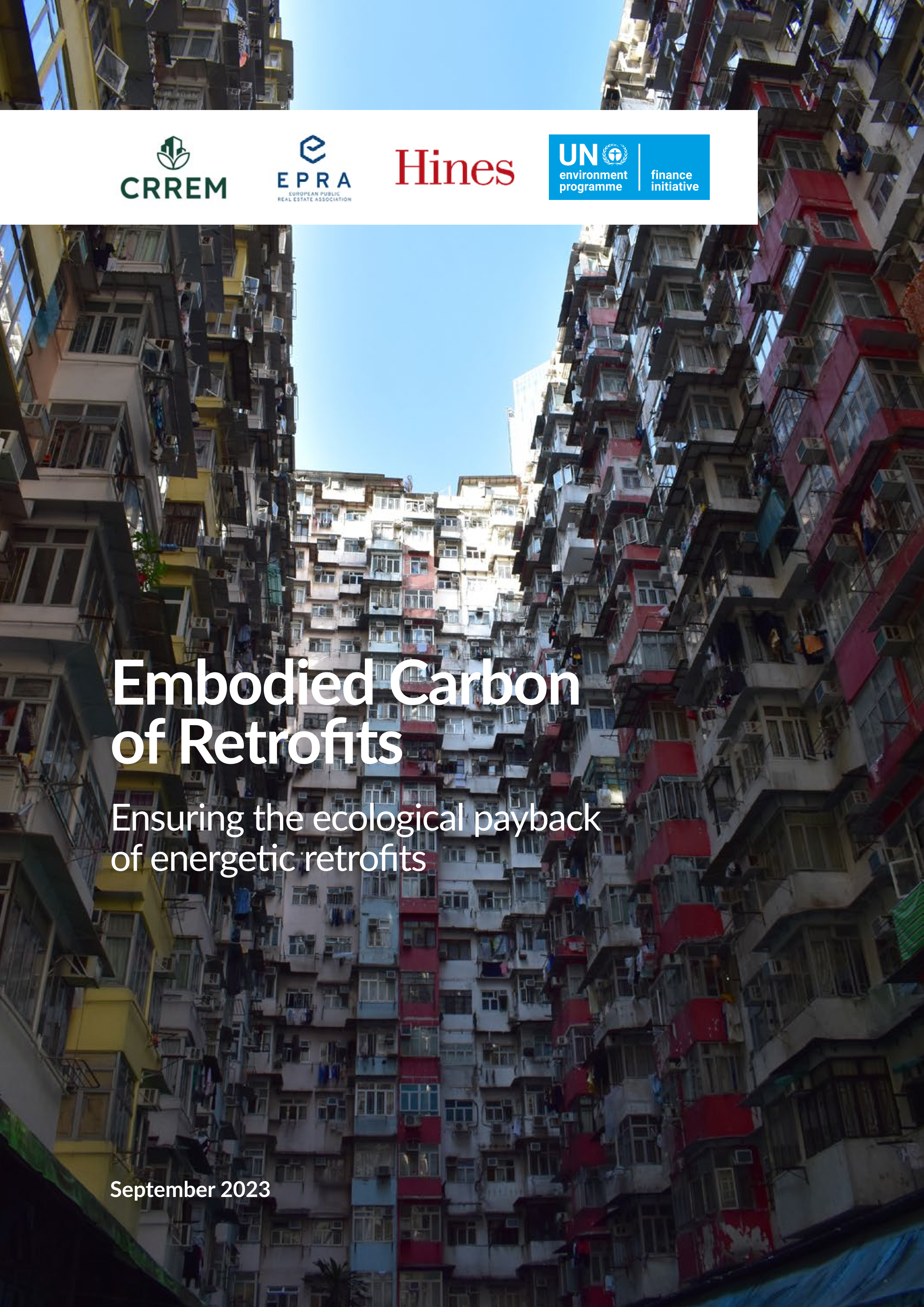

Embodied Carbon of Retrofits

Ensuring the ecological payback of energetic retrofits

September 2023

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This whitepaper is published by IIÖ and the CRREM initiative with the support of Hines (a global real estate investment, development, and property manager.), EPRA (The European Public Real Estate Association is a non-profit organisation representing the interests of European listed real estate companies) and UNEP FI (The United Nations Environment Programme Finance Initiative)

Words from the partners

CRREM
Prof. Dr. Sven Bienert

In the ever-pressing struggle against climate change, the urgency of considering embodied carbon in building retrofits has become paramount. While much attention has rightfully been given to reducing operational carbon emissions, the carbon footprint embedded within a building's materials and construction processes can no longer be overlooked.

EPRA
Hassan Sabir

Taking into account that embodied carbon is the primary origin of GHG from buildings, it's essential to consistently confront these concerns by understanding their inception or fundamental triggers. By fully understanding and reducing embodied carbon to its lowest feasible extent, we can more effectively manage operational carbon, aligning with our goal of net-zero emissions. This study delves into the embodied carbon of retrofits, a crucial piece of the embodied carbon puzzle. We hope this paper serves as a basis for readers to connect this analysis to the whole life cycle of embodied carbon. This emphasis underscores the need for transparent data and a shared set of well-defined concepts and procedures among all stakeholders.

HINES
Michael Izzo

Focusing on embodied carbon reduction is a critical step in our journey to net zero. This shift acknowledges that a building's environmental impact begins even before occupancy, emphasising the significance of sustainable materials and construction processes to achieve our carbon reduction goals.

To make progress, the industry must adopt full lifecycle assessments, prioritise low-carbon materials, and promote transparency in reporting. Collaboration, policy support, and education are essential to drive meaningful change and create a sustainable future for real estate.

UNEP FI
David Carlin

Given that the real estate sector accounts for nearly 40% of global emissions, decarbonising the built environment has become a top priority for societies and policymakers alike. With millions of existing buildings expected to be standing in 2050, retrofits are a key element of the sector's net-zero strategy. However, not all retrofits are created equal. Owners, developers, and investors must have the information and incentives to undertake retrofits that have maximise economics and emissions-reductions. This means focusing on the materials involved in the retrofit and the future operations of the building. The latest piece by CRREM helps key stakeholders to make the right choices when it comes to retrofits for people, profit, and planet.

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CRREM

Carbon Risk Real Estate Monitor

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About CRREM

The Carbon Risk Real Estate Monitor (CRREM) initiative has derived decarbonisationpathways that translate the ambitions of the Paris Agreement (to limit global warming to 1.5°C by the end of the century) into regionally- and property-type-specific trajectories against which real estate assets and portfolios can benchmark themselves. The pathways and the developed freeware tool can be used to derive quantitative figures regarding 'transition risk" (in this case, the risk of assets being stranded due to regulatory incompliance or market obsolescence). The not-for profit-initiative is supported by the EU Commission, Laudes Foundation, as well as APG, PGGM, Norges Bank Investment Management (NBIM). CRREM is the leading global source for benchmarks to reduce the operational carbon footprint of the build environment. The initiative is aligned with SBTi, PCAF, EPRA, INREV, IIGCC, NZAOA and many other global initiatives and organisations.

Acronyms and abbreviations

BMS	Building Management System
CapEx	Capital Expenditures
CDD	Cooling Degree Days
CO_2	Carbon Dioxide
$CO_2e(q)$	Carbon Dioxide Equivalent
CRREM	Carbon Risk Real Estate Monitor
EPD	Environmental Product Declaration
EPRA	European Public Real Estate Association
GHG	Greenhouse Gas
GIA	Gross Internal Area
GWP	Global Warming Potential
HDD	Heating Degree Days
HVAC	Heating, Ventilation, and Air Conditioning
ICMS	International Construction Measurement Standards
IPMS	International Property Measurement Standard
KPI	Key Performance Indicators
kWh	Kilowatt hour
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
LCI	Life Cycle Inventory
LEED	Leadership in Energy and Environmental Design
LETI	London Energy Transformation Initiative
LGD	Loss Given Default
m^2	Square meters
MEP	Mechanical, Electrical, and Plumbing Engineering
n/a	not applicable
PCAF	Partnership for Carbon Accounting Financials
PCR	Product Category Rules
PD	Probability of Default
PV	Photovoltaic
UNEP FI	United Nations Environment Programme Finance Initiative

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1. Management summary and key results

In the race to net zero, the real estate and construction sector takes center stage for achieving global climate goals, as they are responsible for over one-third of worldwide greenhouse gas emissions.[1] For some properties, up to 70%[2] of these emissions can be attributed to the construction, transportation, and demolition of building materials,[3] known as **'embodied carbon'**.

In the pursuit of a decarbonised future aligned with the Paris Climate Agreement, the imperative lies in **effectively tackling the challenge presented by the existing building stock**, since, in developed countries, most of the properties that will be used in 2050 are already erected today. A **key aspect of this endeavor involves retrofitting energy-inefficient buildings** with a primary focus on reducing their energy consumption and, ultimately, operational carbon emissions. In turn, however, energetic retrofits of existing buildings require not only significant investments but simultaneously trigger massive construction activities: Buildings are insulated, triple glazing is installed, and the building automation is mostly renewed.

Our report focuses on the **tradeoff between operational savings and embodied carbon, which are resulting from retrofit activities**. By conducting an in-depth analysis of 36 completed projects from all over the globe, accompanied by a literature review, a survey, and personal interviews with involved stakeholders, we can draw the following conclusions and derive first benchmarks:

- **Significant Carbon Emission Challenge related to Retrofits:** By 2050, existing buildings undergoing typical **energy retrofits** are projected to release **30–40 gigatons of CO_2e**, representing up to 8.5% of the remaining global anthropogenic greenhouse gas budget for a 1.5-degree Celsius compliant world (starting 2020).[4] Using low-carbon solutions and conducting 'smart' refurbishments, this figure could be reduced significantly.
- **Research Gap on Embodied Carbon of Retrofits:** Despite extensive literature on embodied carbon reduction in new construction, there is a notable research gap in **understanding** the **tradeoff between Embodied Carbon** resulting from energetic

1 UNEP (2022): Global Status Report for Buildings and Construction.
2 Note: The share of embodied carbon is higher for particularly energy-efficient ('Net-zero") buildings. This value refers to newly constructed and energy-efficient buildings.
3 wbcsd (2023): Net-zero buildings. Halving construction emissions today; Altria (2022): Sustainability Report; Le Den et al (2022): Towards EU embodied carbon benchmarks for buildings.
4 Rough estimation considering current global floor space and 150 kg CO_2e/m² and no improvement in CO_2e-intensity.

retrofits and their **Operational Carbon Savings**, as well as optimisation strategies in this context. While many publications focus on best-practice case studies for retrofits, globally, only a handful gathered data on embodied carbon.

- **Tightening regulatory framework:** We notice that, at first, **carbon policies and regulations emerge** which/that address EPDs and carbon limits for energetic retrofits and refurbishments, targets, and transparency requirements. Ideas for **more governmental market interventions** range from carbon pricing to LCA requirements—making it even more important for asset-owners to be prepared.

- **Stakeholder perception vs. current market practice:** Our **survey results** which encompass feed-back from more than 80 leading investors, developers, consultants, and asset managers **stress the importance of collecting relevant data**. However, we note a significant discrepancy between stated relevance vs. current market practice. Our study reveals that nearly all investors, based on CRREM or other analyses, identify worst-performing assets in terms of current consumption and associated emissions. Also, refurbishment roadmaps are being developed across the industry to improve property performance. In line with these considerations, financial payback and investment budgets are being clearly allocated. On the other hand, the corresponding **data for optimising energy-efficient refurbishments and thus the ecological payback have not yet been recorded**, or only in rudimentary form.

- **Defining ecological performance assessment and relevant KPIs:** Assessing the ecological performance of retrofit measures is straightforward. A 5-step assessment approach has been developed in this report—linked to common industry guidelines and norms for data collection and procedural steps. Retrofit optimisation should address the balance between **embodied carbon (in kg CO_2e/m^2)** and **operational savings (in kg CO_2e/m^2/year)** by calculating the **carbon payback period (in years)** as a key performance indicator (KPI) for decision making. Additionally, switching from conventional construction material to **low-carbon and bio-based solutions** has the potential to reduce up to 50% of the resulting CO_2e emissions.

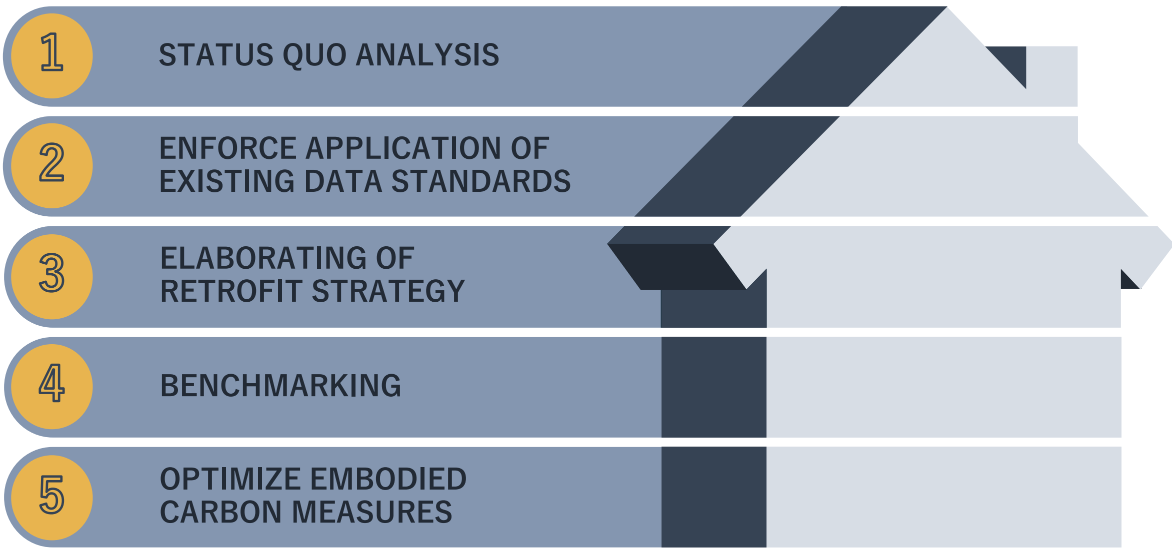


Figure 1: 5-Step Embodied Carbon Optimisation Approach

- **Empirical Results and first Benchmarks:** Based on our analysis of 36 global energetic retrofit projects for different use types in various regions and climate zones, we found that **embodied carbon emissions ranged between 20–140 kg CO_2e/m^2**. Relating these figures to the corresponding operational savings—measured via the carbon intensity in kg CO_2e/m^2/year before and after the retrofit—a **carbon payback period up to eight years** could be derived. So given the much longer remaining lifetime of the assets, all projects were favourable from an ecological point of view. Between the lower end and best-in-class approaches we identified **a significant potential for further optimisation**. Making use of more low-carbon and biobased materials can leverage results and significantly reduce the companies' carbon footprint. Based on our findings, we suggest the following initial KPIs (A1–A3):

Table 1: Benchmark Overview

Residential real estate (Multifamily)				
	Light	**Medium**	**Deep**	***New building*[5]**
Savings	< 25% of energy consumption	25–50% of energy consumption	> 50% of energy consumption	*n/a*
Embodied carbon/ m^2(current market practice)	n/a	In our cases 20 to 80 kg CO_2e/m^2		*600–700 kg CO_2e/m^2*
Typical carbon payback period in years	n/a	1 up to 5 years		*n/a*
Commercial real estate				
	Light	**Medium**	**Deep**	***New building*[5]**
Savings	< 25% of energy consumption	25–50% of energy consumption	> 50% of energy consumption	*n/a*
Embodied carbon/ m^2 (current market practice)	Up to 30 kg CO_2e/m^2	In our cases up to 140 kg CO_2e/m^2		*600–750 kg CO_2e/m^2*
Typical carbon payback period in years	Below 3 years	Up to 8 years		*n/a*

5 Le Den et al. (2022): Towards embodied carbon benchmarks for buildings in Europe.

- **Low-hanging fruits and best-practice case studies:** The **replacement of cooling systems** with lower leakage rates and environmentally friendly refrigerants with reduced Global Warming Potential (GWP) (particularly in the retail sector) turned out to be very beneficial often with carbon payback in the first year. Other quick wins in renovation measures include **replacement of older lightening systems with LED, reviewing heating systems** and power supply, or implementing occupancy sensors and timers for lighting.

Call for action—what asset owners need to do next: Clearly our research supported the assumption that a more intense focus on the ecological pay-back of retrofits and the tradeoff between operational savings vs. one-off carbon emissions which results from the energetic retrofit is essential. Whilst this is a widely accepted proposition amongst real estate professionals, the execution of necessary steps in daily operations—such as data gathering, data quality assurance, EPD assessments for materials, detailed calculation of savings etc.—is still lagging. We identified the following key-aspects to be considered going forward:

- **Budgeting and investment planning:** Retrofit measures should be more intensively **integrated** into **long-term budgeting** and **investment planning**. Consequently, the associated emissions should also be clear and included in the forecasts. Being aware of the ecological impact of the retrofits and possible interventions points for significant reduction ensures the allocation of necessary financial resources and balancing environmental goals with economic considerations. Impacts upon the companies' Scope 3 (and Scope 1 and 2 regarding the operational savings) must be derived.
- **Data quality assurance:** Rigorous **quality assurance** is necessary, including the **separation** of **other asset-related investments** (such as tenant fit out or maintenance measures) and **using actual consumption data**.
- **Consideration of the whole life cycle:** Stakeholders within our sector must not only be prepared for more regulation but also **ensure** a **whole life** and **product cycle** as well as a **circular approach**.
- **Material selection: Know-how** in dealing with **low-carbon materials** can be built up, possible pitfalls can be identified and thus anticipated in the future, and local material sourcing can be established. **Procurement manuals** of investors and developers must be adapted to ensure design optimisation in order to use less materials and choose products with a low carbon footprint.
- **Collaborative approach:** Since data collection poses a major challenge for investors and asset managers who are planning and conducting energy retrofits, a **collaborative approach between all involved stakeholders** (consultants, construction, facilities managers, and public authorities/policy makers) is needed to ensure more and consistent data analysis.
- **Intensifying research: More research** is needed to establish comprehensive databases and resolve challenges in defining and measuring embodied carbon. Currently **available benchmarks** can only be seen as a **starting point** as, due to many/various reasons data accuracy is still a major challenge. Even estimates for material quantities and of course the EPDs are fluctuating a lot.

- **Decision-making framework:** This report offers a decision **framework** for stakeholders **to navigate the complex relationship** between embodied and operational emissions in retrofits. The implementation should be driven forward accordingly.
- **Data quality assurance and verified data:** Especially for Environmental Product Declarations (EPDs) and other input parameters, it is necessary to ensure a like-for-like comparison. Also **EPD databases must be extended**, particularly for more low-carbon-solutions and technical equipment such as heat-pumps that are typically part of the construction materials used for retrofits.
- **Regulatory trends:** Anticipate that regulatory frameworks will continue to evolve, emphasising the **importance** of **accounting** and **optimising CO_2e emissions** in **retrofits**, similar to the standards in new construction.

