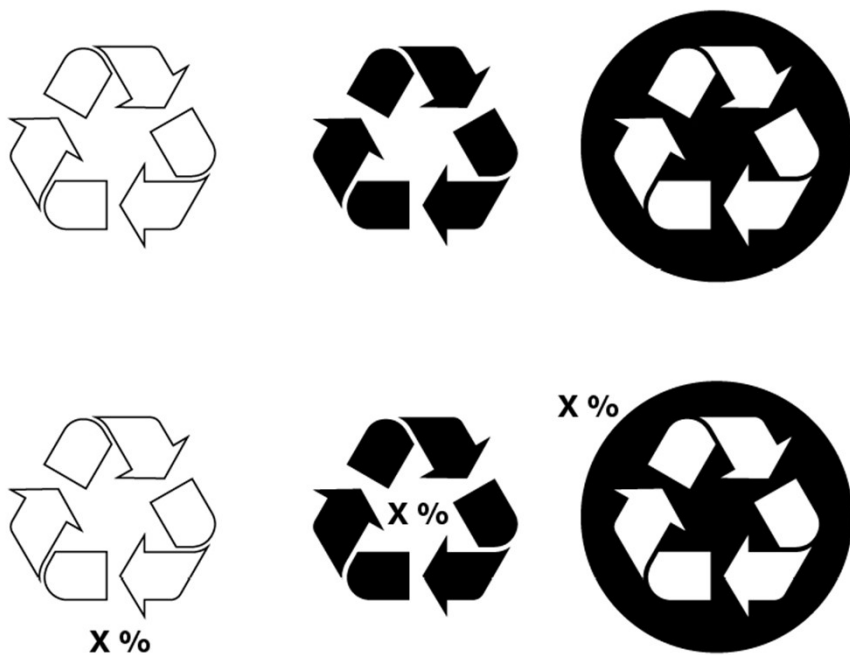
- **Voluntary ecological labels based on a multi-criteria system** (environmental and performance criteria) which considers the entire life cycle of the product.
- The criteria are predetermined for each product category and are in the public domain
- The criteria are defined considering the environmental aspects throughout the **life cycle of the product**, through a process of open consultation with interested parties.
- They are subjected to **external certification by an independent body** ("third party")
- These include, for example, the European eco-label ECOLABEL.



Type II : Auto-declarations

- Eco-labels that include **environmental self-declarations** by manufacturers, importers or distributors of products.
-
- They are **not audited by an independent certification body**.
- They must be substantiated and not misleading: no vague claims should be used.
- The terms selected by ISO 14021 are, for example: **Compostable**, Degradable, Designed for disassembly, Recovered energy, **Recyclable**, **Recycled content**, Reduced energy consumption, **Reduced use of resources**, Reduced water consumption, **Reusable and refillable**

Type II : Auto-declarations



Mobius cycle

Type III : LCA approach

- Ecological labels which report declarations based on established parameters and which contain a **quantification of the environmental impacts associated with the product's life cycle calculated through an LCA system.**
- They are **independently audited** and presented in a clear and comparable form.
- These include, for example, the "**Environmental Product Declarations (EPDs)**".

Type III – Impact categories

Indicator	Abbreviation	Units
Climate change - GWP100	GWP	kg CO ₂ eq
Ozone layer depletion - ODP steady state	ODP	kg CFC-11 eq
Acidification potential - average Europe	AP	kg SO ₂ eq
Eutrophication - generic	EP	kg PO ₄ ³⁻ eq
Photochemical oxidant creation potential	POCP	kg ethylene eq
Depletion of abiotic resources - elements, ultimate reserves	ADPE	kg Sb eq
Depletion of abiotic resources - fossil fuels	ADPF	MJ

EN 15804:2012+A1:2013

EN 15804:2012+ A2:2019

Indicator	Abbreviation	Units
Climate change (total)	GWP-total	kg CO ₂ eq
Climate change (fossil)	GWP-fossil	kg CO ₂ eq
Climate change (biogenic)	GWP-biogenic	kg CO ₂ eq
Climate change (land use and land use change)	GWP-luluc	kg CO ₂ eq
Ozone layer depletion (ODP steady state)	ODP	kg CFC-11 eq
Acidification potential (accumulated exceedance)	AP	mol H ⁺ eq
Eutrophication (aquatic freshwater)	EP-F	kg PO ₄ ³⁻ eq
Eutrophication (aquatic marine)	EP-M	kg N ⁻ eq
Eutrophication (terrestrial)	EP-T	mol N eq
Photochemical ozone creation potential (tropospheric ozone formation potential)	POCP	kg NMVOC eq
Depletion of abiotic resources - elements, ultimate reserves	ADPE	kg Sb eq
Depletion of abiotic resources - fossil fuels	ADPF	MJ
Water use (Water (user) deprivation potential - weighted water consumption)	WDP	m ³ (world-equivalent deprived)