The research presented in this report marks the starting point to shed a light on the relevance of embodied-carbon emissions resulting from energetic retrofits. The use and implementation of low-carbon materials should be promoted and further research especially on low-carbon retrofit solutions and regional & use-type specific benchmarks is needed. In addition, we identified a need to enhance the availability and robustness of EPD data for retrofit materials since this forms the basis for all further analytical steps in our sector.

2. Development and structure of the report

The development of this report has been carried out in several stages beyond the combined expertise of the UNEP-FI, HINES, EPRA, and CRREM teams. Various market participants have helped us greatly with their expertise. The resulting document represents a concerted effort to help all actors along the real estate sector. Thank you to all who took part in this process. Essentially, we clarify in this report the following research question with massive implication for practitioners:

- How much **embodied carbon** does a **typical energetic retrofit** emit? And how can **KPIs** be derived?
- Can **benchmarks in kg/CO_2e** for energetic retrofits be derived?
- What is a typical '**carbon payback**' period (embodied of retrofit vs. operational savings)?
- What are good approaches for **low carbon retrofits**/material? How should a smart retrofit process be structured?
- Which **low-hanging fruits** exist? (low embodied carbon + high operational savings)

Initially, **interviews** were conducted with real estate market participants (investors, developers, and financial institutions) to gain an understanding of their interests, concerns, and experiences regarding embodied carbon in retrofits. These interviews aimed to gather insights into the current practices of the target audience and ensure that the research project addressed relevant topics. Based on the findings from these interviews, a simplified data sheet was developed to systematically capture implemented measures (or '**case studies**'). The template served as a practical tool for collecting and analyzing data, which then facilitated an analysis of the implemented measures.

Additionally, a **survey** was conducted to further validate the importance of research in this field. As seen in Figure 2 , the respondents of the survey highly acknowledged the significance of embodied carbon, with over 50% recognising its **very high impact for the real estate sector**.

Q: ‘How do you generally assess the future relevance of embodied carbon for the real estate sector?’

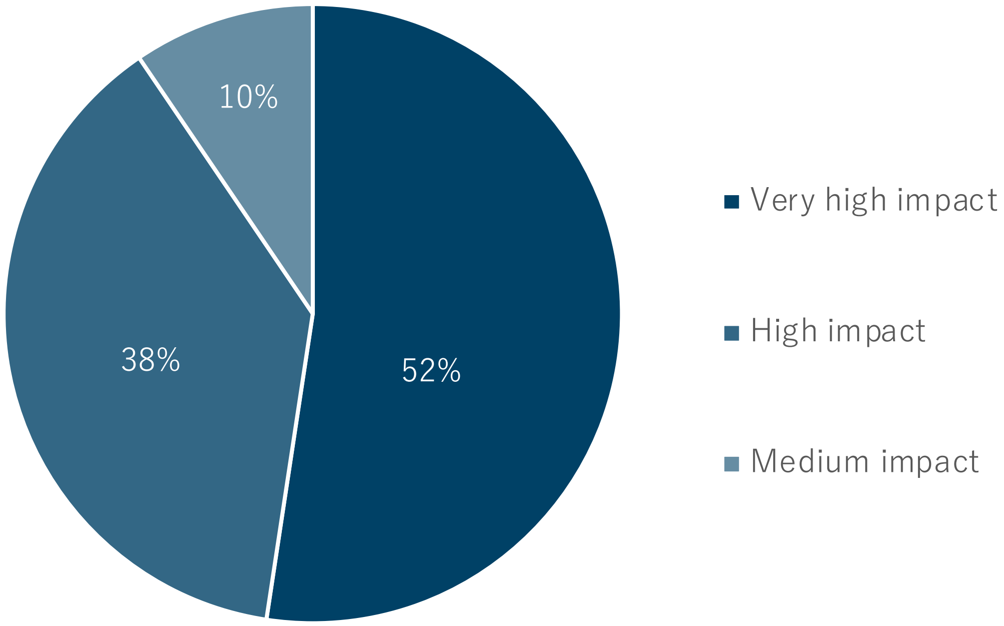


Figure 2: Future relevance of embodied carbon for the real estate sector[6]

The insights gained from interviews, data sheet analysis, and survey responses formed the foundation for the subsequent chapters of this report.

Chapter 3: ‘Embodied carbon of energetic retrofits—ensuring ecological pay-back’

This chapter sheds light on the fundamental issue of embodied carbon in energetic retrofits. It elucidates the challenges and environmental impacts linked to embodied carbon, emphasising its role in climate change. In addition, it showcases how implementing ecological measures can generate positive climate benefits. Essential KPIs are introduced, and a focus is set on trade-offs between embodied carbon and operational savings.

Chapter 4: ‘Collection of data on embodied carbon of materials’

This chapter focuses on the comprehensive collection of data regarding the embodied carbon of building materials, which are primarily installed during retrofits. Various methods and approaches for data collection and evaluation of embodied carbon are presented. Furthermore, relevant data sources and databases are introduced to support the determination of accurate embodied carbon values.

6 Results of own conducted survey. Note: The options of ‘Low impact’ or ‘No impact’ were provided in the survey, however, none of the participants selected these options.

Chapter 5: ‘Deriving benchmarks for embodied carbon of retrofits’

This chapter delves into the process of deriving embodied carbon benchmarks specifically tailored for retrofits. It explores the criteria and indicators necessary for facilitating comparisons and evaluations across different retrofit projects. Developing these benchmarks is crucial for making well-informed decisions concerning climate-friendly retrofits.

Chapter 6: ‘Recommendations for action’

Drawing upon the preceding analyses and findings, this chapter puts forth concrete advice for action. It proposes measures aimed at reducing embodied carbon in energetic retrofits. These recommendations target planners, builders, and decision-makers, and enable them to undertake sustainable and climate-friendly retrofit initiatives.

Chapter 7: ‘Outlook: Growing significance of embodied carbon’

The final chapter provides an outlook on future developments and research requirements in the realm of embodied carbon in energetic retrofits. It discusses unresolved queries and potential solutions for further advancements. Additionally, it outlines possible trends and developments in sustainable retrofits.

This document is intended for managing directors, asset managers, and project managers, consultants and any other stakeholder involved in decision making regarding energetic retrofits, refurbishments of standing investments and any other capex planning among real estate companies globally.

3. Embodied carbon of energetic retrofits—ensuring ecological pay-back

To **limit the increase in global temperatures to 1.5°C above pre-industrial levels**, the real estate sector must undertake significant **decarbonisation efforts** and strive for a **climate-neutral building stock by 2050**. Real estate and construction play a crucial role in achieving global climate goals, as they account for more than one third of global greenhouse gas emissions.[7] A considerable portion of existing buildings lack the necessary energy efficiency to achieve this goal. The main objective is therefore, to **reduce operational emissions and energy use intensities of existing buildings drastically** from the current global average of approximately 35 kg CO_2e/m^2 in 2020 to 0.4 kg CO_2e/m^2 in 2050.[8] Global release of 30–40 Gigatons CO_2e through transforming existing buildings into Net-Zero Ready (assuming current market practice). This represents approximately 7–9% of the remaining anthropogenic greenhouse gas budget (1.5°C).[9] In many parts of the world, new buildings are already required by law to be net zero or net-zero ready at the time of construction.[10] **The major challenge** will hence be to also improve **existing buildings** through **energetic retrofits**[11] and thus to specifically avoid emissions in the use stage.[12] For real estate portfolio holders, a closer look reveals **four strategic challenges** that must be addressed as part of their own decarbonisation strategy.

7 UNEP (2022): Global Status Report for Buildings and Construction.

8 CRREM (2023): Global Decarbonisation Pathways.

9 Rough estimation considering current global floor space and 150 kg CO_2e/m^2 and no improvement in CO_2e-intensity.

10 Note: Definition for Net-Zero-Buildings see PCAF (2022): The Global GHG Accounting and Reporting Standard for the Financial Industry: Both are highly energy efficient buildings that do not cause any CO_2e emissions on site.

11 Energetic retrofits are to be clearly distinguished from generally necessary refurbishments for the extension of the economic life cycle (see Chapter 4).

12 Estimates suggest that, for instance, in EU countries, 80% to 95% of the buildings that will be utilised in 2050 already exist today (see EU-Commission (2020): A Renovation Wave for Europe—greening our buildings, creating jobs, improving lives). Similar figures can be observed for other continents and countries.

i. (Reduce) Embodied carbon of new construction

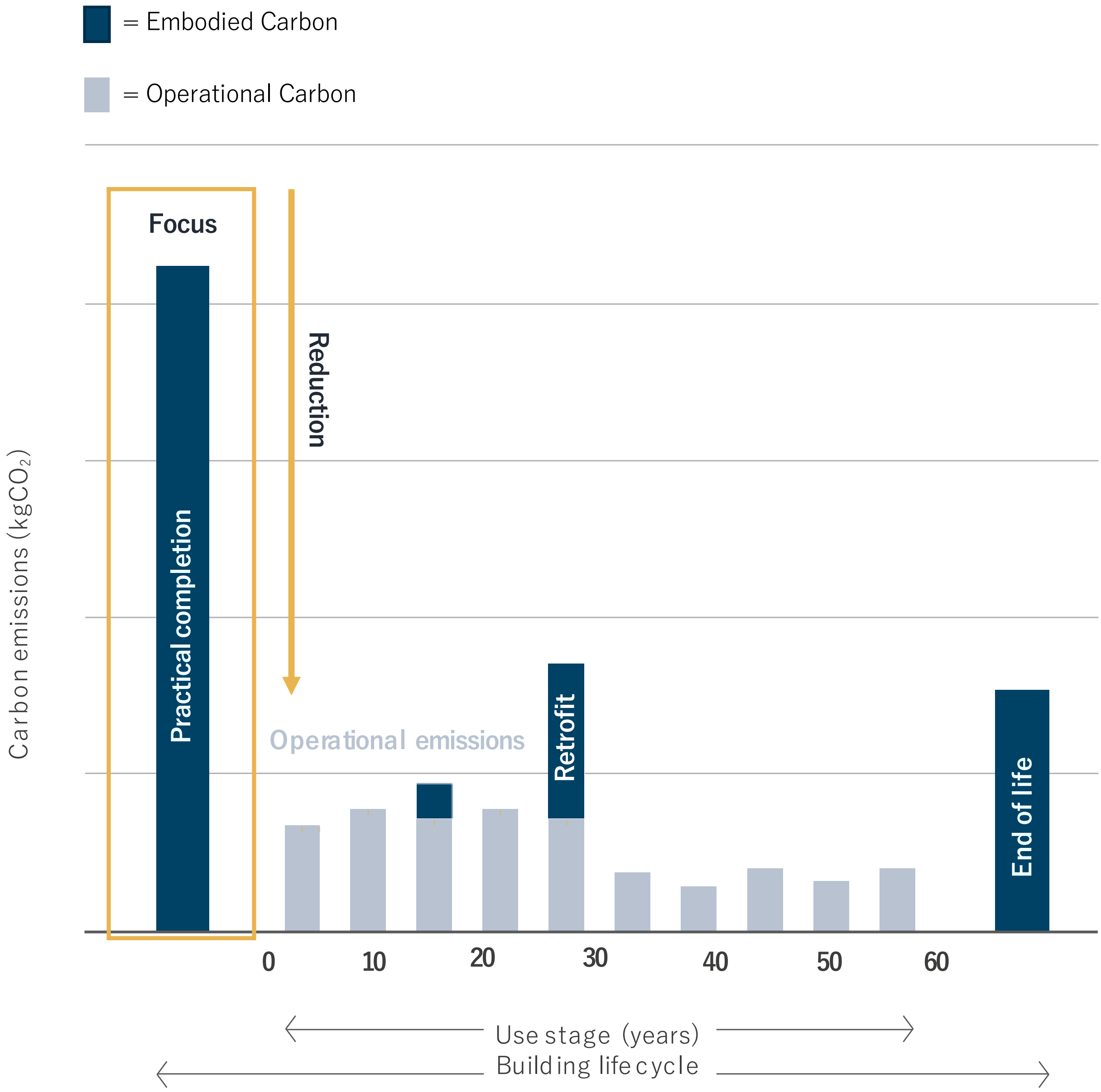


Figure 3: Reduction of upfront embodied carbon[13]

In the case of new buildings, it is important to set targets for embodied carbon in advance and analyze the materials in relation to both operational and embodied carbon emissions. A significant amount of recent research has focused on the concept of embodied carbon in the context of new construction. An overview of selected studies can be found in the appendix, which has also allowed for the derivation of benchmarks.[14] For example, modern standard office buildings contain embodied carbon of up to 1,000 kg CO_2e/m^2 before operation (A1–A5). Even if these buildings are energy efficient, they still emit around 25 kg CO_2e/m^2/year of operational emissions based on the current electricity

13 Own depiction based on LETI (2020): Embodied Carbon Primer.
14 E.g. Röck et al. (2020): Embodied GHG emissions of buildings—The hidden challenge for effective climate change mitigation or De Wolf et al. (2015): Material quantities and embodied carbon dioxide in structures.

mix, during the use phase.[15] Considering a total service life of 50 years, the embodied carbon accounts for 44% of the overall lifetime carbon of the building. This 'carbon spike', as depicted in Figure 3, highlights the challenge of offsetting high upfront emissions through subsequent savings. Consequently, numerous research projects and regulations are currently exploring limits and best practices for reducing embodied carbon in new construction.[16] But reducing the embodied carbon of new construction is not the only challenge for real estate investors.

ii. (Extend) the economic life of buildings:

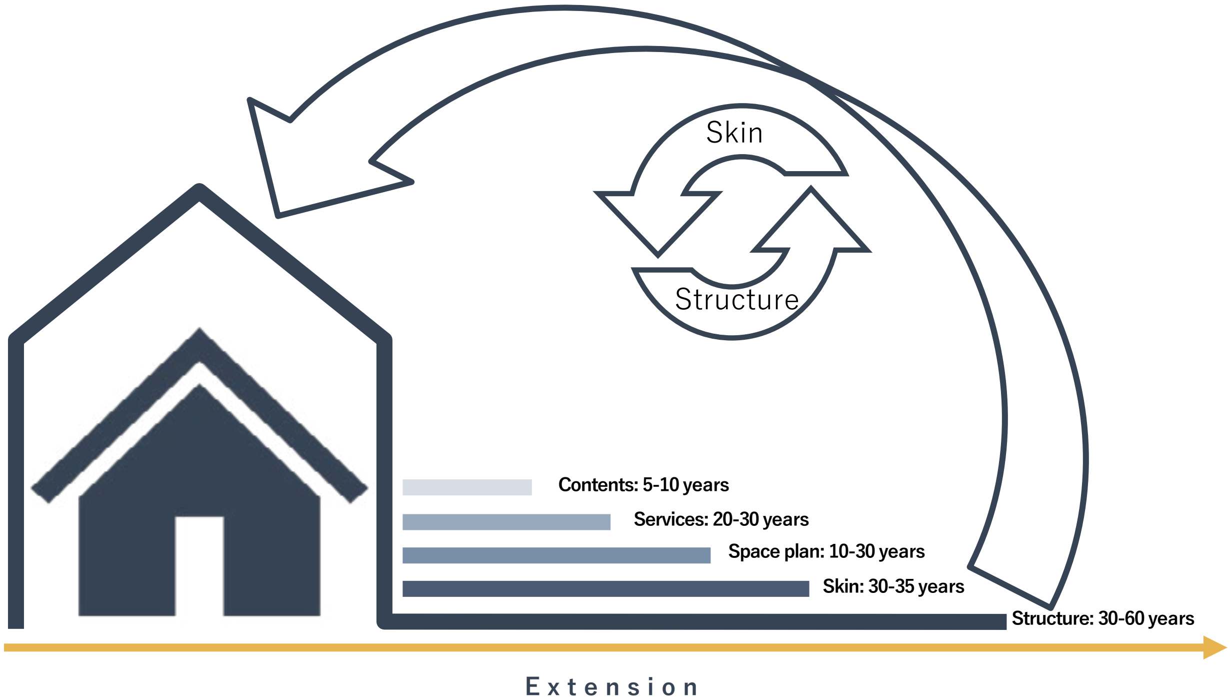


Figure 4: Extension of economic life cycle[17]

To reduce embodied carbon in construction, it is advisable to prioritise the re-use of existing (especially concrete and steel) structures rather than to demolish and rebuild/construct a new building. Additionally, during the design phase, emphasis should be placed on future proofing of the building to achieve a flexible layout and high reusability, aiming to minimise future structural changes. Materials selection of refurbishments should prioritise materials with a long lifespan and lower environmental impact (see Table 4). When making tenant modifications, it is recommended to ensure they are also to suit future users, rather than being overly specific to a particular use case. In addition, implementing proactive maintenance and repair strategies to prolong the lifespan of building components and systems can help to extend the life cycle of the property. In the context of reusing buildings, urban mining is also relevant. Reusing materials that have been used

15 LETI (2020): Embodied Carbon Primer; alstria (2021): Sustainability Report; Le Den et al. (2022) calculated an average of 600 kg/CO_2e/m^2 for office buildings.

16 E.g. British Property Federation (2023): Towards Net Zero: Challenges, opportunities, and policy recommendations; European Environment Agency (2022): Modelling the Renovation of Buildings in Europe from a Circular Economy and Climate Perspective; Hines (2022): Embodied Carbon Reduction Guide; Le Den et al. (2022): Towards embodied carbon benchmarks for buildings in Europe; London Energy Transformation Initiative LETI (2020): Embodied Carbon Primer; World Green Building Council (2023): Policy Briefing.

17 Own depiction based on wbcsd (2023): Net-zero buildings. Halving construction emissions today.

in a building can be of high importance to minimise environmental impact and contribute to a circular economy.

iii. (Reduce) operational carbon emissions of existing building stock

The first challenge here is to collect data on the current energy consumption and emissions levels of the buildings. This is crucial for benchmarking and working on improvements of the portfolio. In the past, the availability of data in particular has made it difficult for owners to gain a reliable overview of the consumption of their own portfolio. It can be helpful for landlords and tenants to agree on data exchange obligations or to establish them when the lease is signed. The whole buildings energy consumption data (in kWh/m^2/year) can then be analysed using the CRREM methodology and resources[18] to derive the asset specific carbon intensity (in CO_2e/m^2/year) and benchmark results against the SBTi-CRREM 1.5-degree-aligned decarbonisations pathways. By applying asset class and country specific pathways and deriving the properties transitions risk (e.g., by identifying the stranding-point of being not anymore on a Paris-aligned trajectory) alternative strategic options can be identified to reduce the operational carbon footprint of standing investments. Typical approaches include:

- Consideration of additional investments to enhance the energy efficiency of the property,
- Increase in renewable energy production on site,
- Influence on tenant behaviour and incentivise savings,
- Installation and upgrading building automation (smart metering, etc.),
- Purchase of renewable energy for any remaining energy demand.

The global CRREM decarbonisation pathway is shown in Figure 5:

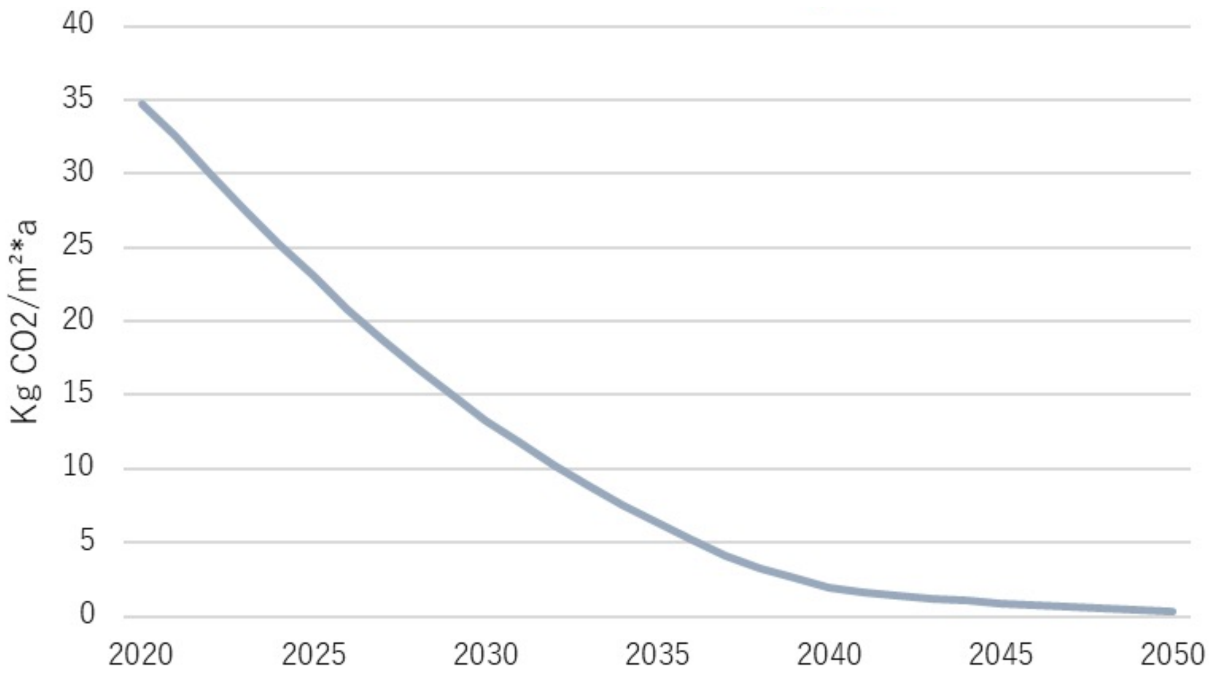


Figure 5: Global CRREM Pathway

18 CRREM: https://www.crrem.eu/tool/

Enhancing the energy efficiency of any existing building is clearly the cornerstone of any retrofit project and first logical step to reduce the energy consumption and improve the carbon intensity of existing properties. This involves upgrading insulation, windows, and HVAC systems, as well as optimising lighting and appliances. However, it is not only important to recognise that an energetic retrofit should take place. Other strategic considerations for optimising the investment and to define how and when the measures should be carried out and which materials should be used are equally important—and are in most cases not sufficiently considered to date.

iv. (Optimise) energetic retrofits of buildings

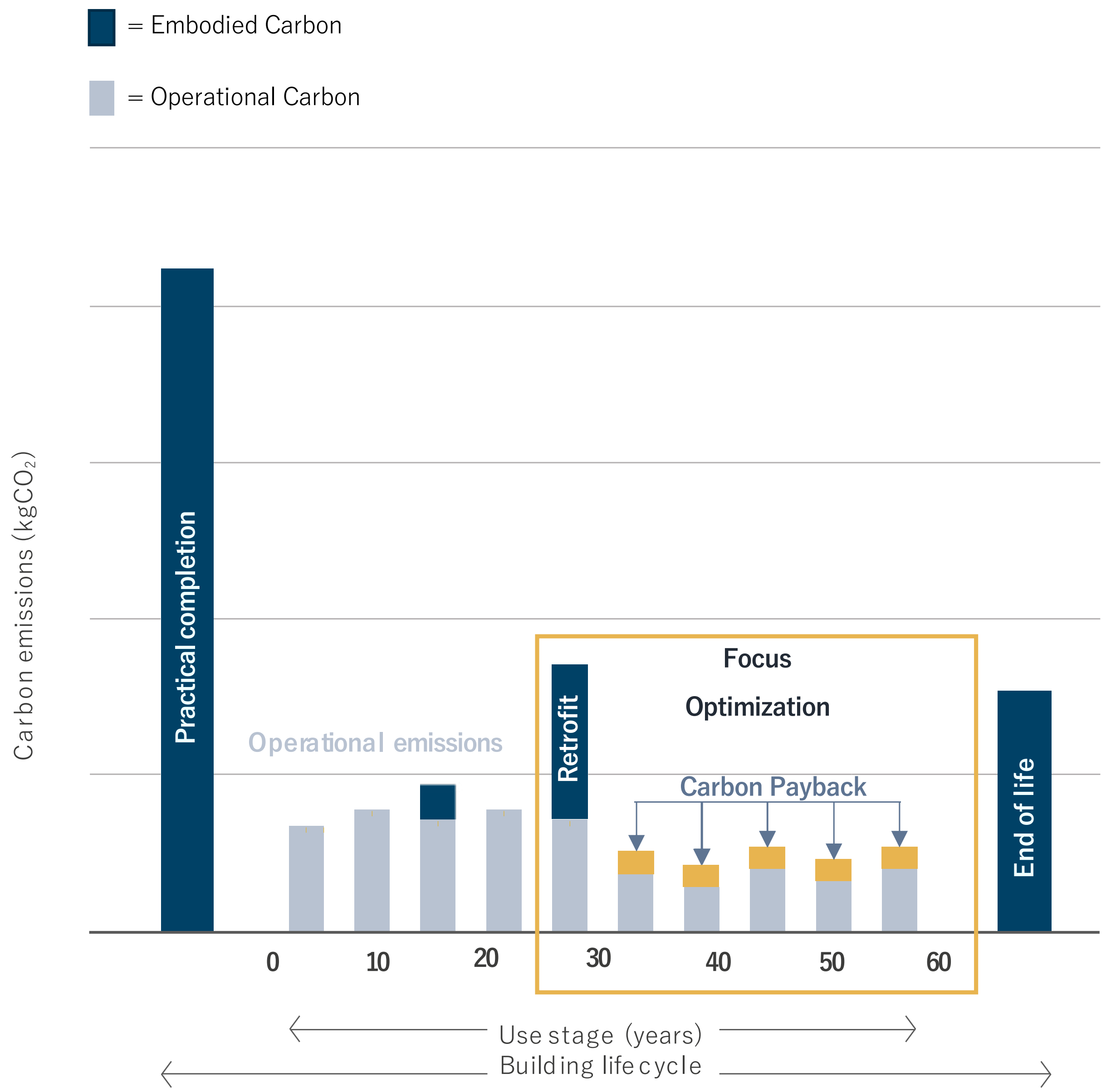


Figure 6: Optimisation of energetic retrofits[19]

19 Own depiction based on LETI (2020): Embodied Carbon Primer.

The general term 'retrofit' is based on the ISO 6707 definition: It is a modification to an asset in order to generate an improved condition for the property.[20] There are multiple possible scopes of work related to retrofitting an asset, ranging from only interior improvements to extensions and even major refurbishment. An '**energetic retrofit**' is only referring to any kind of measure that improves energy efficiency and decarbonises the use-phase of a property. To overcome this challenge, it is essential to consider the **interplay and trade-off between operational carbon emissions and embodied carbon emissions.**

Operational carbon emissions refer to the emissions generated during the use phase of buildings, such as energy consumption for lighting, heating, cooling, and technical appliances. These emissions can be reduced through energetic retrofitting of buildings. However, it is important to note that any kind of **energetic retrofit causes embodied carbon emissions**. Over the entire life cycle of a building, embodied carbon emissions can account for more than 70% of emissions.[21] If current renovation practices continue to rely on virgin materials until 2050, the total **consumption of raw materials is projected to double** by the middle of the century and new construction is still expected to grow.[22] This substantial increase in the sector's emissions will have a significant impact on temperature increase.[23]

Given that, there is an urgent need to **prioritise energetic retrofitting and refurbishment of existing building stocks** in a manner that **minimises the absolute amount of a property's carbon emissions** (see Figure 3). A successful decarbonisation strategy weighs the additional embodied carbon emissions over a lifetime from retrofits against the savings in operational carbon emissions and optimises the outcome until the **lowest overall emission scenario has been identified before starting the energetic retrofit**.

We assess the trade-off by (1) quantifying the **embodied carbon of the energetic retrofit** (in CO_2e/m^2 GIA[24]) through material quantities and embodied carbon factors (see Figure 7).

20 See for more details also: RICS (2023): Whole Life Carbon Assessment for the Built Environment—2nd edition and International Organization for Standardization (2017): ISO 6707—Buildings and civil engineering works.

21 wbcsd (2023): Net-zero buildings. Halving construction emissions today; Altria (2022): Sustainability Report; Le Den et al (2022): Towards EU embodied carbon benchmarks for buildings. Note: The share of embodied carbon is higher for particularly energy-efficient ('net-zero") buildings. This value refers to newly constructed and energy-efficient buildings.

22 Virgin or raw materials refer to resources that are newly extracted or harvested from nature and have not been used or processed before. Source: KPMG (2023): Embodied carbon management for global infrastructure/Future of Construction- A global forecast for construction to 2030.

23 WGBC (2019): Bringing embodied carbon upfront; European Environment Agency (2022): Modelling the Renovation of Buildings in Europe from a Circular Economy and Climate Perspective.

24 IPMS2 used as a standard for deriving the Gross Internal Area (GIA).

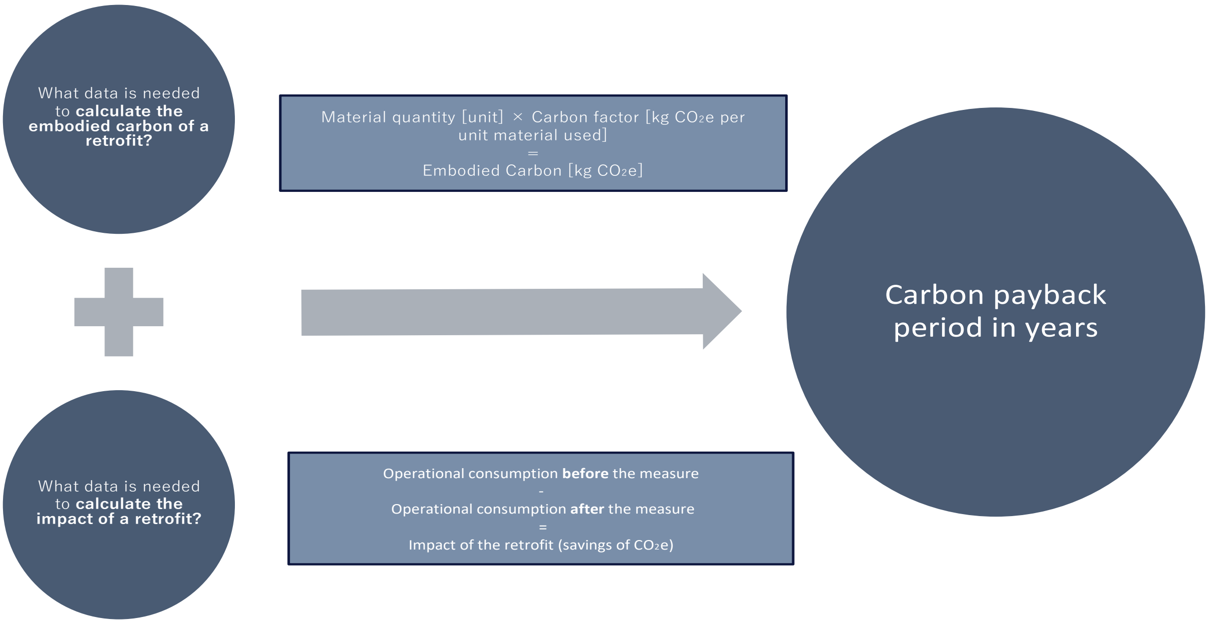


Figure 7: Data requirements and derived KPIs for the evaluation of energetic retrofit projects

(2) Subsequently, we calculate the annual reduction in CO_2e emissions by determining the difference in operational emissions before and after the retrofit, expressed as Carbon intensity savings (**in kg $CO_2e/m^2/year$**).

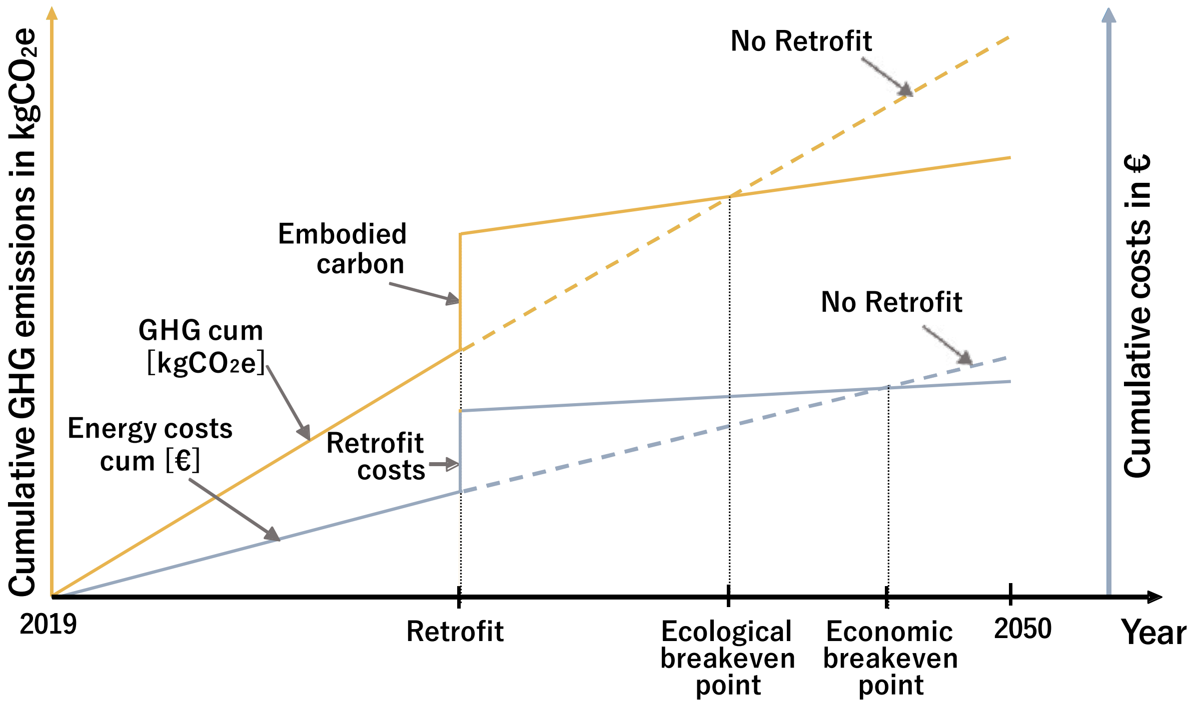


Figure 8: Cumulative GHG emissions, energy costs, and breakeven points of retrofit measures including embodied carbon and retrofit costs (in kg/CO_2e and EUR)

The combination of both figures results in the (3) so-called **carbon-payback period** (in years)—emissions resulting from the investment divided by the annual savings during the use phase. The shorter the carbon-payback period, the more favorable is the energetic retrofit measure from an ecological point of view. The CRREM team already highlighted the need to focus more intensively on this trade-off between embodied carbon and operational savings in its first report[25] formerly referred to as '**Ecological Breakeven Point**'.

Energetic retrofit measures in existing buildings are crucial for decarbonisation strategies. Well-executed renovations within the broader context often offer the greatest emissions reduction opportunities.[26] As elaborated in the subsequent chapters, **adopting a holistic approach is essential** to identify the optimal retrofit strategy for the portfolio.

When addressing embodied carbon, it is crucial to consider the entire life cycle through **LCA (Life Cycle Assessment)**. This methodology, standardised in ISO 14040/14044, encompasses emissions from all life stages, from product production and operation to end-of-life disposal. The life cycle of a building is divided into stages A1–A5, B1–B5, C1–C4, and D. Although the industry primarily focuses on upstream and core activities, which account for approximately two-thirds of the whole-life embodied carbon,[27] stage B and C should not be underestimated. These stages involve repairs, renovations, retrofits, and disposal. Although data may be lacking and comparisons may be challenging due to diverse building characteristics, these stages play a significant role in the overall embodied carbon impact.

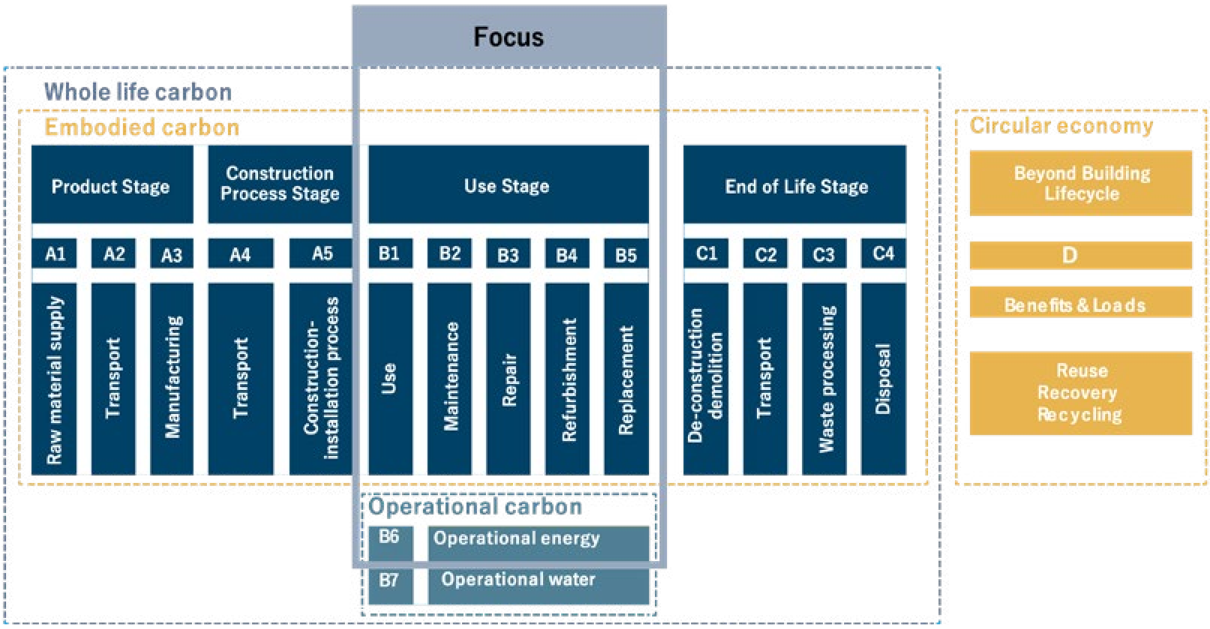


Figure 9: Whole life carbon assessment information[28]

25 Cf. CRREM (2019): STRANDING RISK & CARBON—Science-based decarbonising of the EU commercial real estate sector.

26 European Environment Agency (2022): Modelling the Renovation of Buildings in Europe from a Circular Economy and Climate Perspective.