Type III – energy indicators

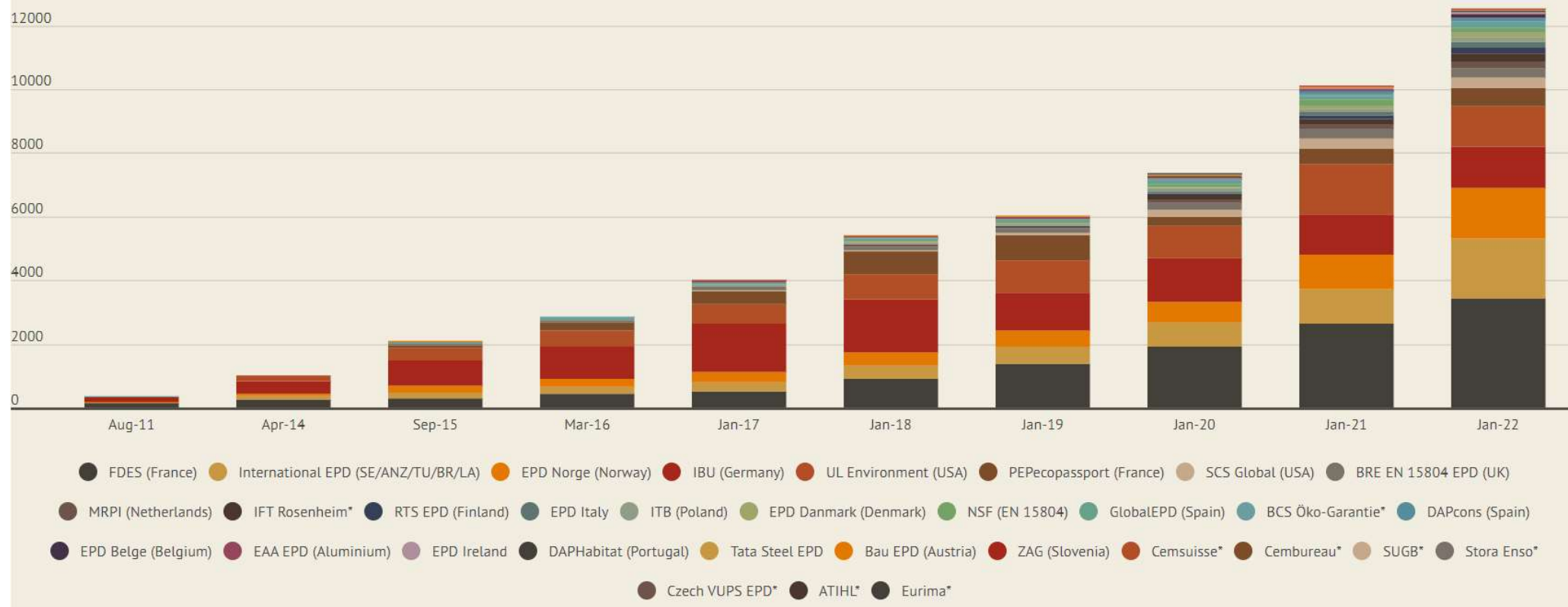
Indicator	Abbreviation	Units
Renewable primary energy as energy carrier	PERE	MJ
Renewable primary energy resources as material utilisation	PERM	MJ
Total renewable primary energy use (sum of the two parameters above)	PERT	MJ
Non-renewable primary energy as energy carrier	PENRE	MJ
Non-renewable primary energy resources as material utilisation	PENRM	MJ
Total non-renewable primary energy use (sum of the two parameters above)	PENRT	MJ

Type III: Program Operators and Product Category Rules

-



Growth in numbers of Construction Product EPD to EN 15804



Numero di EPD di prodotti da costruzione pubblicate per program operator (Jane Anderson, <https://www.eco-platform.org>).

Thermal insulating materials

Cleaner Environmental Systems 2 (2021) 100032



Contents lists available at ScienceDirect

Cleaner Environmental Systems

journal homepage: www.journals.elsevier.com/cleaner-environmental-systems



Embodied energy and carbon of building insulating materials: A critical review

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<https://doi.org/10.1016/j.cesys.2021.100032>

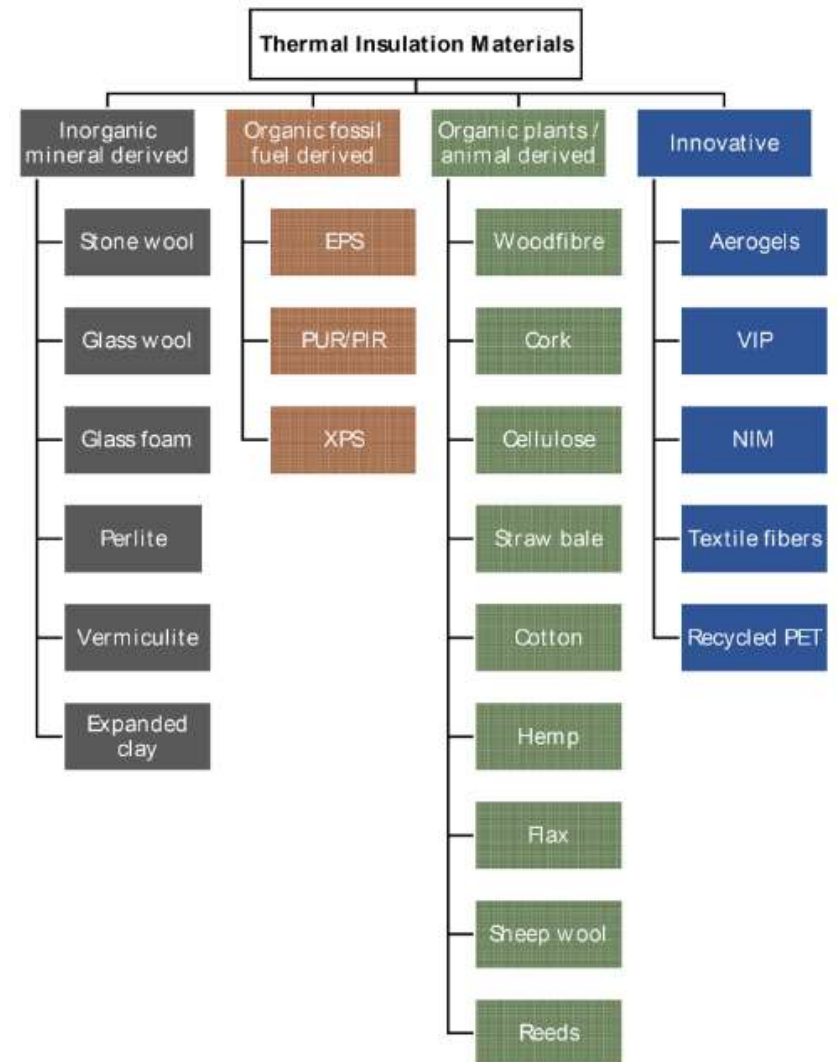


Aim of the study/functional unit:

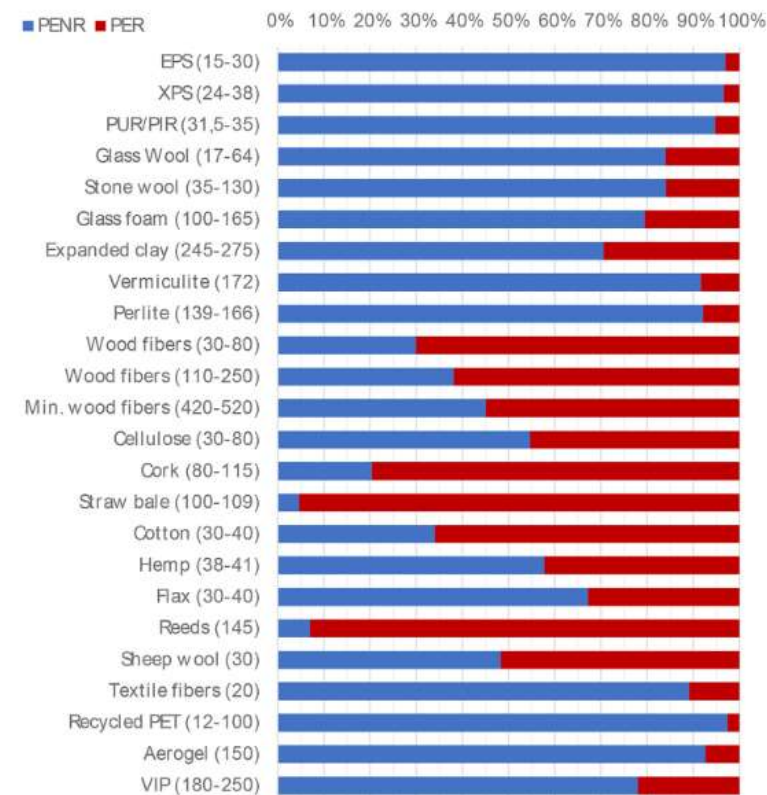
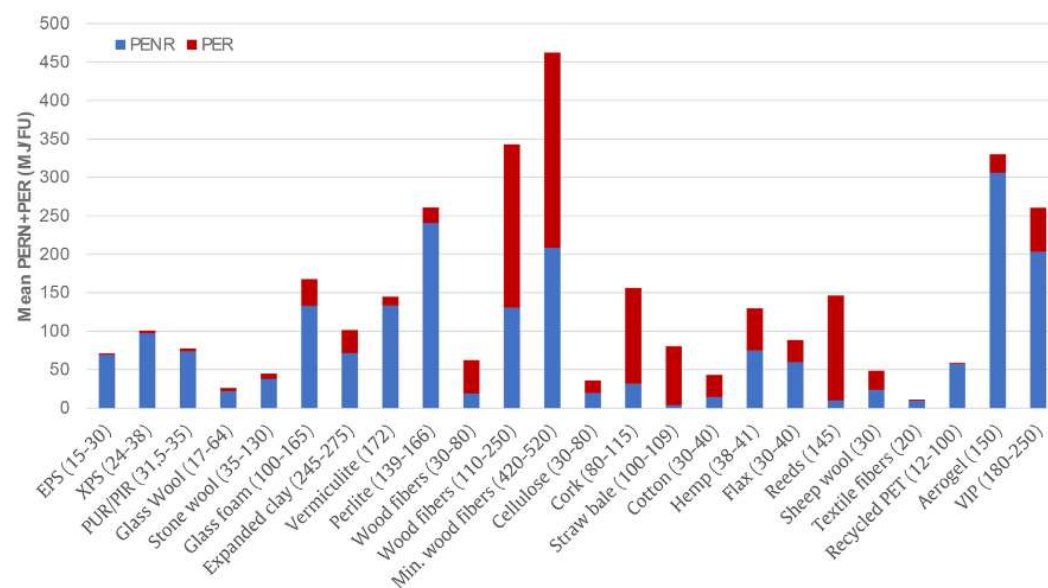
- Comparison of embodied energy and carbon data for different types of insulation materials taken from EPDs.
- Life cycle stages: A1-A3
- Embodied primary energy: non-renewable (PENR) and renewable (PER)
- Embodied emissions: Global Warming Potential (GWP 100y)
- Functional unit: 1 m² of an insulation panel with a thickness that gives a thermal resistance $R = 1 \text{ m}^2 \text{ K/W}$, and with a design life span of 50 years as suggested by European Commission

Classification

- Mineral Inorganic
- Fossil
- Organic vegetal or animal
- Engineered (biopolymers, nano technologies, reflecting panels, VIP, PCM)