27 Le Den et al. (2022): Towards embodied carbon benchmarks for buildings in Europe.

28 EN 15978.

Benchmarking embodied carbon still presents a challenge, primarily due to the limited availability of data.[29]

Several organisations have developed guidelines for embodied carbon values.[30] However, these **(first) benchmarks predominantly focus on new construction** projects (stages A1 to A5). For instance, LETI's Climate Emergency Design Guide recommends target values of < 350 kg CO_2e/m^2 for non-residential buildings and < 300 kg CO_2e/m^2 for residential buildings.[31] These benchmarks can be regarded as best-in-class and low-carbon-construction, as other sources such as Ramboll state that current averages for new construction are ranging between 600 kg CO_2e/m^2 (Single-family house) and 750 kg CO_2e/m^2 (Multi-family house) for residential and 600 kg CO_2e/m^2 (Office) and 750 kg CO_2e/m^2 (School and daycare) for non-residential buildings.[32] Hines also states roughly 500 kg CO_2e/m^2 (for A1–A3 stage only).[33] Likewise, wbcsd reports between 500 and 650 kg CO_2e/m^2 for residential and office buildings but advocates a possible reduction of 50% for green projects already today.[34] Given the discrepancies between the status quo and best-in-class low-carbon construction, the industry is striving to reduce embodied carbon in new buildings. However, the same level of attention is lacking when it comes to retrofitting, despite a lot of construction work especially in developed markets is occurring in this domain.

Although predicting embodied emissions and associated costs can be relatively accurate (see chapter 4 and 5), **assessing the embodied life cycle impacts proves to be more challenging.**

The assessment process for energy-related retrofit measures is influenced by various factors, including the **number, timing, and scope of retrofits**. To evaluate accurately the impact of an energy-related retrofit, it may be necessary to distinguish between emissions associated with general maintenance measures and those specifically related to climate protection and energy improvement of the building (as discussed in Chapter 4). Considering the timing aspect, it becomes crucial to examine how the decarbonisation of building materials and the potential for emissions reduction may evolve over time.

In addition, the regional context and diverse uses of buildings have significant implications for embodied carbon considerations. When comparing regions such as Asia Pacific, Europe, and America, variations in climate and used materials have a profound impact on the ecological payback of construction projects. Differences in heating degree days (HDD) and cooling degree days (CDD) contribute to varying energy demands and, consequently, the embodied carbon associated with building materials. Furthermore, different use types, such as residential, office, or retail buildings, require tailored measures to address their specific challenges and opportunities in reducing embodied carbon. By exploring these implications and **understanding the distinct requirements of each region and use type**, we can develop targeted strategies to effectively minimise embodied carbon throughout the built environment.

29 Cf. Cabeza et al. (2021): Embodied energy and embodied carbon of structural building materials: Worldwide progress and barriers through literature map analysis.

30 Cf. Giesekam & Pomponi (2018): Briefing: Embodied carbon dioxide assessment in buildings: guidance and gaps.

31 See LETI (2021): Climate Emergency Retrofit Guide.

32 Le Den et al. (2022): Towards embodied carbon benchmarks for buildings in Europe.

33 Cf. Hines (2022): Embodied Carbon Reduction Guide.

34 Wbcsd (2021): Decarbonizing construction—Guidance for investors and developers to reduce embodied carbon.

Balancing embodied carbon emissions involves **different requirements for various stakeholders**, as outlined in Table 2. Asset owners, typically account for grey energy emissions as Scope 3 emissions. Conversely, project developers consider them under their Scope 2.[35] Tenants, however, hold significant sway over the efficacy of retrofit initiatives, as the observed 'real-life' consumption subsequent to the intervention may either align seamlessly with the anticipated/projected energy reduction or deviate considerably, contingent upon the behavioral choices made by the tenant.[36] Given the divergent interests and influences of each stakeholder-group, ensuring successful energetic retrofits and implementing a comprehensive package of measures can pose significant challenges.

35 Cf. Greenhouse Gas Protocol (2011): Corporate Value Chain.

36 Cf. Bienert, S., Groh A. (2020): Wissenschaftliche Plausibilitätsprüfung bzgl. der errechneten öffentlichen Förderungslücke zur Erreichung der Klimaziele durch energetische Gebäudesanierungen im Mietwohnungsbau.

Table 2: Stakeholders enabling successful low-carbon retrofits

Stakeholder	Influence on Embodied Carbon	Pro-active behavior supporting optimised energetic retrofit outcome
Financial institutions/ banks	Medium	▪ Providing subsidised financing for energetic retrofits ▪ Integrate also data requirements on LCA in credit rating ▪ Make data submission on (possibly inefficient) status quo of energy condition/requirement for renovation roadmaps for existing properties a pre-requisite ▪ Integration of transition risk resulting from the loan book into own risk analysis. Resulting in effects on credit conditions and interest rates (due to changes impacting LGD, PD) ▪ Promoting low-carbon-financing[37]
Asset owner/ investor	High	▪ Also ensure data gathering of embodied carbon within retrofit phase for correct sustainability reporting (Scope 3) ▪ The investors internal (or external) asset management must factor in and align the typical CapEX (Capital Expenditures) cycles with the required energetic retrofitting and must also allocate costs and benefits (as well as the corresponding embodied carbon portion) to the respective investments made
Construction companies	High	▪ Responsible for carrying out the retrofit measures ▪ Increasing capacities for energetic developments ▪ Offering low-carbon solutions ▪ Ensuring proper communication regarding cost-benefit of low-carbon materials ▪ Data reporting and standardisation
Building materials industry	High	▪ Engineering and providing materials ▪ Providing information regarding details of embodied carbon of building material (EPD, see chapter 4) ▪ Further development of low carbon materials and projections of emission factor development (to be integrated in investors‘ strategic planning)
Government/ community	High	▪ Establishes policies, laws, and plans related to energy efficiency retrofits ▪ Providing subsidies where needed if low-carbon-solutions turn out to be more costly for investors and tenants
Consultants/ Service providers	Medium	▪ Ensure/enable proper data gathering and analysis ▪ Support capacity building
Occupier/ user	Low	▪ Fostering demand for highly energy efficient buildings ▪ Focusing on the overall occupancy cost of rented property instead of just net-rent for decision making ▪ Collaboration with investors regarding data sharing (of overall whole building consumptions before and after the measure)

37 Cf. PCAF (2021): The Global GHG Accounting and Reporting Standard for the Financial Industry; NZBA (2022): Progress Report.

Addressing these challenges requires a **collaborative effort and a nuanced understanding** of the interests and motivations of each stakeholder group. By fostering dialogue and aligning objectives, it becomes possible to create an environment where retrofits are seen as attractive and viable solutions. This calls for innovative strategies that consider the entire value chain from asset owners to project developers and occupants, ensuring a **holistic approach to embodied carbon reduction in the refurbishment process**.

Key Takeaways

- Embodied carbon contributes about 11% of all global emissions
- Between 2023 and 2050, embodied carbon can represent over 90% of a new building's emissions
- Often low-carbon and bio-based material can ensure the same operational gains, although resulting one-off embodied carbon emissions can be reduced significantly

Call to Action

- Retrofits should minimize embodied carbon, not just operational emissions
- A clear strategy for embodied carbon needs to be developed and comprehensive data collected
- Lack of benchmarks for retrofit projects needs to be overcome
- Strategic considerations for retrofits: Timing and scope
- Ignoring trade-off will lead to competitive problems and possibly higher transitions risks
- Collaboration of all stakeholders along the value chain is needed

4. Collection of data on embodied carbon of materials

An energetic retrofit typically utilises the existing structures of a building, enabling the preservation of embodied emissions emitted in the past. As a result, a **retrofitted building has the potential to outperform a newly constructed** one when considering its entire life cycle. This advantage can primarily be attributed to the **reduced need for high-impact materials** such as concrete, steel, and other metals (see Figure 18), since these components can typically remain with a retrofit. However, it is important to note that the replacement or installation of specific products such as insulation, windows, and heating systems can still have a significant impact on the energetic retrofit and therefore the extent of the retrofit. Alternative material choices can make a noticeable difference, too.

To **facilitate the assessment of embodied carbon emissions**, relevant information is collected and compiled into an aggregated form within **commercial or governmental/ public (open source) databases**. Globally, various sources are available, offering different benchmarks and datasets on the **environmental impact of construction materials**, as depicted in Table 3. These product databases vary in terms of their: (1) number of included datasets, (2) geographical coverage, the (3) life cycle stages they encompass, (4) data origin and quality, (5) update cycles, as well as (6) availability and access.

Additionally, certain **software solutions have integrated the product benchmarks** derived from these databases, offering a means to determine embodied carbon emissions.

Table 3: Selection of various databases[38]

Provider of database	Name of database	Number of included datasets	Geographical coverage	Life cycle stages covered	Cost/ Access	Data origin	Type of tool	Latest Update
University of Bath	ICE Database	> 200	UK	A1–A3	Free	LCI Data, Reports, Journals, Literature	Excel-based	2019
Federal Ministry for Housing, Urban Development and Building	Ökobaudat	>1,400	Germany	A1–D	Free	EPD, generic data	Online Application	2023
HQE-GBC Alliance	INIES	> 7,000	France	A1–A5	Free	EPD, generic data	Online Application	-
Carbon Leadership Forum/ Building Transparency	EC3	> 90,000	US	A1–A5	Free	EPD	Cloud-based	2023
Sphera	GaBi	> 15,000	EU	A1–C4	Fee required	-	Desktop software application	-
Athena Sustainable Materials Institute	Athena Impact Estimator	> 200,000	US & Canada	A1–C4	Free	TRACI v2.1 Database, Athena LCI Database	Desktop software application	2020
Melbourne School of Desing	Epic Database	> 850	Australia	A1–A3	Free	EPD	Online Application	2019
Nationale Milieudatabase	NMD	> 3.000	Netherlands	n/a	Fee required	EPD, generic data	Online Application	2020
Climate Earth	Climate Earth	> 25,000	US	A1–A3	Fee required	EPD, generic data	Cloud-based	-
ASTM International	ASTM International	> 15.000	US	A1–A3	Free	EPD	Online Application	-

38 These are the databases with the highest availability of data. There are also further databases with a smaller number of data sets.

The verification process is not hamonised. Ökobaudat, for example, relies on verified data suppliers and on generic data sets. Other databases mainly rely on third party datasets and perform uncertainty analyses. Some offerings are commissioned by government entities, whereas others are initiated privately.

The reliability and validity of the included data is significantly influenced by the quality of the EPDs[39]—ranging from self-declared to third-party assured data sources. EPDs set the global standard for quantifying the carbon footprint of construction materials such as concrete. In the year 2023, approximately 130,000 EPDs were accessible, aligning with both EN 15804 (around 40,000) and ISO 21930 (roughly 90,000) standards.[40] They are pivotal in shaping buyers' choices and are guided by industry Product Category Rules (PCRs) that outline reporting requirements. These rules follow ISO guidelines and are updated approximately every five years. Similar to nutritional labels on food, an EPD acts as a comprehensive document used by manufacturers to offer verified insights into their product's environmental performance.[41] Additionally, generic data is frequently presented in a cautious manner to accommodate market heterogeneity. This is achieved by applying a top-up factor to the stated emissions of any given product. Providers typically utilise a **combination of generic and manufacturer-provided datasets** to assess embodied carbon. Generic datasets lack a specific classification of product characteristics and instead focus on comparability for a given component's intended purpose. Conversely, manufacturer-provided datasets may consider unique production methods, such as the use of self-generated renewable energy or low CO_2e-intensive primary materials. However, the transparency of these calculations is not always evident (since they are to some extend self-declared), and carbon offsets may also be factored in.

ISO 21930 and **EN 15804+A2** set **standards for EPDs in the construction product sector.** These standards offer vital information about the environmental impact of these products.

ISO 21930, an international standard, focuses on environmental declarations for construction products through Life Cycle Assessment. It enhances transparency and comparability of environmental data. This standard mandates consistent approaches to data collection, evaluation, and presentation, specifying the aspects to analyze and how results should be communicated. ISO 21930 aids manufacturers in providing precise environmental information, helping stakeholders make eco-conscious choices.[42]

As a regional example, the European Standard EN 15804+A2 establishes rules for creating EPDs for construction products. It provides a comprehensive view of a product's environmental effects throughout its lifecycle, covering extraction, manufacturing, transport, use, and disposal. It also defines the principles of Life Cycle Assessments for construction products, specifying factors such as greenhouse gas emissions, energy use, and resource consumption. This standard ensures consistent data collection and evaluation methods, enabling accurate environmental reporting.

39 An Environmental Product Declaration (EPD) transparently reports objective, comparable and mostly third-party verified data about the environmental performance of products and services from a lifecycle perspective.

40 Cf. Anderson (2023): ConstructionLCA's 2023 Guide to Environmental Product Declarations (EPD).

41 Cf. Hines (2022): Embodied Carbon Reduction Guide.

42 ISO 14025 describes the generally applicable definition for EPDs across all sectors.

The application of a particular database is depending on the specific geographical location of a given retrofit project—clearly properties located in Europe should be analyzed applying European datasets, whereas the embodied carbon emissions for the same measures in the US might be significantly different due to other production processes, longer or shorter transport etc. For instance, the Athena Impact Estimator Calculator is well-known in North America due to its collaboration and compatibility with green building certifications such as LEED®. It utilises average transport distances and allows customisation of results within the United States, accounting for environmental impacts during construction, maintenance, and demolition. Another tool with a regional focus on the United States is the Embodied Carbon in Construction Calculator (EC3). Its publicly accessible database comprises over 90,000 datasets for concrete, steel, wood, insulation, and many other building materials or products. In the UK, the Inventory of Carbon and Energy (ICE) database provides cradle-to-gate data for carbon and energy regarding primary building materials. Its latest publication in 2019 covers over 200 commonly used construction materials.

Table 4 shows as an example the EPD labels of Ökobaudat, indicating frequently employed materials.

Table 4: Excerpt from the Ökobaudat database

Material EPD label	Approx. kg CO2e (GWP) | A1- A3	Unit
Basement Ceiling insulation 4 - 16 cm	2 – 9	m^2
Facade insulation 14 cm - 30 cm	7 – 14	m^2
Rockwool 14 cm - 30 cm	7 – 15	m^2
LED Suspended Luminaire	21 – 36	Piece
Solar panel	104 – 297	m^2
Air water heat pump	643	Piece
Central fan 30000 m^3/h	847	Piece
Gas heat / power plant (500 kW)	4,150	Piece

Embodied Carbon (in kg / unit)

Insulation materials play a crucial role in determining the lifecycle-embodied carbon emissions of a building´s energetic retrofit measure, with their **CO_2e intensity varying greatly, depending on the specific material employed**. Two commonly used materials, expanded polystyrene and rockwool insulation walls, typically exhibit emissions in the range of 7–15 kg CO_2e/m^2 (depending on thickness). Given the same operational gains regarding the resulting energy consumption, it becomes evident that **choosing low-carbon bio-based materials** (e.g. straw, wood, hemp for insulation etc.) has a significant influence on the embodied carbon profile of the retrofit. In contrast to traditional insulation material for facades like illustrated above, bio-based material like hemp can even capture (and not emit) carbon, as the following table illustrates:[43]

43 Note: The U-values of the insulation materials must be considered.

Table 5: Low carbon materials[44]

Material EPD label	Approx. kg CO2e (GWP) | A1- A3	Unit
Straw insulation	-127	m^3
Hemp fibre insulation 10 cm	-2	m^2
Cork panel 6 cm	-0,34	m^2
Cork panel 1 cm	0,03	m^2
Aerogel 1 cm	12	m^2
Wood fibre insulation boards	-82	m^3
Flexible wood fibre panels	-28	m^3
Glass wool insulation 3,4 cm	3	m^2

Embodied Carbon (in kg / unit)

An insulation by wood fiber, which can also be used for the insulation of facades and ceilings, would 'emit' a negative amount from -3.28 to -13.12 kg CO_2e/m^2 with a thickness of 40 mm to 160 mm.

To obtain a preliminary understanding of the emissions associated with a retrofit project, it is possible to utilise one of the mentioned databases and **calculate the total emissions by using the following formula:**

Material quantity [unit] × Carbon factor [kg CO_2e per unit material used]

= Embodied Carbon [kg CO_2e]

Clearly these datasets offer great insights into the carbon-intensity of individual components, allowing for a comprehensive overview of commonly used materials. However, it should be noted that limited industry data is available for the GWP of MEP (Mechanical, Electrical and Plumbing Engineering) systems, as compared to other materials such as concrete, steel, etc.

Besides selecting the correct EPD and related carbon factor, ensuring that only the construction material of the energetic retrofit is analyzed poses another challenge.

In retrofitting projects, the **distribution of embodied carbon emissions and corresponding costs can be categorised into two distinct sets of measures** (see Figure 10).

44 EPDs of: School of Natural Building (SNaB), FASBA e.V., Ekolution, Traspira, Aspen Aerogels, Inc., European Cellulose Insulation Association, STEICO, Isover.

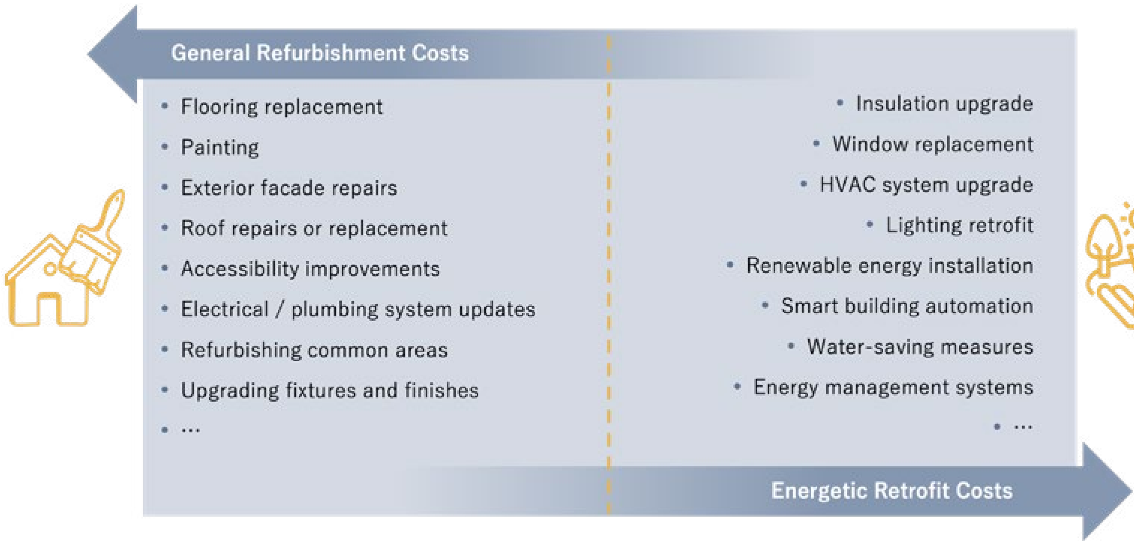


Figure 10: Breakdown of potential embodied carbon measures

The first set of measures addresses the embodied carbon emissions attributed to tenant fit-outs and necessary 'normal' ongoing maintenance and refurbishment activities (**general refurbishment costs**, sometimes also referred to as CapEx). Tenant fit-outs, encompassing interior renovations or customisation, contribute to the building's overall carbon footprint. Similarly, emissions arising from maintenance activities, such as repairs and replacements, must be taken into account. The second set of measures focuses on the embodied carbon associated with the implementation of energy-efficient measures due to the retrofit **(energetic retrofit costs). From a financial and ecological perspective, it would be incorrect to allocate the entirety of investment costs and resulting emissions indiscriminately to energy-related measures.** For instance, if a window with standard insulating glazing is replaced as part of routine replacement cycles, only the cost portion related to the upgrade, such as triple glazing, should be attributed to the energy improvement. In practical implementation, distinguishing between the costs and resulting emissions associated with essential replacements from those pertaining to additional energy-related expenses often poses challenges—since, in most cases, these activities are executed and combined simultaneously. Furthermore, even a 'like-for-like' approach has its limitations, as the enhancement in quality for occupants and the ensuing benefits for the building must also be considered. These benefits include augmented home value, tenant satisfaction, building value, rent, and decreased turnover.