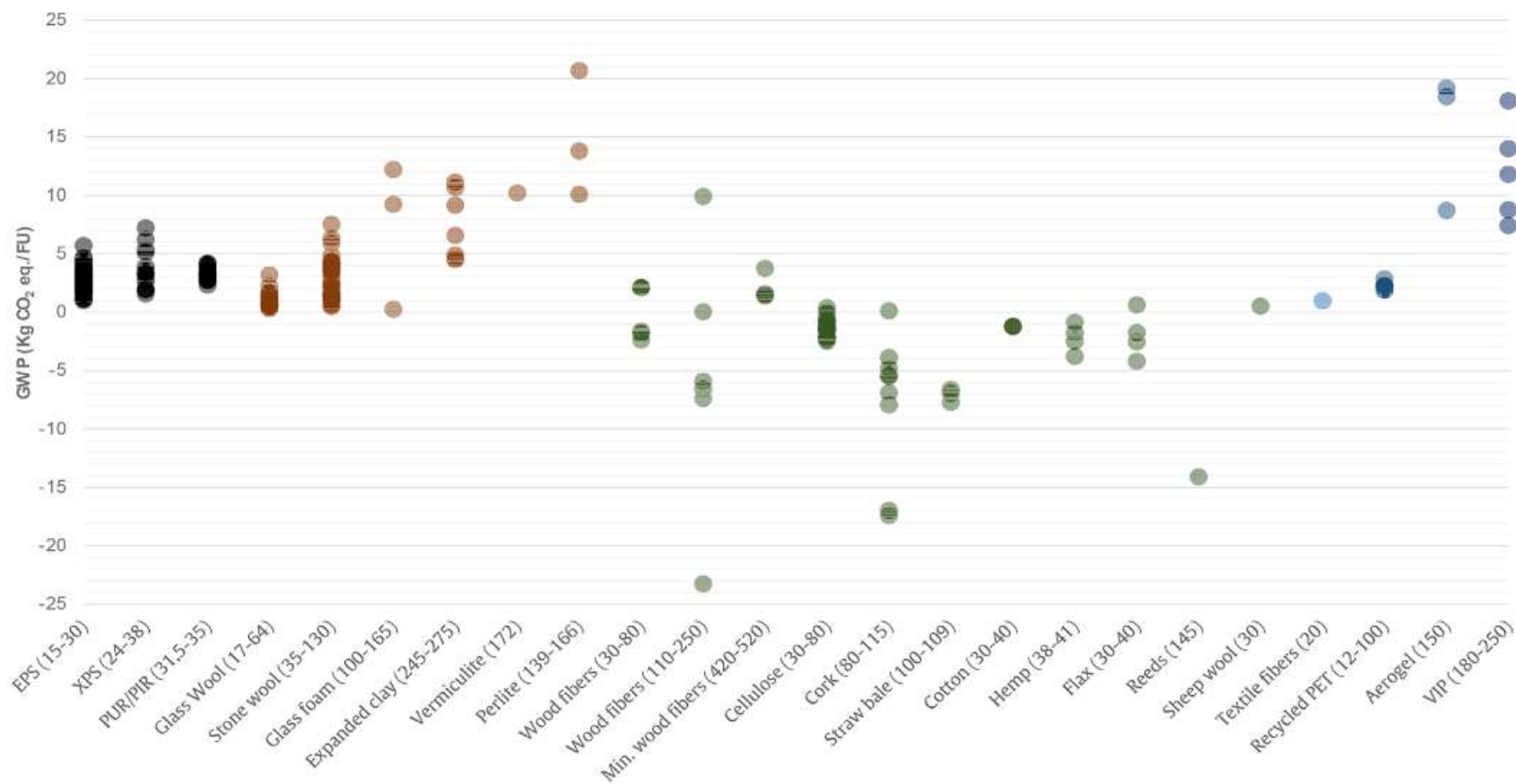


Results



Energia primaria rinnovabile e non rinnovabile per ogni tipologia di materiale isolante, valori medi e percentuali (FU: 1 m² con R = 1 m²K/W).

Results



Global Warming Potential per ogni tipologia di materiale isolante (FU: 1 m² con R = 1 m²K/W).

Results

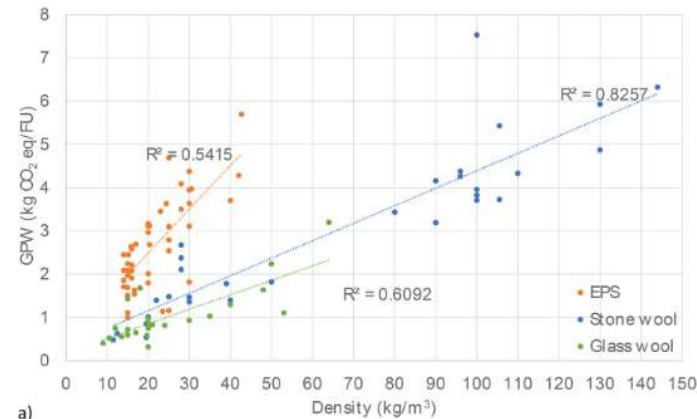
Linear Fitting:

PENR vs ρ (kg/m³)

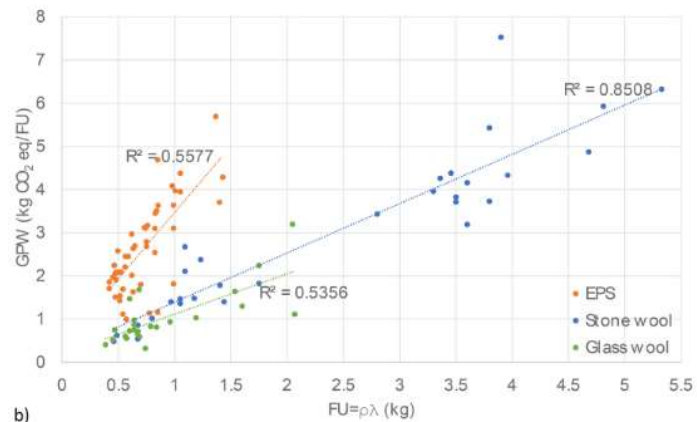
PENR vs $\lambda\rho$

GWP vs ρ (kg/m³)

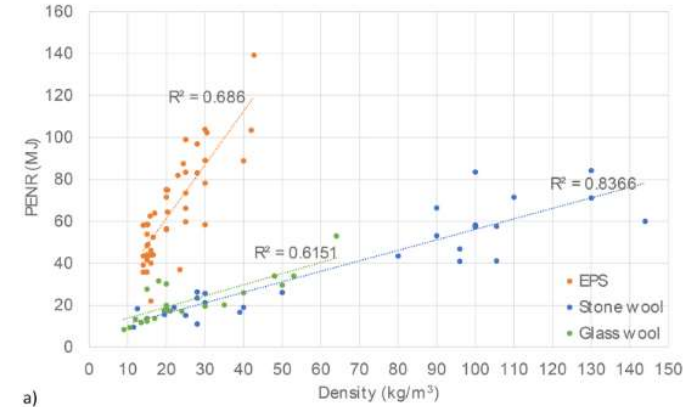
GWP vs $\lambda\rho$



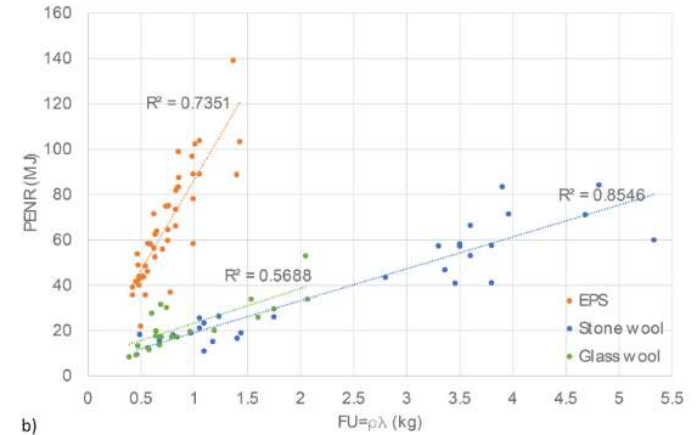
a)



b)



a)



b)

Energia primaria non rinnovabile e GWP vs densità e unità funzionale.

Windows



Review

Embodied Energy and Embodied GWP of Windows: A Critical Review

Francesco Asdrubali *, Marta Roncone  and Gianluca Grazieschi 

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gianluca.grazieschi@uniroma3.it (G.G.)

* Correspondence: francesco.asdrubali@uniroma3.it

<https://www.mdpi.com/1996-1073/14/13/3788>



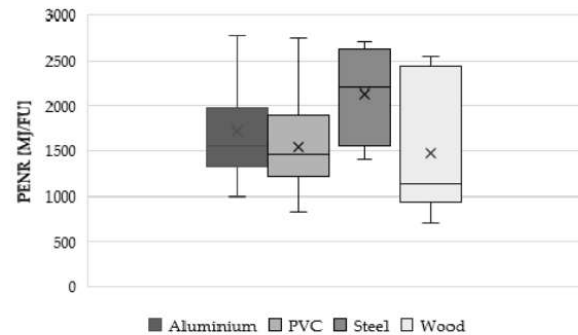
Aim of the study/functional unit:

- Compare embodied energy and carbon data for different types of windows taken from EPDs.
- Life cycle stages: A1-A3
- Embodied primary energy: non-renewable (PENR) and renewable (PER)
- Embodied emissions: Global Warming Potential (GWP 100y)
- **Functional unit: 1 m² of window (including frame).**

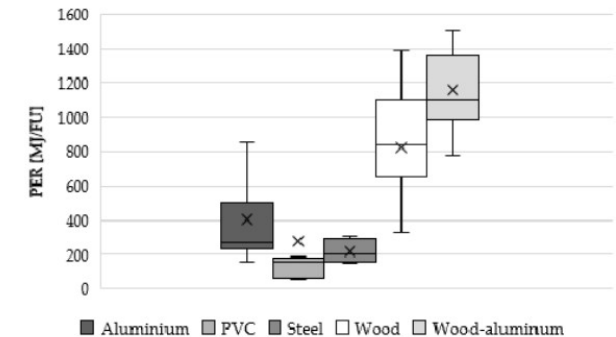
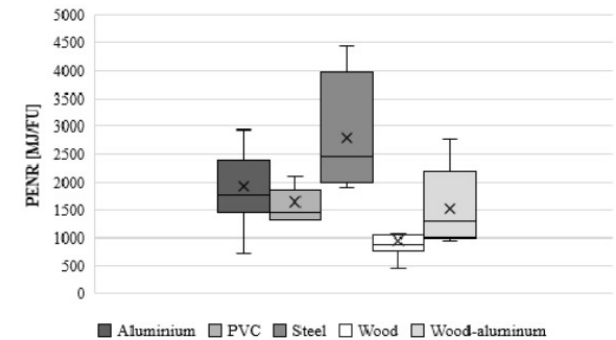
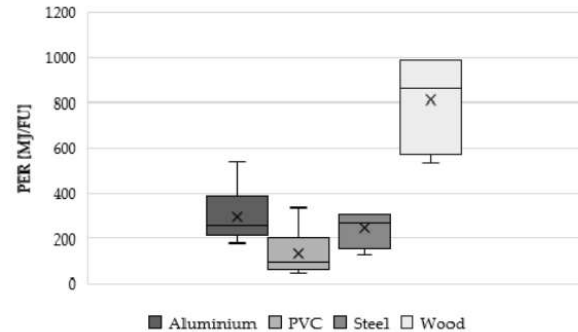
Results

The frame is the main driver of variability: the wooden window has high PER, the steel frame causes a high PENR.

Little information on the type of glass (float, tempered, laminated).



(a)



Results

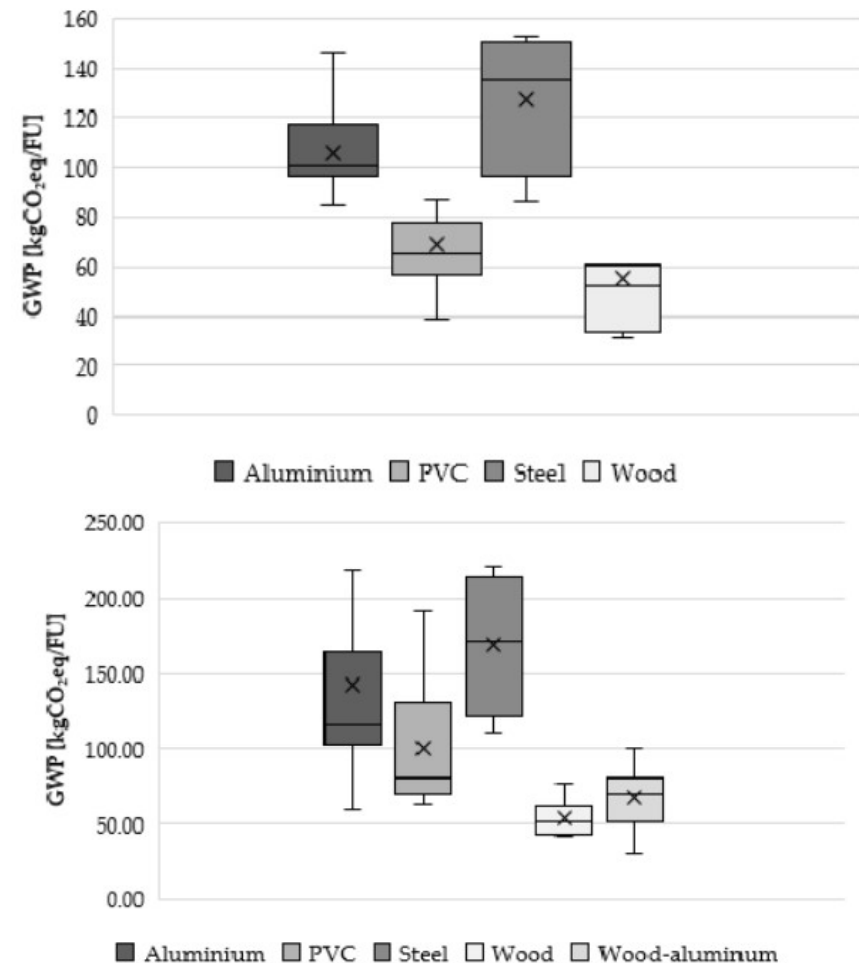
The frame is the main driver of variability (which remains very high):

The wooden window has low GWP.

The steel frame causes a high GWP.

This result is linked to the inclusion of biogenic carbon.