In general, our survey indicates that market **participants are actively striving to incorporate more embodied carbon data in their decision making regarding retrofit projects.** As market participants recognise the significant impact of embodied carbon in the future, its importance becomes evident (see Figure 2)

As a result, the use of the beforementioned databases will become even more important in the future; likewise the need for the (precise) accounting of embodied carbon emissions will increase, stressing the need for more robust and third-party validated EPDs.

Our results also provide insights into how market participants are dealing with the capture of embodied carbon in retrofit projects. Several databases and other sources were used to support this process. Only few companies (14%) collect their own data, relying on consultants instead (38%).

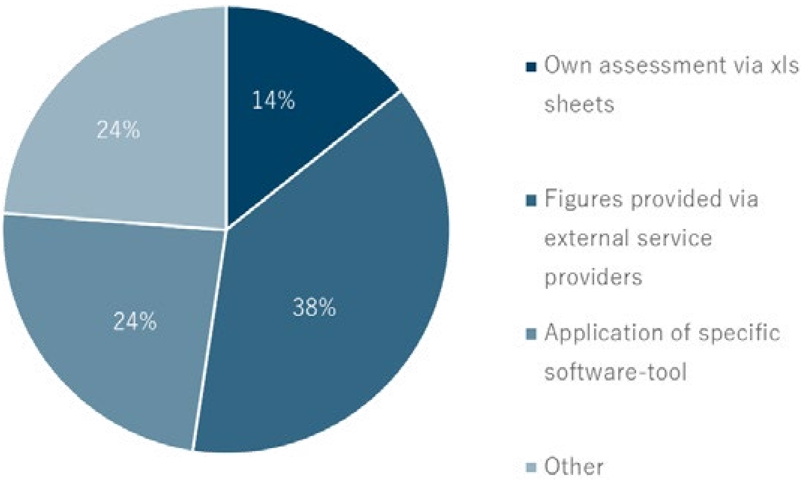


Figure 11: Calculation of embodied carbon by market participants[45]

We note that an increasing number of **software solutions have integrated product benchmarks** derived from the LCAs within these databases, offering means to determine embodied carbon emissions. The use of databases or software-tools (such as: deepki, KPI intelligence, etc.) will facilitate this process and enable market participants to make informed decisions to achieve a more sustainable and low carbon investment.[46] It is important to note that the choice of the database or related software-tool largely depends on the individual preferences and needs of the users. Each product offers its own set of features and functionalities to meet the requirements and objectives of stakeholders.

Understanding the embodied carbon in relation to the operational savings achieved from the retrofit is crucial. By appropriately tackling both aspects, building retrofit initiatives can take a well-rounded approach to reducing carbon emissions over the building's whole life cycle. This enables stakeholders to put the retrofit in perspective when compared to new construction projects.

45 Results of own conducted survey.

46 Cf. ZEBx (2021): Life Cycle Assessment Practice to Estimate Embodied Carbon in Buildings.

Key Takeaways

- Utilizing databases is beneficial for selecting the appropriate materials in a retrofit project
- Existing tools assist in the necessary calculations
- Often low-carbon and bio-based material can ensure the same operational gains, although resulting one-off embodied carbon emissions can be reduced significantly

Call to Action

- Multiple global databases provide information on building material emissions, but significant discrepancies exist, especially regarding EPD data derived from manufacturers
- Currently, there is very limited data available for MEP systems, which makes it difficult to assess the embodied carbon of retrofits that include replacement of MEP systems.
- Investors must prioritize collecting emissions data and carefully evaluate low-carbon options based on cost-benefit analyses
- When energy efficiency retrofits accompany broader refurbishments, users must accurately attribute only the additional emissions resulting from the retrofit.

5. Deriving benchmarks for embodied carbon of retrofits

The available data on embodied carbon of retrofits and the associated operational emissions savings is currently limited and not adequately stored or displayed as a benchmark for interested parties. Thus, comprehensive and accessible information in this area is lacking. To address this gap, we have gathered **data from 12 real estate companies in a sample size of 36 energetic retrofits projects.** These case studies encompass a diverse range of asset classes and varying levels of depth in terms of energy-efficient renovations. Our research faced most challenges in identifying companies that tracked the required data already. Altogether we approached more than 60 investors, asset managers, and consultants. Since all market participants stated that they need the resulting KPIs and intend to track them in the future, this could also be interpreted as a wake-up call for the real estate industry.

The retrofits in our sample contain a variety of measures aimed at reducing energy consumption and emissions. These measures encompass a broad range of improvements, including but not limited to the insulation of the basement, facade, and attic, as well as the replacement of heating and cooling systems and windows. By including such a comprehensive array of retrofit types, our research aims to capture a holistic perspective on the potential emissions savings and energy efficiency gains associated with these measures.

We have gathered data on 47[47] cases, enabling us to analyze 36 of them and subsequently derive the embodied carbon resulting from the investment and calculate the carbon payback period.[48] To ensure a 'like-for-like' comparison, we collect the **gross internal area** (GIA) of the asset in accordance with International Property Measurement Standards (IPMS2). It is evident that the benchmarks derived in this report merely serve as a preliminary foundation for further comprehensive research. Additionally, in this chapter, we aim to highlight selected projects as examples of best practices. The analysis focused on implementing retrofits using conventional materials. However, when considering the utilisation of (even more) low-carbon materials (such as straw insulation or wood fiber insulation) the resulting embodied emissions could be reduced accordingly (to ultimately accomplish a low-carbon-retrofit).[49]

47 Due to data gaps and missing information, only 36 case studies were evaluated in total.

48 To calculate carbon payback, energy consumption must be measured before and after the measure. The difference between these consumption values represents the actual operational savings. In addition to energy consumption, it is important to consider the materials used in the retrofit. The value of kg CO2e associated with the production-stage of these materials are offset against the savings achieved by the measure. This calculation determines the carbon payback in years.

49 Cf. Besana & Tirelli (2022): Reuse and Retrofitting Strategies for a Net Zero Carbon Building in Milan: An Analytic Evaluation.

It is important to **distinguish between the life cycle of the building and the products used for the retrofit**. While the emissions considered here belong to life cycle phases B (mainly B4) for the building (see Figure 9), they have their own life cycle at the product level. For the calculations made here, the product level is therefore decisive in accounting for the emissions occurring during the life cycle phase B4 of the building. To be able to use the results as broadly as possible, we **consider the product life cycle phases A1 to A3**. Since the **emissions from transport and construction can vary greatly** from one project to another, the resulting figures cannot be generalised. Most databases reveal benchmarks for the life cycle phases A1–A3 more accurately, or even do not present the phases B–D at all (see Table 3). As such the life cycle phases B–D were not included in our calculation.

To classify retrofit measures based on the degree or intensity of intervention, we categorise them into three **'Scopes of Retrofit' (Light, Medium, or Deep)**, depending, on the one hand, on asset class and, on the other hand, on the scope of the measures carried out in relation to the costs.[50] However, defining the project scope can be challenging as it is not always straightforward to categorise a retrofit as light, medium, or deep. This is because measures that promise high savings may not necessarily be expensive, and costly measures may not always result in significant energy savings in the use-phase. To simplify the evaluation process, a practical criterion that must be considered is the amount of embodied carbon implemented, expressed in kg CO_2e/m^2. Examples of light, medium, and deep retrofit measures include:

- **Light measures** that require minimal effort, such as replacing light bulbs with LEDs or the optimisation of the BMS (Building Management System), leading to a fast carbon payback due to low material input;
- **Medium measures**, such as facade insulation or window replacement, that significantly change the building but exclude structural interventions;
- **Deep retrofits** that occur when an asset has reached a certain stage of its life cycle (see Figure 9) or when calculated savings greatly reduce operational consumption. They involve major equipment replacement, complete renewal of the building envelope (facade and windows), and result in substantial reductions in net energy. Extensive retrofits often require long-term planning, e.g. they are typically undertaken during renewal events, in case of new occupancy or ownership, and for green building certifications. Deep retrofit measures should be prioritised in buildings over 35 years old.

50 Note: The definition of the scope of measures in the light, medium, and deep categories is defined by the authors and does not follow a standardised definition. One possible definition can be found, for example, in UKGBC (2022): Delivering Net Zero: Key Considerations for Commercial Retrofit.

Table 6 provides an overview of the different retrofit segments and their corresponding characteristics, resulting from our samples:

Table 6: Scope of retrofits

	Light	Medium	Deep
Typical carbon payback in years	**~ 1,3 year**	**~ 4,1 years**	**~ 4,4 years**
Typical measures	▪ Replacement of convention light bulbs with LED light bulbs ▪ Insulation attic ▪ HVAC replacement and retro-commission-ing ▪ Other electronical measures with low risk and short payback periods	Individual measures on the building envelope: ▪ Façade and roof insu-lation ▪ Basement insulation ▪ Replacement of windows ▪ Remediation of ther-mal bridges ▪ Improved building air tightness	Measures on the entire building envelope: ▪ Window replacement ▪ Combined bundle of HVAC, thermal enve-lope, and renewable power and heat supply ▪ Downsizing of HVAC system due to lower heating and cooling demands ▪ Elimination of perime-ter zone conditioning ▪ Building envelope insulation ▪ Improved airtightness
Tips for optimization	Take note of the low-hanging fruit: ▪ Review of the heating systems and power supply (Electrical / plumbing system updates) ▪ Install occupancy sensors or timers to automatically control lighting in areas with low occupancy ▪ Install smart meters	▪ Choose low carbon material (e.g. renew-able raw materials) ▪ Prioritize insulation upgrades in the build-ing envelope, particu-larly in areas with the highest heat loss or gain ▪ Address and remediate thermal bridges to improve the overall thermal performance of the building ▪ Evaluate the cost-ef-fectiveness of each measure bundle and consider the long-term benefits of energy savings and comfort improvements	▪ Choose low carbon material (e.g. renew-able raw materials) ▪ For retail: the replace-ment of old refrigera-tion systems should be accelerated ▪ Take a holistic approach by combin-ing HVAC system upgrades, thermal envelope improve-ments, and renewable power and heat supply solutions. ▪ Conduct thorough modeling and life cycle cost (LCC) analysis to determine the tech-nical characteristics and economic viability of core technology measures

Altogether our data request for the retrofit projects included:

- Materials used in the retrofit (in quantities)
- Size of the project (in m^2 GIA)
- Overall investment cost of the energetic retrofit (in EUR)
- Energy consumption (before and after) incl. energy source split

As a result, the following key figures of the retrofits were calculated:

- Cost of energetic retrofit (in EUR per m^2)
- Embodied carbon of energetic retrofit (in kg CO_2e/m^2)
- (Operational) Carbon intensity (in kg CO_2e/m^2/year before/after retrofit)
- (Operational savings) Reduced carbon intensity (in kg CO_2e/m^2/year)
- Carbon payback period (in years)
- Grouping of the retrofit (light, medium, deep)
- Stranding Point[51] in CRREM (in year before/after retrofit)

For your own asessment of the embodied carbon in a retrofit, we recommend that you record the information as shown in the Appendix.

51 Cf. CRREM (2022): Managing Transition Risk in Real Estate.

Our research has a broad geographical scope, encompassing assets from 11 countries across the globe and allowing for a diverse representation of various markets, regulatory environments, and climate conditions. The distribution of asset classes is illustrated in Figure 12:

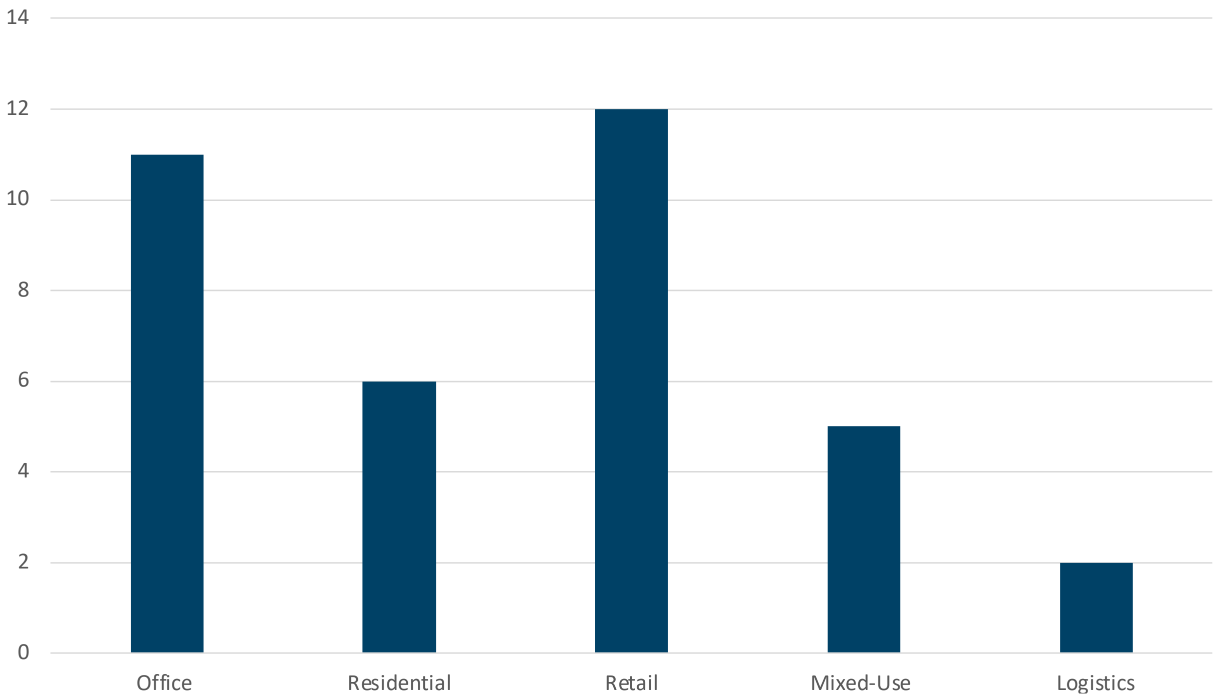


Figure 12: Asset types[52]

Depending on the asset class, the individual **retrofit measures can vary significantly**. Residential retrofits are characterised by building envelope upgrade, installation of PV (photovoltaic) systems, or implementation of more sustainable heating systems. Our research has especially for commercial assets shown that **retrofit measures involving the replacement of older cooling systems** can have a particularly high impact and enable significant environmental benefits. This is due to the high GWP of refrigerants (F-gases) emitted by outdated cooling systems.

Figure 13 and Figure 14 illustrate the distribution of CO_2e values of embodied carbon of retrofits over the whole sample:

52 Allocation of the analyzed case studies by asset types.

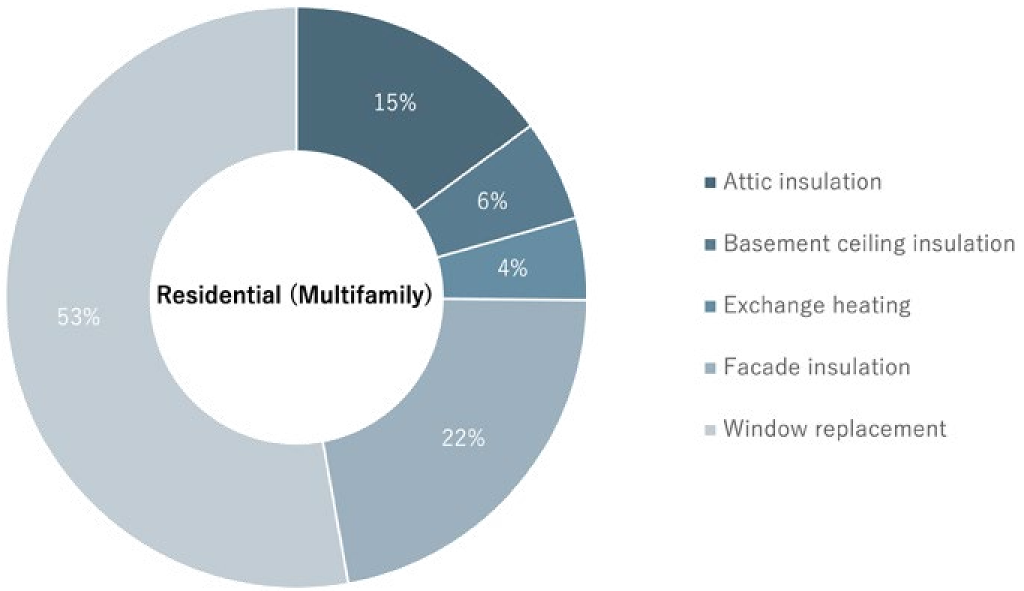


Figure 13: Embodied carbon of analysed measures (multi-family)

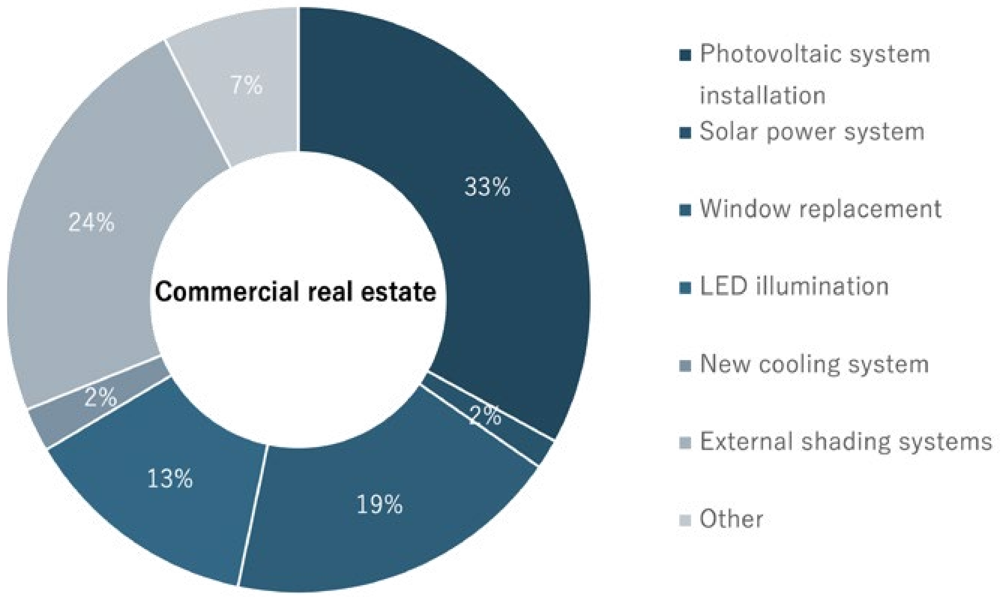


Figure 14: Embodied carbon of analysed measures (commercial real estate)

Only very little research has been done regarding precise benchmarks for the embodied carbon emissions of retrofit measure and even less research was undertaken addressing the next analytical step which would be the trade-off between embodied emission of the retrofit vs. operational savings resulting thereof. One of the few studies was a report in France on seven case studies. Carbon payback for optimised projects was ranging between 5 and 7 years with corresponding one-off embodied emissions for most projects that did not include cultural heritage or complete redevelopment between 150 kg CO_2e/m^2 and 250 kg CO_2e/m^2.[53]

53 Alliance HQE (2022): NZC RENOVATION COLLABORATIVE INNOVATION PROGRAMME Optimisation and NZC scenarios of selected generic cases. **Note:** Differences in the scope of the measures, result in the different embodied carbon figures and therefore in different carbon payback periods. This must be considered when comparing cases studies.

Besana & Tirelli (2022), in their examination of an individual office building in Milan, demonstrate that by conducting a deep retrofit to achieve a Net Zero Carbon Building standard and incorporating low-carbon solutions such as wood structures and bio-based materials for insulation and finishes, the emissions associated with these measures totaled only 72 kg CO_2e/m^2 for the A1–A3 stages.[54]

The materials and construction components utilised in our case studies are primarily conventional in nature and thus not particularly low-carbon or similar.

In the overall context of our case studies, Figure 15 presents a comprehensive summary that outlines our findings regarding the evaluation of ecological payback in relation to the extent of the retrofit and embodied carbon:

Table 7: Average figures of the dataset

	$kWh/m^2/a$	kg $CO_2/m^2/a$
Average consumption before retrofit	188 $kWh/m^2/a$	40 kg $CO_2/m^2/a$
Average consumption after retrofit	109 $kWh/m^2/a$	26 kg $CO_2/m^2/a$

Averaged achieved savings:

Deep:
25 kg $CO_2/m^2/a$

Light and Medium :
10 kg $CO_2/m^2/a$

54 Cf. Besana, D., Tirelli, D. (2022): Reuse and Retrofitting Strategies for a Net Zero Carbon Building in Milan: An Analytic Evaluation.

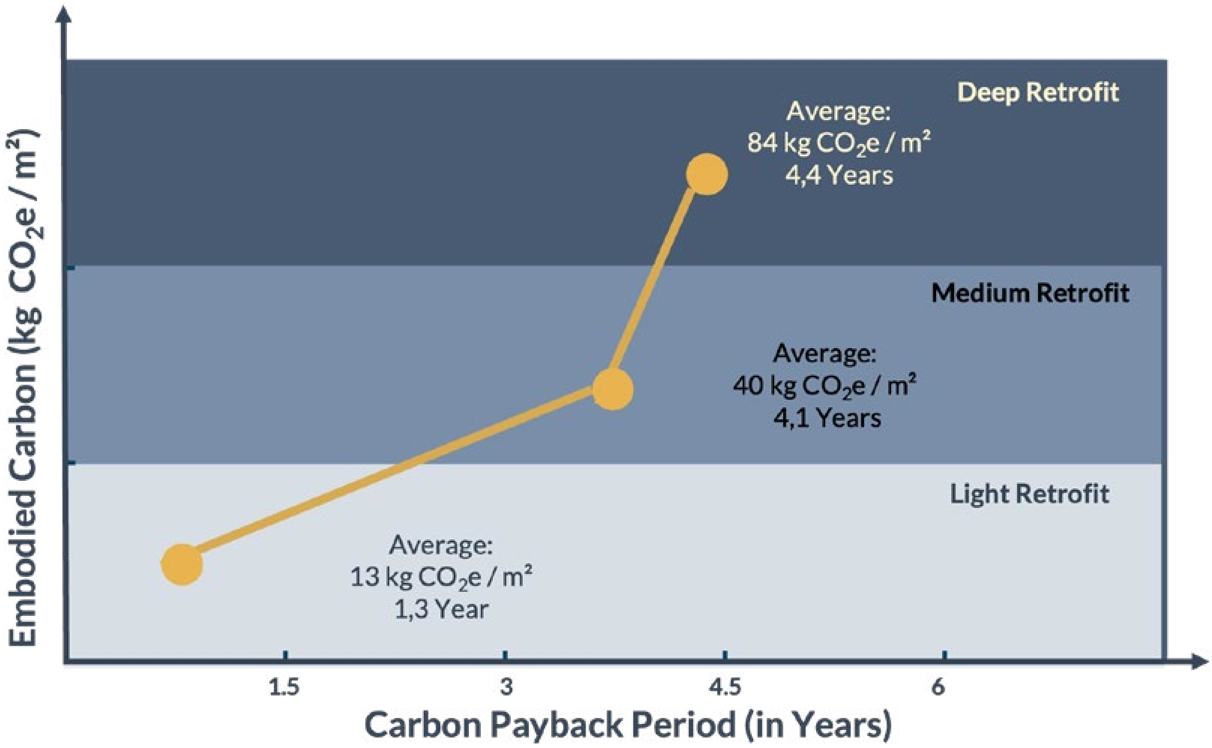


Figure 15: Aggregated results based on analyzed Case Studies[55]

To address the characteristics of each asset class, **four case studies** of individual retrofits are presented.

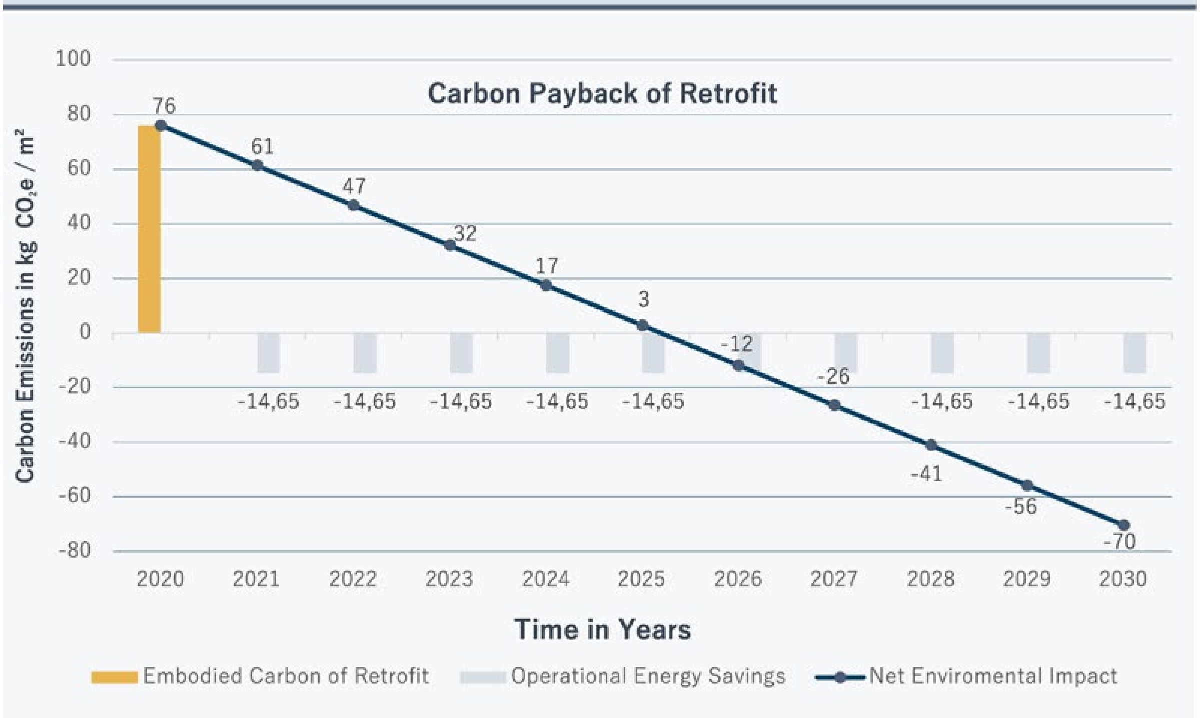
55 The retail properties were not considered for the calculation of the medium scope of the retrofit, as the carbon payback is lower than 0.4 years in all cases. Note: This is a very reasonable measure with high savings and low embodied carbon.

Case Study 1: Residential Retrofit

Asset Type	Residential / Germany
Gross Internal Area	500 – 1,000 m²
Retrofit Embodied Carbon	76 kg CO_2e/m^2
Costs per sqm	705 €/m²
Scope of Retrofit	Medium
Carbon Payback Period	5.2 Years

Measures taken:

- Enhanced energy efficiency through facade insulation with polystyrene insulation and mortar, reducing heat loss and improving thermal performance.
- Upgraded windows to PVC frames, enhancing insulation and reducing energy consumption.
- Improved attic insulation using rockwool insulation, minimizing heat transfer and improving energy efficiency.
- Enhanced basement ceiling insulation with polystyrene insulation, preventing heat loss and improving overall energy efficiency in the building.
- There has been no change to the heating system.

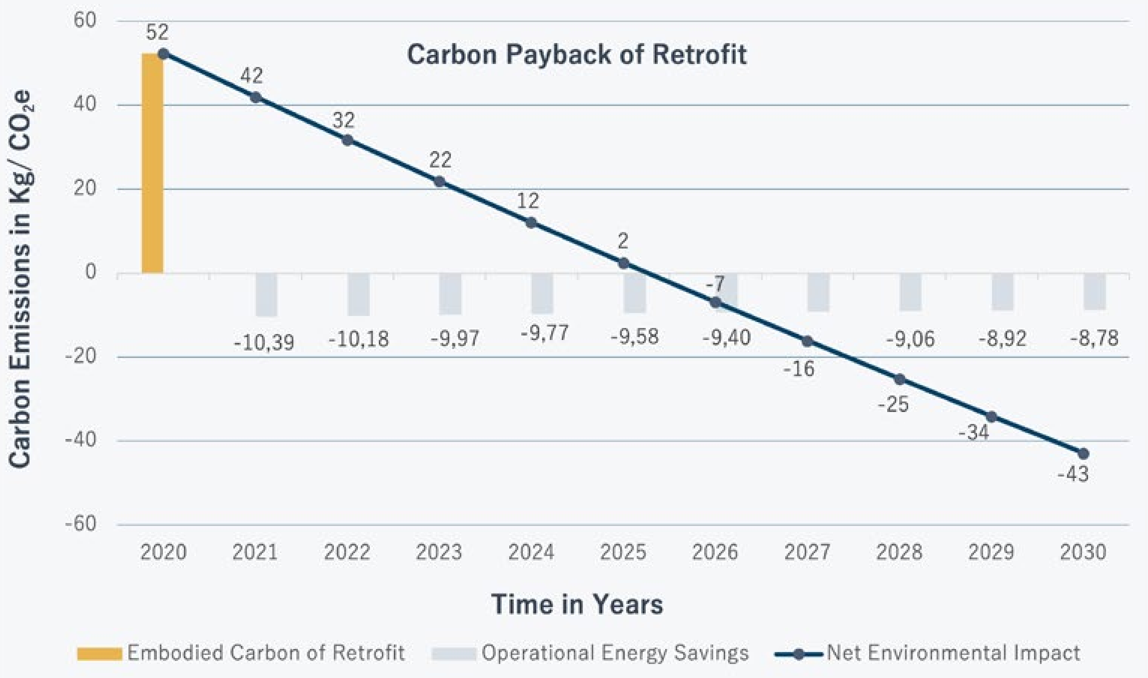


Case Study 2: Office Retrofit

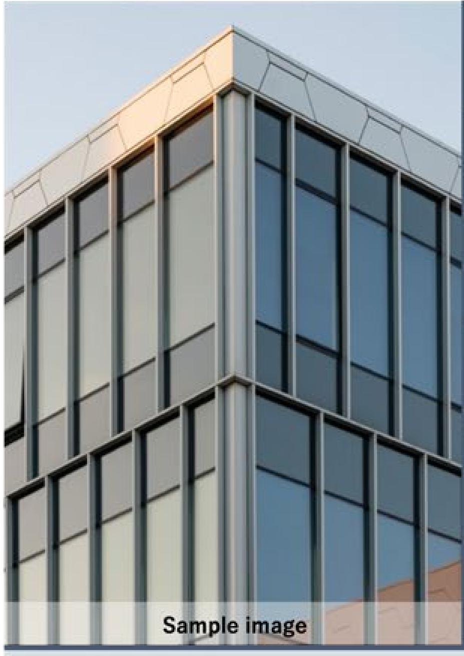
Asset Type	Office / USA
Gross Internal Area	25,000 – 35,000 m²
Retrofit Embodied Carbon	52 kg CO_2e/m^2
Costs per sqm	188 € / m²
Scope of Retrofit	Medium
Carbon Payback Period	5.3 Years

Measures taken:

- Photovoltaic system installation (approx. 1,000 m²)
- Installation of external shading systems
- Dx Unit upgrade - high efficiency, variable speed: Upgrading the direct expansion (Dx) unit to a high-efficiency model with variable speed capabilities
- Chiller Water Cooling Conversion: Conversion from air-cooled chiller systems to water-cooled chiller systems
- Building integrated Photovoltaic system installation



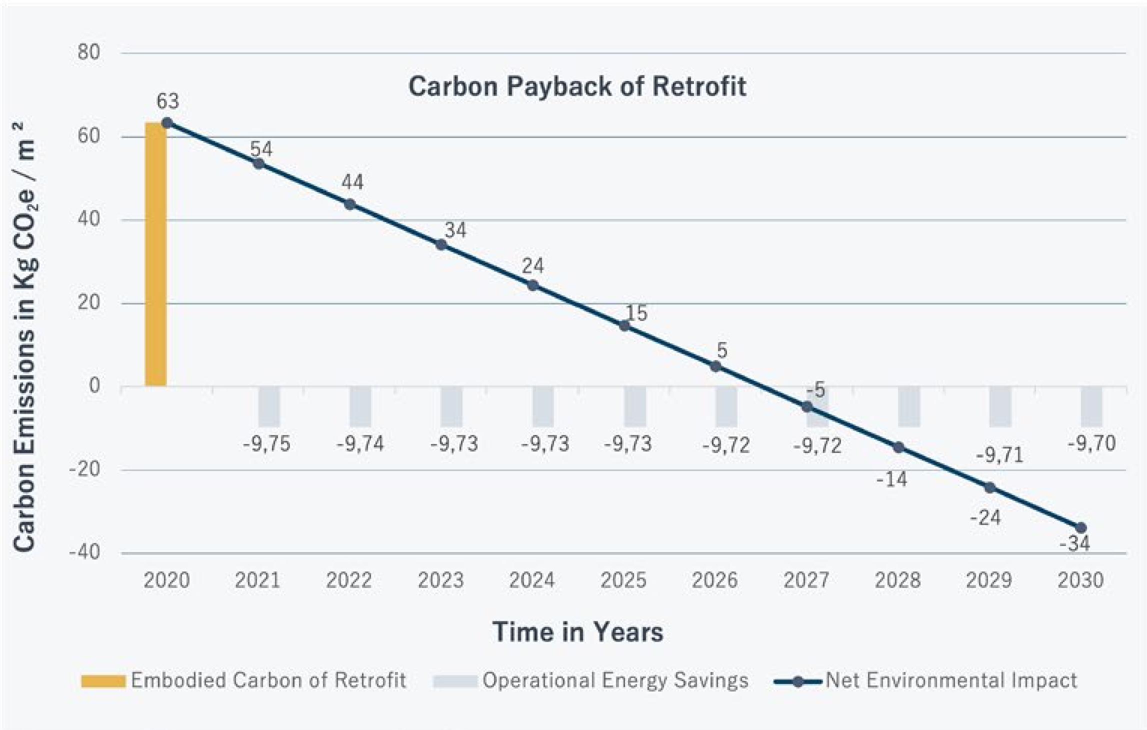
Case Study 3: Mixed-Use Retrofit



Asset Type	Mixed-Use / Germany
Gross Internal Area	12,000 – 20,000 m²
Retrofit Embodied Carbon	63 kg CO_2e/m^2
Costs per sqm	368 € / m²
Scope of Retrofit	Deep
Carbon Payback Period	6.5 Years

Measures taken:

- Upgraded the lighting to energy-efficient LED fixtures
- Replaced the windows with modern, high-performance windows, improving insulation and minimizing heat loss or gain
- Installed a photovoltaic (PV) system on the building (approx. 300 m²)
- Implemented a comprehensive roof insulation measure, including a 16 cm insulation layer effectively minimizing heat transfer and optimizing energy efficiency



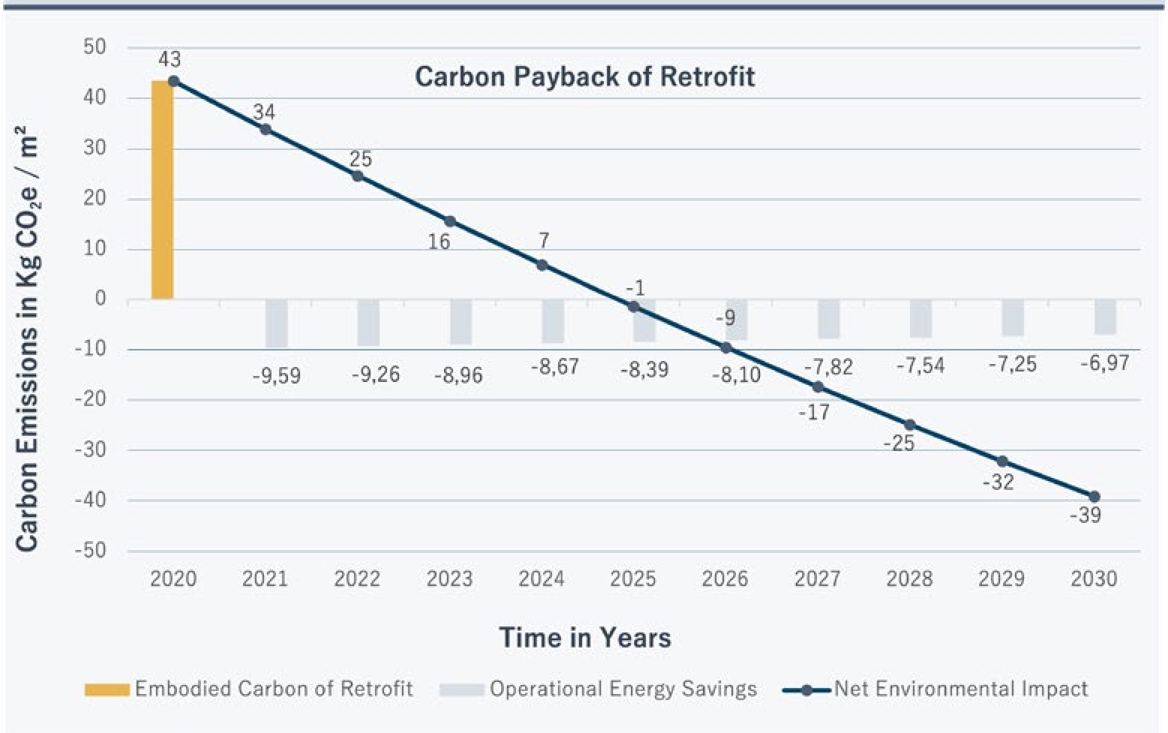
Case Study 4: Logistics Retrofit

Sample image

Asset Type	Logistics / UK
Gross Internal Area	2,500 – 5,000 m²
Retrofit Embodied Carbon	43 kg CO_2e/m^2
Costs per sqm	425 € /m²
Scope of Retrofit	Medium
Carbon Payback Period	4.8 Years

Measures taken:

- Electrification of heating: installation of air to water heat pump
- Underfloor heating
- LED exchange
- Insulation of facade with stone wool insulation
- Insulation roof with glass wool insulation



The case studies provide exemplary illustrations of the heterogeneity of key performance indicators across different asset classes. Based on our initial findings we suggest some basic KPIs and present first benchmarks[56] for residential and commercial properties:

Residential real estate (Multifamily)				
	Light	**Medium**	**Deep**	***New building*[57]**
Savings	< 25% of energy consumption	25–50% of energy consumption	> 50% of energy consumption	*n/a*
Embodied carbon/ m^2(current market practice)	n/a	In our cases 20 to 80 kg CO_2e/m^2		*600–700 kg CO_2e/m^2*
Typical carbon payback period in years	n/a	1 up to 5 years		*n/a*
Commercial real estate				
	Light	**Medium**	**Deep**	***New building*[5]**
Savings	< 25% of energy consumption	25–50% of energy consumption	> 50% of energy consumption	*n/a*
Embodied carbon/ m^2 (current market practice)	Up to 30 kg CO_2e/m^2	In our cases up to 140 kg CO_2e/m^2		*600–750 kg CO_2e/m^2*
Typical carbon payback period in years	Below 3 years	Up to 8 years		*n/a*

Table 8: Benchmark overview

Clearly our findings can only be regarded as a first starting point and call for more research on this topic: Especially a wide variety of regional datasets and a significant sample for each asset class would be needed to enable investors to analyze their energetic retrofit alternatives in a more profound way going forward.