The lack of data (useful life, maintenance needs, thermal, optical, acoustic performance, etc.) makes it difficult to find significant statistical relationships between environmental and physical-technical performance.



GWP per finestre a doppio (in alto) e triplo vetro (in basso).

Construction blocks



Article

Sustainability of Building Materials: Embodied Energy and Embodied Carbon of Masonry

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² Department of Architecture and Design, Politecnico di Torino, Viale Pier Andrea Mattioli 39, 10125 Torino, Italy

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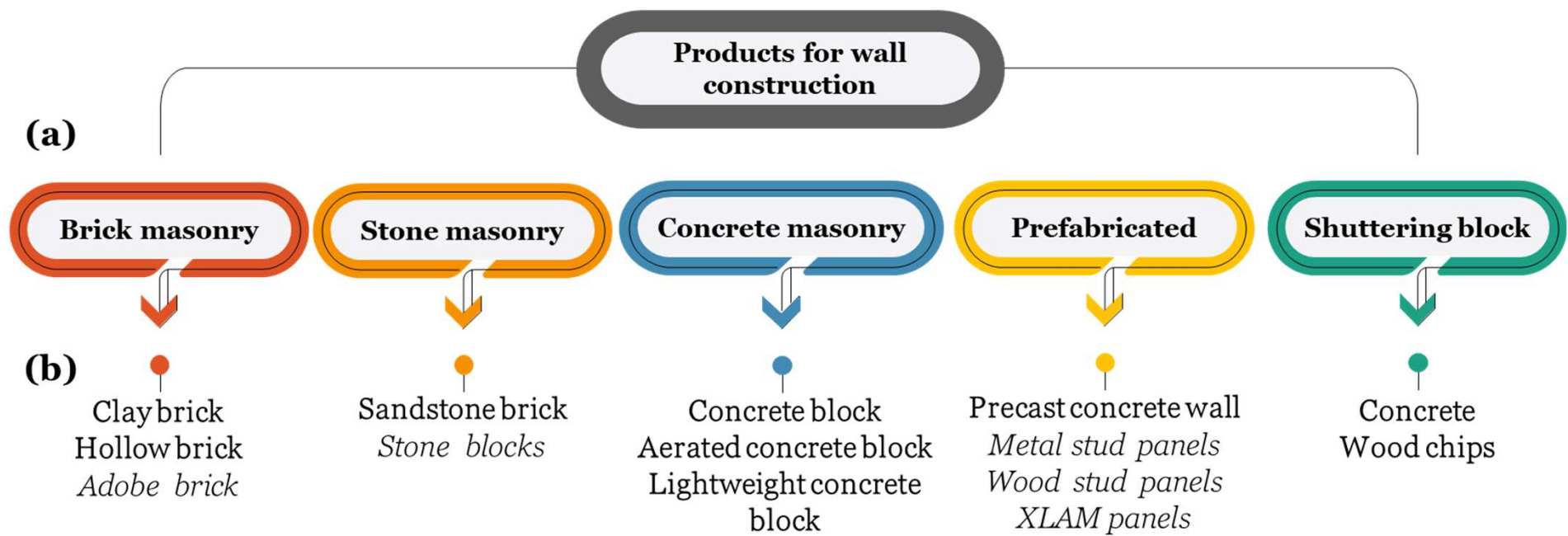
Aim of the study/functional unit:

- Compare embodied energy and carbon data for different types of building blocks derived from EPDs.
- Life cycle phases: A1-A3, +A5 in case of formwork.
- Embodied energy: non-renewable (PENR) and renewable (PER)
- Embodied carbon: Global Warming Potential (GWP 100y)

Functional Unit:

- 1 kg of block/product.
- 1 m² of non-load-bearing wall with $R \approx 5 \text{ m}^2\text{K/W}$, $M_s \approx 260 \text{ kg/m}^2$ to compare the performance of walls made with different building blocks and having similar thermal resistance and surface mass.