56 The present benchmarks refer only to stages **A1–A3** (cradle-to-gate). The reason for this selection is that this is the most accurate data base for the calculation. Stages A4–A5 are individual, depending on the location of the building and the transportation methods used. (Note: The value of the benchmark would change/increase if stages A4–A5 were included).

57 Le Den et al. (2022): Towards embodied carbon benchmarks for buildings in Europe.

Key Takeaways

- The different asset classes exhibit significant heterogeneity in terms of embodied carbon in retrofits
- Particularly short carbon payback times are observed when replacing cooling systems with high GWP

Call to Action

- Stakeholders are encouraged to further improve the data foundation
- The calculated carbon payback values can serve as a benchmark for upcoming retrofit measures.
- In terms of ecological payback, bundling coordinated measures can be useful

6. Recommendations for action

It will be essential for market participants to begin measuring and evaluating the embodied carbon of retrofits. To enable these comprehensive sustainability assessments, it is crucial to address both operational and embodied impacts. This involves analyzing the carbon emissions and resource consumption associated with retrofit materials, construction processes, maintenance, and eventual demolition. By incorporating considerations of embodied carbon into energetic retrofit projects, stakeholders can actively contribute to long-term sustainability goals and develop strategies that minimise carbon emissions and lower their Scope 3 figures accordingly. Moreover, prioritising retrofit projects with **favourable ecological payback aligns with** a company's emission reduction targets across all scopes. The strategic imperative is to use available data to align retrofit measures with their environmental impact, and ultimately to **derive a strategy for the interplay between operational and embodied emissions at the portfolio level.**

In order to adequately address environmental concerns, research on energy efficiency retrofits underlines the need for market participants to expand their understanding in several critical areas.

The following summarises a key considerations:

- From an environmental perspective, it is important to determine **which assets** should be remediated first and to what extent. Factors such as environmental impact, resource efficiency, and potential energy or costs savings must be taken into account. A thorough analysis and assessment is needed to identify and prioritise the actions required.
- Another important part are **data needs** and **ongoing data collection**. To make informed decisions, sufficient and accurate information on the condition of the equipment, energy consumption, and other relevant parameters must be available. In this regard, ongoing monitoring and regular data collection are required to track the progress of refurbishments and to identify potential improvements.
- The **selection of materials** also plays a crucial role. It is important to use fabrics that have a high energy efficiency and a low environmental impact. It is advisable to rely on sustainable and environmentally friendly products to achieve long-term ecological benefits (low-carbon retrofits).
- **Integrating retrofit measures into long-term** budgeting and investment planning is another important step. A more holistic strategic approach is needed to identify and plan for the necessary financial resources. Long-term budgeting enables efficient implementation of remediation measures and helps to outbalance environmental goals with economic considerations.

- Finally, **developing an appropriate policy framework** is essential. Global harmonisation, incentives for low environmental impacts of retrofits and increased requirements regarding the transparency and data sharing of operational and embodied emission will be corner stones to enable more low-carbon retrofits. Consistent standards facilitate the sharing of information and experience among market participants and promote continuous improvement.

The evolving regulatory framework holds significant importance for the building sector, as regulations play a pivotal role in driving sustainable practices. Not only the European Union is actively pursuing more ambitious regulations pertaining to Life Cycle Assessment and embodied carbon limits, demonstrating their commitment to advancing sustainability in the industry. Furthermore, the global evolution of policy instruments for the implementation of carbon pricing will incentivise low carbon solutions while increasing the cost of present construction techniques and materials.[58] We identified in various regions a **wide range of different policy instruments that were lately introduced or are about to be released in order to promote more low-carbon construction:**

- Public procurement could prioritise properties with optimised embodied carbon profiles and favorable EPDs.
- Financial incentives such as subsidies or tax reductions might be available for low-carbon retrofit projects, adaptive reuse, or preservation efforts.
- Pre-requisites for construction could include disassembly, adaptability, and circularity criteria.
- Strategies focused on material performance and implementing carbon limits/caps for procuring building materials could be introduced.
- Circular economy strategies and transformative solutions that minimise emissions might be promoted.
- Regulations pertaining to construction waste diversion are likely to become more stringent.
- Prohibition of demolition, permitted only when scenarios are compared. Demolition and new construction will be approved only if it results in lower CO_2 emissions.

The real estate industry is not yet sufficiently prepared for most of these policy interventions. Especially the upcoming circular economy regulations and material quotas will require significant efforts within our sector.[59]

To outperform their respective markets, companies must **prioritise staying ahead of regulatory requirements**. By proactively adhering to emerging sustainability standards, organisations can establish themselves as leaders in sustainable building practices and gain a competitive advantage. It is crucial to acknowledge the interdependence between data availability and regulatory frameworks within the building sector.

58 UKGBC (2023): Carbon Offsetting and Pricing Guidance; Worldbank (2023): State and Trends of Carbon Pricing 2023.

59 ibid.

Over the recent decades, the real estate industry has witnessed significant transformations driven by regulatory measures. However, to address this challenge effectively, there is **a clear need for regulations that ensure independent verification and oversight.** In addition, regulations should tackle other critical issues, including the requirement for certified and verifiable data at every stage of the building lifecycle, starting from the asset level. The presence of **reliable and transparent data plays a crucial role** in assessing sustainability performance and ensuring accountability.

Summarising our research findings, we can derive the following five steps as actionable recommendations for investors and asset managers:

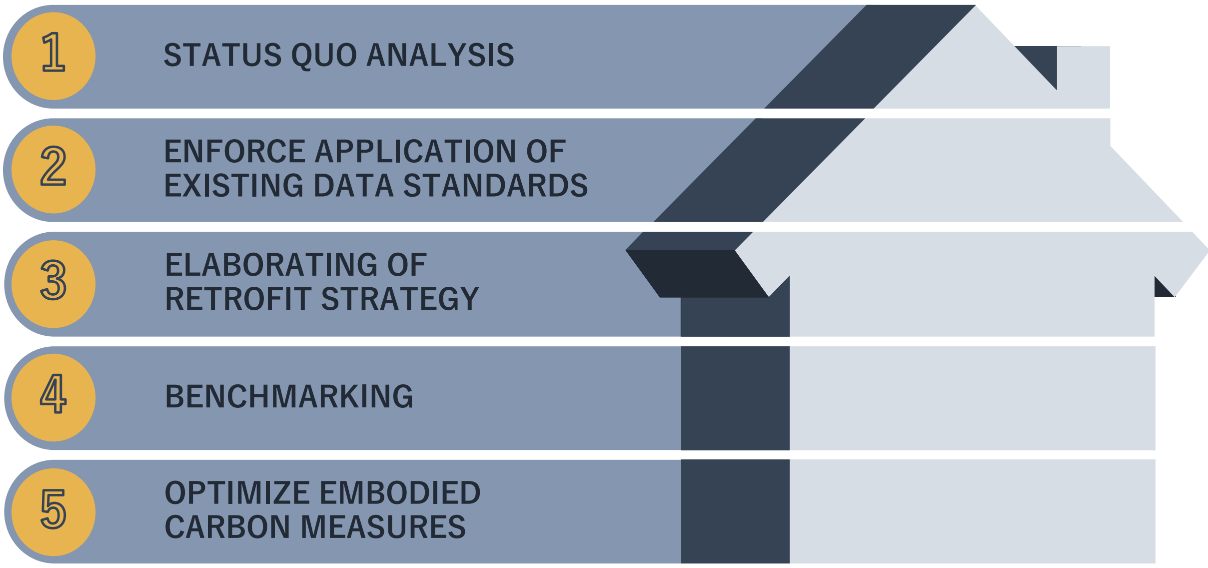


Figure 16: 5-Step Embodied Carbon Optimisation Approach

1. Status quo Analysis:

This should also involve utilising CRREM pathways.[60] Placing a priority on identifying and addressing buildings with significant operational emissions is essential. Data sources and activities should encompass the following information:

- CRREM portfolio analyses to derive the current carbon intensity profile of the portfolio and evaluate gaps regarding a 1.5-degree-Paris aligned situation,
- Defining and closing data gaps, reducing assumption-based decision making,
- Defining strategic priorities and investment budgets for short-, mid- and long-term refurbishments,
- Increasing the capacity and frequency for data

60 Cf. CRREM (2022): Managing Transition Risk in Real Estate.

Based on a thorough assessment of the current situation, properties were identified that should be prioritised for energetic retrofits. However, this would require additional analytical steps to clearly define and optimise the ecological impact.

2. Enforce Application of Existing Data Standards:

While operational emissions are already widely monitored in the industry, only 50% of respondents currently perform a comprehensive assessment of embodied carbon. However, an encouraging 85% of respondents plan to measure and analyze embodied carbon in the future.

To **ensure standardised decision-making processes for retrofits** and avoid inaccuracies, it is crucial to establish clear guidelines for uniform data collection methods.

To avoid duplication efforts, it is crucial to adhere to support established global standards for carbon counting. This involves specific guidelines, recommendations, norms and methodologies, such as the RICS Professional Statement titled 'Whole life carbon assessment for the built environment,' which serves to clarify the stipulations outlined in EN 15804,[61] EN 15978,[62] and the worldwide ISO 21930. These standards define the prerequisites for conducting a uniform Life Cycle Assessment.

The utilisation of the International Construction Measurement Standards (ICMS) is also an option. ICMS places a greater emphasis on standardised measurement and evaluation of construction expenses and other quantifiable factors within the construction sector. This multifaceted approach ensures comprehensive adherence to recognised guidelines and streamlines the carbon assessment process.

Collecting **comprehensive data on quantities and alternative options regarding the construction material** that could be installed in the course of the energetic retrofit is important. Without this essential information, accurate calculations of the retrofit's embodied carbon is not possible.

Key performance indicators include:

- Embodied carbon (kg CO_2e/m^2)
- Operational emission savings (kg CO_2e/m^2/year)
- Carbon payback period (in years)
- Cost of retrofit (in EUR per m^2)
- Materials used in the retrofit (in quantities)
- Emission factor of the materials used (kg CO_2e per unit)
- Stranding Point (before/after retrofit)
- Lifecycle analysis of the building

61 Aims to manufacturers of construction products who wish to provide accurate and comparable information on the environmental impact of their products in order to facilitate the selection of environmentally friendly products.

62 This standard is intended for building professionals who would like to perform a comprehensive assessment of the environmental impact of buildings.

It is imperative for market participants to adopt a **holistic approach** when making retrofit investment decisions, **considering both financial and ecological aspects**, such as the embodied carbon payback period.

40% of the surveyed participants still rely on external service providers for data collection. Given the growing importance and regulatory requirements that are the primary drivers of the embodied carbon discussion for the majority of respondents (90%), building internal capacity and expanding staff with qualified experts appears beneficial and cost effective in the long run.

3. Elaboration of Retrofit Strategy:

Developing a comprehensive retrofit strategy entails careful deliberation of **cost considerations alongside the potential for embodied carbon savings** (and at the same time maximising the reduction of operational emission).

The majority of surveyed market participants presently formulate their retrofit strategy primarily based on financial indicators, neglecting the ecological lifecycle perspective in their analyses, with only 50% considering it. Our research shows that even the best market participants do not have enough explicit information to allow embodied carbon to be accurately calculated. Consequently, in many cases, a foundation for informed decision-making regarding alternative retrofit packages did not exist.

To ensure a thorough evaluation, it is advisable to assess the embodied carbon of all renovation measures within the framework of a whole life carbon assessment. **Market participants are urged to include their strategic decisions and corresponding calculations of embodied carbon in retrofit efforts as part of their ESG reporting** to demonstrate their commitment to sustainable practices.

Priority in implementing retrofit measures should be given to properties that offer the highest GHG (greenhouse gas) savings per unit of invested capital and, at the same time, fostering optimal environmental impact. Thoughtful sequencing of retrofit initiatives, devised with a long-term perspective, allows for the maximisation of their cumulative effect. In this context, it is essential to **develop energetic retrofit roadmaps that are linked to the overall development and life cycle** of the property: tenant turnover, planned renovations, regular CapEx expenditures for building maintenance, or planned disposals can provide useful linkages.

Embracing these fundamental principles empowers stakeholders to craft robust retrofit strategies that harmonise financial objectives with environmental sustainability goals. The practical procedure is illustrated in Figure 17, outlining the step-by-step process:

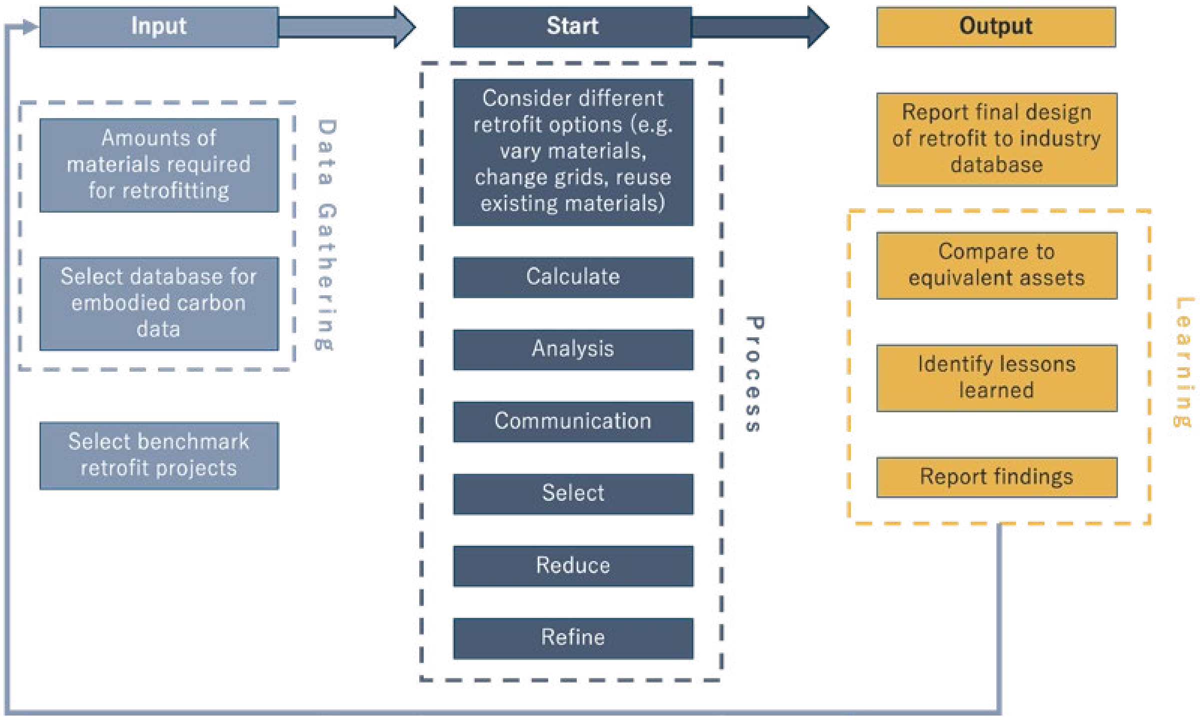


Figure 17: Process map for implementation of embodied carbon calculations[63]

4. Benchmarking

Benchmarking plays a crucial role in **assessing and validating retrofit strategies**. While it is increasingly common knowledge to have a clear idea of a 'good' energy consumption level or the operational carbon-intensity of a property, most market participants lack benchmarks for determining favorable or unfavorable levels of embodied carbon emissions in retrofitting projects.

Benchmarks from external sources can be implemented at various stages of the LCA, commonly observed at the asset, product, and individual measure levels. We propose **(1) indicators for the embodied carbon of light, medium, and deep retrofits based on current market practice** and standard material choices, as well as **(2) benchmarks for low-carbon and bio-based retrofits** at asset level. By combining this embodied carbon figure with resulting operational savings over time, the **(3) carbon payback-period** can be derived. Given that different regions have varying requirements for building materials due to their distinct heating and cooling days, it is crucial to consider regional alignment when selecting benchmarks. In addition to benchmarking emissions, financial indicators associated with retrofit initiatives can also be considered.

63 Own depiction based on The Institution of Structural Engineers (2022): How to calculate embodied carbon 2nd edition.

Chapter 4 provides an overview of additional external databases that offer valuable insights into typical GHG-emissions associated with construction materials and products. These databases can serve as a source for obtaining more underlying information on carbon factors and related data, enabling a more comprehensive understanding of the embodied carbon of different materials choices made. Yet it is also important to note that data quality needs to improve.[64] This ultimately supports the selection of **low-carbon-materials**.

It is important to note that benchmarking can be conducted not only using external data, but also internal data based on results of projects carried out. **Establishing an internal database** proves advantageous in this regard, enabling informed decision-making and enhancing the effectiveness of benchmarking practices.

5. Optimise Embodied Carbon Measures

Based on the gathered information, external and internal benchmarks and the retrofit strategy, the final step involves assessing the ecological benefits of retrofit measures and determining if further optimisations of already planned measures or/and additional retrofits are required to achieve the company's targeted emission reductions. **Comparing different materials can enhance the ecological benefits**, although some low-carbon materials may still face challenges such as limited economies of scale. Figure 18 categorises construction materials based on their total share of embodied carbon within the global infrastructure context. Special attention is directed towards the primary contributors, cement and steel, which collectively account for over 60% of the embodied carbon. Nevertheless, **substantial potential for reduction exists** and can be significantly influenced through the implementation of intelligent processes and the selection of **Low-Carbon Materials**.