Classification



a) construction technique , b) element/product

Products considered in the study

Hollow bricks



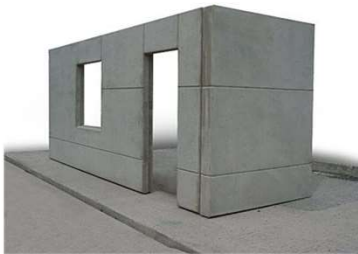
Bricks



Concrete Blocks



Prefabricated panels



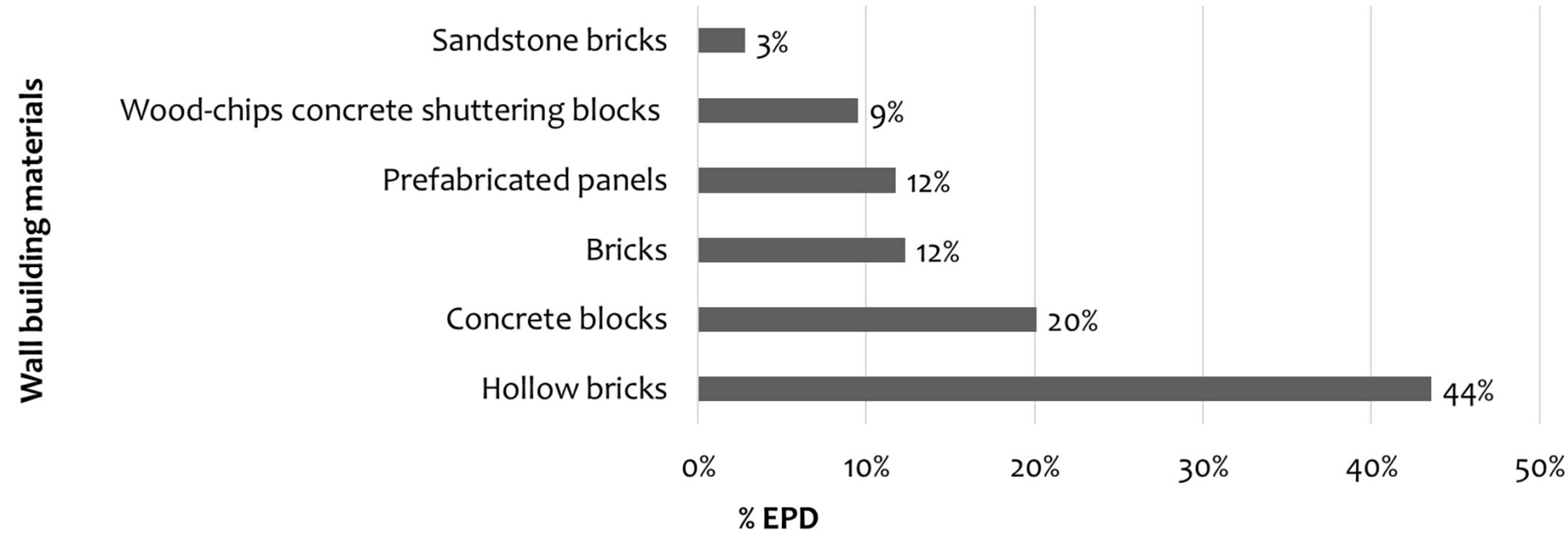
Sandstone bricks



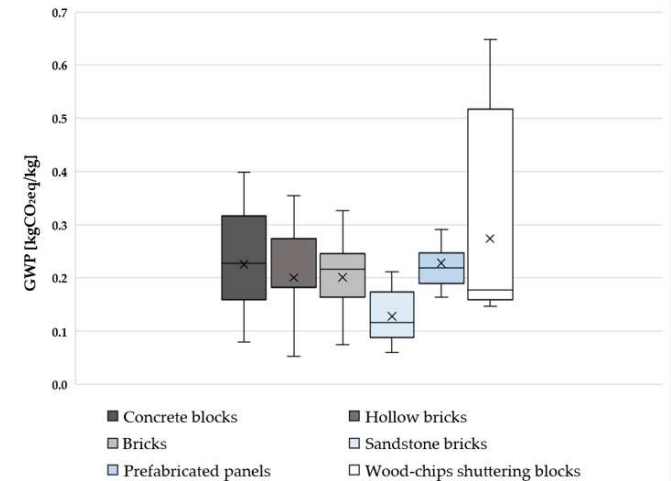
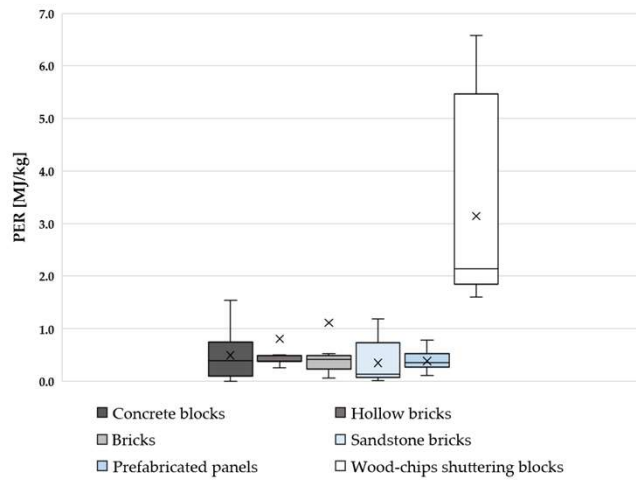
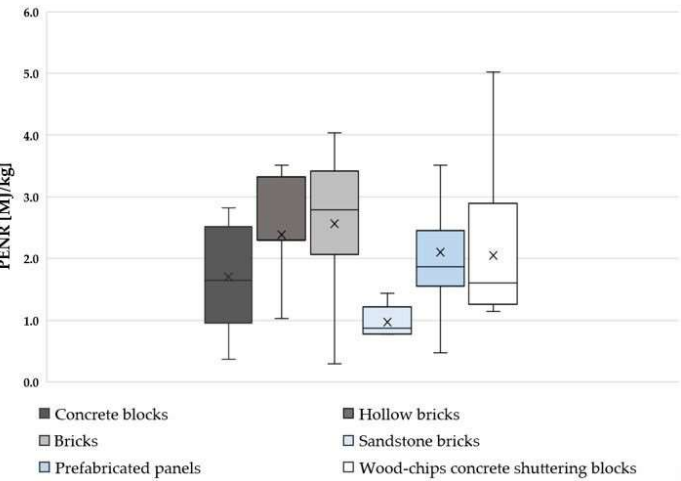
Wood-chips concrete shuttering blocks



EPDs



Results (products)

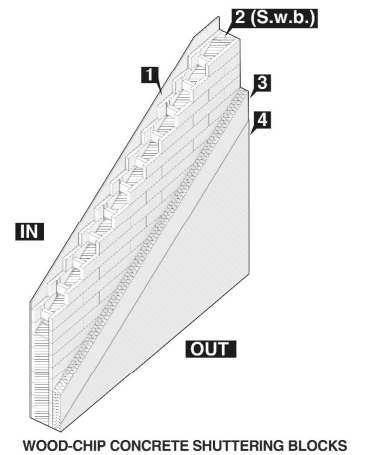
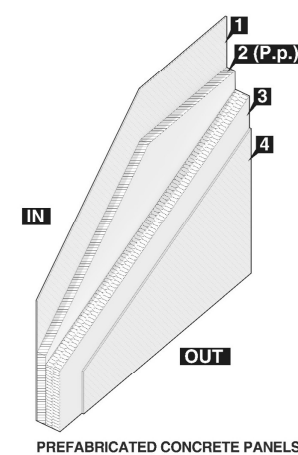
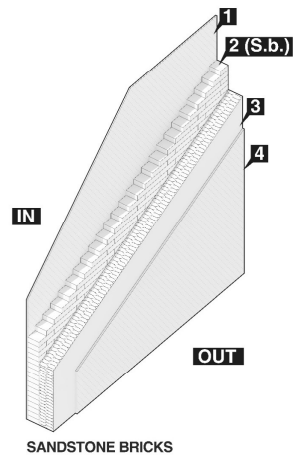
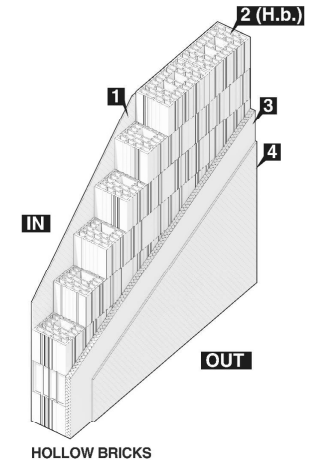
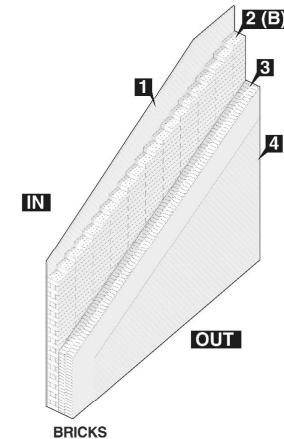
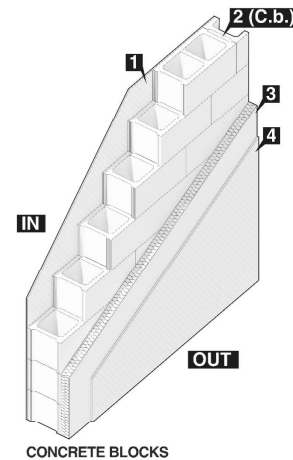