64 Cf. Mohebbi et al. (2021): The Role of Embodied Carbon Databases in the Accuracy of Life Cycle Assessment (LCA) Calculations for the Embodied Carbon of Buildings; Waldman et al. (2020): Embodied carbon in construction materials: a framework for quantifying data quality in EPDs.

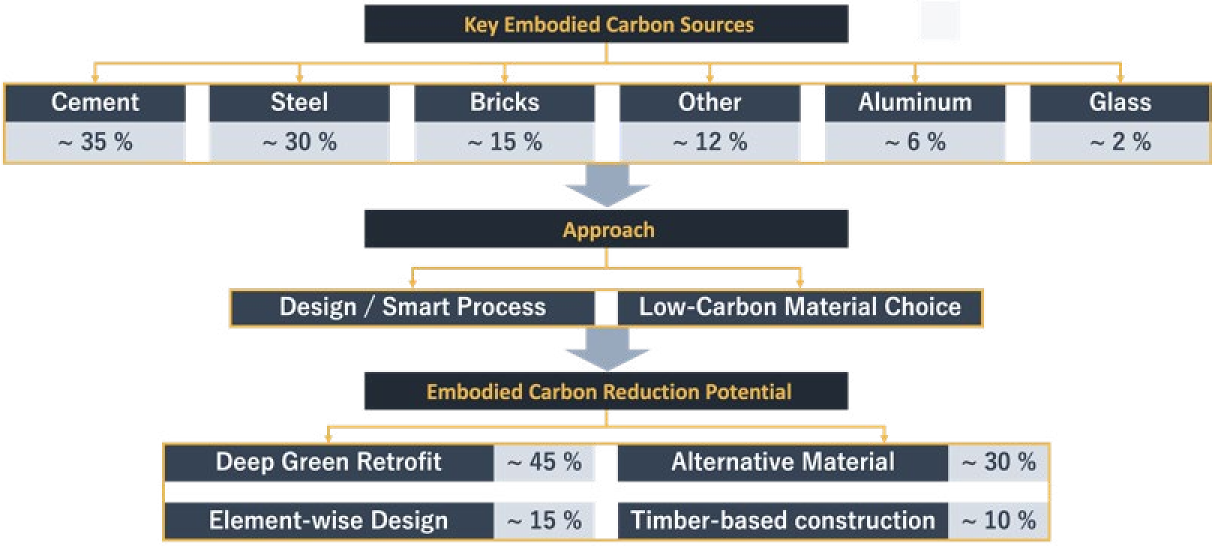


Figure 18: Key embodied carbon sources and reduction potential[65]

As new construction is typically more carbon-intensive and costly compared to (major) refurbishments, proactive renovation/energetic-refurbishment strategies alongside with decent modernisation of a portfolio of standing investments is crucial for maintaining or enhancing competitiveness and managing (transition) risks. Furthermore, as building materials manufacturers continue to innovate and reduce carbon emissions, **the promotion of low carbon materials presents an opportunity to gain a competitive edge** and improve the efficiency of future retrofit measures. Three steps are essential in this process of retrofitting and optimising embodied carbon:

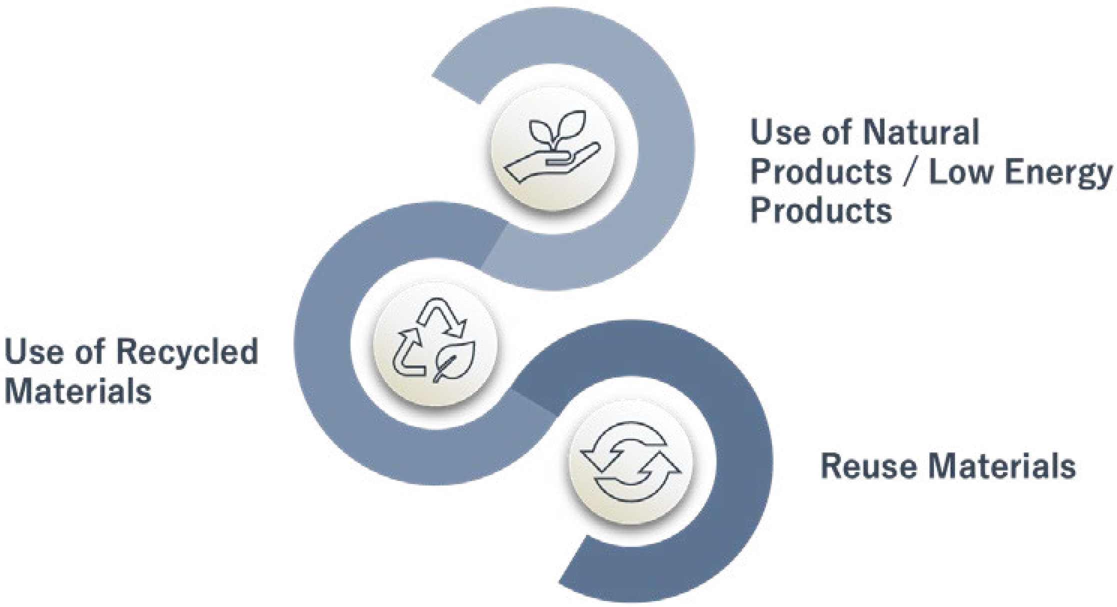


Figure 19: Low carbon approach in retrofits

65 Cf. KPMG (2023): Embodied carbon management for global infrastructure.

Continued attention to these three principles during retrofit planning and implementation are important. High savings result for the most important elements of a building:

Building Envelope—up to 50% Embodied Carbon Savings by:

- **Analyze natural or low-energy alternatives** during the early phases of building envelope design, enhance material configurations (such as wood or natural insulation), and aim for attaining a surplus of negative embodied carbon emissions.
- **Integrate recycled elements** like repurposed insulation, reused roofing tiles (including rubber and shingles), and reclaimed aluminum into the retrofitting process.
- **Emphasise the reusability of materials** (for instance, by designing products for easy reintegration, distinct material separation, and maximising the utilisation of previously commingled construction materials).

Building Structure—up to 45% Embodied Carbon Savings by:

- **Compare natural or low-energy alternatives** during early design, optimise material arrangements (e.g. low carbon concrete/steel) and set embodied carbon limits.
- **Strategically incorporate recycled materials** such as reclaimed timber, recycled steel, and crushed recycled concrete, while ensuring structural integrity.
- **Prioritise material reusability** (e.g. by preserving various metallic elements in good condition, repurposing structural components, and embracing circular economy principles) in the building structure.

Building Systems—up to 35% Embodied Carbon Savings by:

- **Assess low-energy options**, refine system configurations (for instance, embracing a 'low-tech' philosophy that reevaluates technological necessity and fosters simpler, resource-efficient solutions), or incorporate passive approaches (illustrations for cooling: ceiling fans, natural ventilation).
- **Integrate reconditioned systems** and explore the utilisation of pre-owned or revitalised equipment based on the opportunities presented by this evolving market landscape.
- **Give precedence to the recyclability of systems** (for example, by adopting simplified technology solutions or employing systems amenable to enhancements through software or hardware updates) and avoid utilising quickly outdated individual hardware solutions.

7. Outlook: Growing significance of embodied carbon

Extensive efforts of significant magnitude are required to align the operation of the global building stock with a 1.5°C pathway. The key challenge lies in enhancing the existing stock, as more than 75% of the buildings that will exist in 2050 already exist today.[66] Embracing sufficiency principles is pivotal in sustainable building practices, as it promotes responsible resource utilisation and optimisation of existing assets. Prioritising retrofitting existing buildings over new construction is consistently advocated. Increasingly, both Europe and the US acknowledge the imperative to enhance the sustainability performance of buildings through retrofit projects. **Achieving a balance between reducing operational emissions and mitigating embodied carbon emissions will be critical** in meeting the objectives outlined in the Paris Agreement.

In recent years, there has been a growing recognition of the significance of embodied carbon impacts, which have traditionally taken a backseat to operational considerations. Initially, the focus on embodied carbon has primarily been directed towards newly constructed real estate. However, it is essential that this emphasis extends to retrofit projects as well. It is becoming increasingly apparent that adopting a **whole-life perspective**, which takes into account the environmental impacts throughout the entire lifecycle of retrofit projects, **is vital for achieving the necessary emission reductions**.

Policy frameworks, not limited to the state level but potentially even at the city level, are poised to exhibit a high degree of creativity in their efforts to mitigate emissions. Specifically targeting the energy expended in retrofit and renovation endeavors, these frameworks could give rise to **increased regulations relating to products and buildings**. These measures might encompass several facets, including the following: Firstly, in public procurement, a preference could emerge for properties demonstrating optimised embodied carbon profiles along with favorable EPD. Secondly, financial incentives such as subsidies or tax reductions might become accessible for projects involving low-carbon retrofits, adaptive reuse, or preservation. Thirdly, prerequisites might incorporate criteria centered around disassembly, adaptability, and circularity. Fourthly, strategies concerning material performance, as well as carbon limits or caps pertaining to the procurement of building materials, might be introduced. Additionally, strategies aligned with the circular economy could gain prominence, featuring transformative solutions that effectively sidestep emissions. Furthermore, waste regulations aimed at diverting construction-related waste would likely be subject to greater stringency.

66 For Europe, this rate is as high as 85–95%, cf. EEA (2022).

The topic of embodied carbon in retrofits requires further research, as market participants currently lack a comprehensive and holistic view of this issue, and building materials change and decarbonise. In-depth research is needed for a better understanding of the scope and impact of embodied carbon in retrofits. A fundamental problem is the lack of data availability. Without sufficient and reliable data, it is difficult to make accurate statements about the actual embodied carbon in retrofit projects. This leads to uncertainty and makes it difficult to develop effective strategies to reduce the carbon footprint. Studies should be conducted to gather comprehensive data on different materials, construction processes and retrofitting methods. This will enable informed decisions to reduce CO_2e emissions associated with retrofits. The focus should not only be on individual aspects of embodied carbon, but it is important to take a holistic and comprehensive approach. It is crucial to approach retrofits with a conscientious mindset, considering not only the materials and processes involved. But also conducting a thorough life cycle assessment and evaluating energy consumption during the operational phase. By carefully examining the embodied carbon of retrofits, we can strive towards developing innovative and sustainable solutions that minimise the environmental impact associated with building retrofits. We perceive our research as an initial stride in that direction, recognising the importance of taking proactive measures to address these concerns.

Appendix

Further reading:

Canada Green Building Council (2017): A roadmap for retrofits in Canada.

Canada Green Building Council (2021): Embodied Carbon: A Primer for Buildings in Canada.

Canada Green Building Council (2022): Green Retrofit Economy Study.

Carbon Leadership Forum (2023): North American Material Baselines.

Christoph Meili; Niels Jungbluth; Maresa Bussa (2021) Kurzstudie: Ökologische Amortisationsrechnung für Heizsysteme.

European Commission (2023): Transition pathway for Construction.

Green Finance Institute (2023): Broker's Handbook on Green Home Retrofit and Technologies.

Institut Wohnen und Umwelt (2015): Deutsche Wohngebäudetypologie—Beispielhafte Maßnahmen zur Verbesserung der Energieeffizienz von typischen Wohngebäuden.

McKinsey (2023): Building value by decarbonizing the built environment—Uncovering how decarbonization can create unprecedented value.

NIBE (2021): Paris Proof Embodied Carbon Background Report.

PCAF, CRREM, GRESB (2023): Accounting and Reporting of GHG Emissions from Real Estate Operations—Technical Guidance.

UK House of Commons Environmental Audit Committee (2022): Building to net zero: costing carbon in construction.

World Green Building Council (2023): Policy Briefing—Whole life carbon reporting and targets.

Wuppertal Institute (2022): Energetic refurbishment of existing buildings or new construction.

Academic literature on embodied carbon

Citation	Title	Journal	Country	Case studies	Keywords
(Bahramian & Yetilmezsoy, 2020)	Life cycle assessment of the building industry: an overview of two decades of research (1995–2018)	Energy and Buildings	Turkey	230	Life cycle assessment, Building sector, Embodied energy, Construction process, Life cycle inventory
(Chastas et al., 2018)	Normalising and assessing carbon emissions in the building sector: A review on the embodied CO_2 emissions of residential buildings	Building and Environment	Greece	95	Residential buildings, Embodied CO_2 emissions, Normalisation, Energy mix, GWP
(De Wolf et al., 2015)	Material quantities and embodied carbon dioxide in structures	Engineering Sustainability	Global	200	Embodied environmental impact of building structures
(De Wolf et al., 2017)	Measuring embodied carbon dioxide equivalent of buildings: A review and critique of current industry practice	Energy and Buildings	UK	n/a	Embodied carbon dioxide equivalent, Construction sector, Greenhouse gas emissions, Industry practice
(Finnegan et al., 2018)	The embodied CO_2e of sustainable energy technologies used in buildings: A review article	Energy and Buildings	UK	n/a	Embodied carbon, CO_2e, Sustainable energy technology Solar PV, Solar thermal, Air source heat pump (ASHP), Ground source heat pump (GSHP), LED lighting, Life Cycle Assessment (LCA)
(Francart et al., 2021)	Influence of methodological choices on maintenance and replacement in building LCA	The International Journal of Life Cycle Assessment	Sweden	7	Building, Maintenance, Replacement, Embodied, Service life, Methodology
(Gan et al., 2017)	A Comparative Analysis of Embodied Carbon in High-Rise Buildings Regarding Different Design Parameters	Journal of Cleaner Production	Hong Kong	1	Building height, Construction material, Embodied carbon, High-rise building, Recycled material, Structural form

Citation	Title	Journal	Country	Case studies	Keywords
(Gan, Cheng, et al., 2017)	Developing a CO_2-e accounting method for quantification and analysis of embodied carbon in high-rise buildings	Journal of Cleaner Production	Hong Kong	n/a	Construction material, Embodied carbon, Green procurement, High-rise building, Life cycle assessment, Low carbon building
(Göswein et al., 2021)	Influence of material choice, renovation rate, and electricity grid to achieve a Paris Agreement-compatible building stock: A Portuguese case study	Building and Environment	Portugal	n/a	Straw, Timber, Cork, Dynamic LCA, Bottom-up Renovation
(Horup et al., 2023)	Defining dynamic science-based climate change budgets for countries and absolute sustainable building targets	Building and Environment	Denmark	n/a	Environmental performance buildings GHG emissions, Carbon budget, Budget allocation, Top-down targets, Climate policy, Decision support, Absolute sustainability, assessment Buildings, Life cycle assessment LCA
(Hu, 2020)	A Building Life-Cycle Embodied Performance Index—The Relationship between Embodied Energy, Embodied Carbon and Environmental Impact	Energies (MDPI)	USA	8	embodied energy, embodied carbon, environmental impact, life-cycle embodied performance
(Hu, 2022)	Embodied Carbon Emissions of the Residential Building Stock in the United States and the Effectiveness of Mitigation Strategies	Climate (MDPI)	USA	64	Embodied carbon emissions, residential building stock, mitigation strategies, archetypes, whole-building life cycle
(Kang et al., 2019)	Dynamic Lifecycle Assessment in Building Construction Projects: Focusing on Embodied Emissions	Sustainability (MDPI)	Korea	1	Life cycle assessment, recurrent embodied carbon, system dynamics, buildings

Citation	Title	Journal	Country	Case studies	Keywords
(Simonen et al., 2017)	Benchmarking the Embodied Carbon of Buildings	Technology|Architecture + Design	USA	n/a	
(Kayaçetin & Tanyer, 2020)	Embodied carbon assessment of residential housing at urban scale	Renewable and Sustainable Energy Review	Turkey	3	Embodied carbon, Life cycle assessment (LCA), Mass housing projects Transportation, Neighborhood-scale development, Data management
(Li et al., 2017)	A Life Cycle Analysis Approach for Embodied Carbon for a Residential Building	Springer Science+Business Media Singapore 2017	China	1	Life cycle assessment, Embodied carbon, Residential building, Inventory analysis
(Meneghelli, 2018)	Whole-building embodied carbon of a North American LEED-certified library: Sensitivity analysis of the environmental impact of buildings materials	Building and Environment	USA	n/a	Embodied carbon, building materials, energy efficiency, climate change, LEED, recycling content
(Mirabella et al., 2018)	Strategies to Improve the Energy Performance of Buildings: A Review of Their Life Cycle Impact	Buildings (MDPI)	Global	178	Life cycle Assessment (LCA), building life cycle, energy efficiency, embodied energy, embodied carbon, insulation materials, renewable energy systems
(Priore et al., 2022)	Exploring the gap between carbon-budget-compatible buildings and existing solutions—A Swiss case study	Energy and Buildings	Switzerland	0	Nationale Emissionsbudgets (OC/EC), Carbon budget, Buildings, Climate neutral, Net-zero, Building stock
(Rodrigo et al., 2019)	Embodied Carbon Mitigation Strategies in the Construction Industry	CIB World Building Congress 2019	Australia	22	Embodied carbon, mitigation strategies, construction industry, expert forum

Citation	Title	Journal	Country	Case studies	Keywords
(Röck et al., 2020)	Embodied GHG emissions of buildings—The hidden challenge for effective climate change mitigation	Applied Energy	Global	650	Systematic analysis of 650+ building LCA cases on life cycle greenhouse gas emissions, New building upfront GHG
(Shirazi & Ashuri, 2020)	Embodied Life Cycle Assessment (LCA) Comparison of residential building retrofit measures in Atlanta	Building and Environment	USA	n/a	Single family residential houses, Atlanta, Retrofit options, Embodied impacts
(Simonen et al., 2017)	Embodied Carbon Benchmark Study	University of Washington Department of Architecture Faculty Papers	USA	> 1,000	Embodied carbon, Life cycle assessment (LCA), Benchmarking, new construction
(Su et al., 2021)	Assessment models and dynamic variables for dynamic life cycle assessment of buildings: a review	Springer	Global	48	Dynamic life cycle assessment, Temporal variation, Environmental impact, Building, Sustainable development
(Xiao et al., 2018)	A recycled aggregate concrete high-rise building: structural performance and embodied carbon footprint	Journal of Cleaner Production	China	2	Recycled aggregate concrete (RAC), High-rise building, Dynamic characteristic, Embodied carbon, CO_2 emission analysis, Life cycle assessment (LCA)

Data requirements for embodied carbon accounting in retrofits:

Information on the building	Example
Property type	Residential
Energy consumption (before)	162.00 kWh/m²*a
Energy consumption (after)	82.00 kWh/m²*a
Energy source:	Gas, oil, etc.
GIA:	1,606 m²
Facade area (only required if a measure was carried out on the facade):	782 m²
Window quantity (only required if a measure was carried out on the window):	234 m²
Number of heating systems (only required if a measure was carried out on the heating system):	1
Ground area (only required if a measure was carried out on the attic):	652 m²

Information about the measure	Example
Type of measure	Insulation facade;basemaent;attic, Window replacement ,Exchange heating system
Used materials	Timber, Thermal insulation composite systems, MEP, etc.
Description of the measure	Installed TICS of the brand doitBAU ESP WLG031 XXm²; Replacement of old boiler; replaced by new HK BRAND BUDERUS XSD "DF
Realization of the measure	2020
Costs of the measure	EUR 865.050

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