Walls

Different models of non-load-bearing walls were considered.

Stratigraphy includes:

- Internal plaster
- Building block
- Thermal insulation (EPS)
- External plaster.

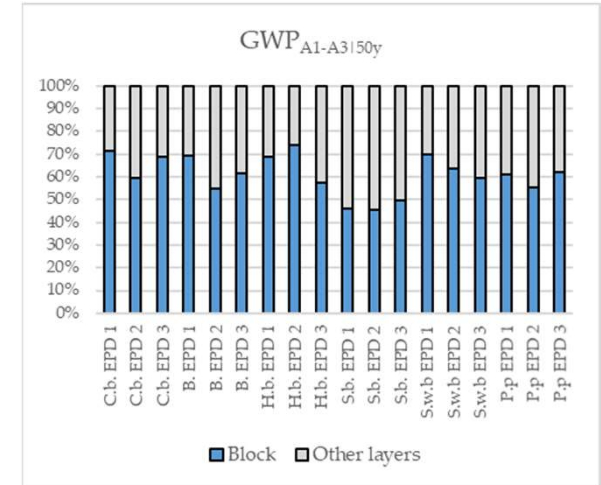
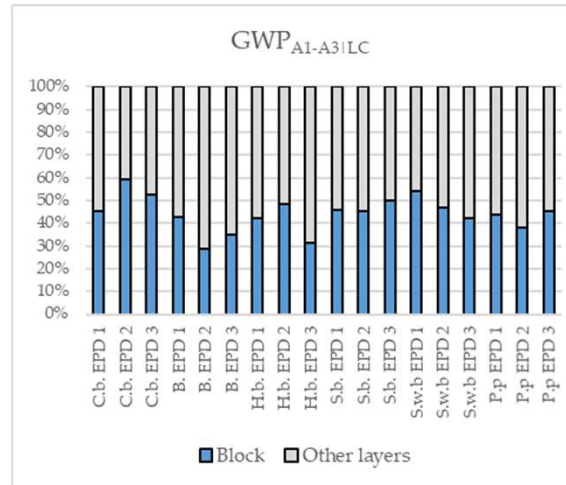
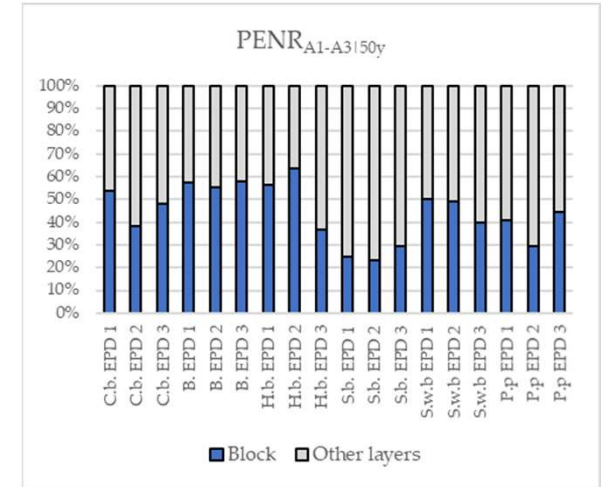
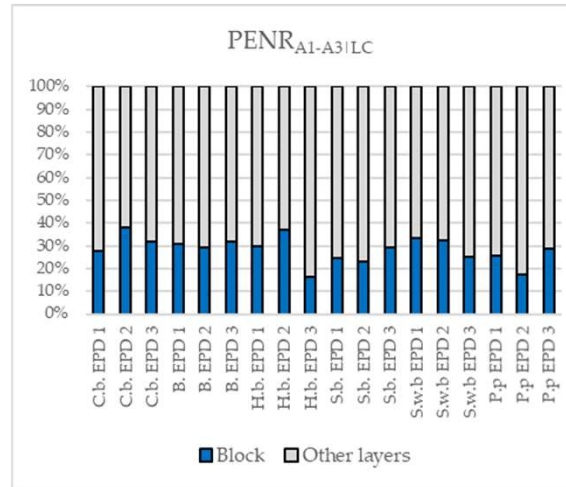


($R=5\pm0.25 \text{ m}^2\text{K/W}$, $M_s=260\pm30 \text{ kg/m}^2$).

Results

Contribution of the construction block to GWP/PENR along the wall life cycle (150 years):

- 16-40% of total PENR
- 29-54% of total GWP



Conclusions and references

Conclusions (1/2)

- The building sector can give a big contribution to climate change issues, but the decarbonization process is slow
- It is essential that the design of new buildings and the refurbishment of existing ones is oriented towards decarbonization
- There are many tools and indicators available, perhaps too many, but most of them are still at voluntary base
- The review of benchmarks shows a very high variability due to differences in benchmark approach, scope, system boundaries, applications
- The LCA approach is essential in order to minimize the reduction of carbon emissions through the entire life cycle of the building

Conclusions (2/2)

- The spread of NZEB is going to increase the impact linked to the construction phase of the buildings causing a shift of burdens
- Interventions with lower energy and carbon payback times have to be preferred
- The payback periods calculated are generally much lower than the useful life of the building, confirming the important role on NZEB in addressing climate change and energy supply issues.
- It is essential to pay attention to the choice of building materials and components embodied energy (especially the non-renewable energy) and embodied carbon
- The increasing spread of EPDs for building components and materials is positive but there is still the need of some standardization

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Thank you for your attention !

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