SCIENCE BASED TARGETS

DRIVING AMBITIOUS CORPORATE CLIMATE ACTION

1.5°C PATHWAYS FOR THE GLOBAL BUILDINGS SECTOR'S EMBODIED EMISSIONS: DEVELOPMENT DESCRIPTION

VERSION 1.0

AUGUST 2024

ABOUT SBTi

The Science Based Targets initiative (SBTi) is a corporate climate action organization that enables companies and financial institutions worldwide to play their part in combating the climate crisis.

We develop standards, tools and guidance which allow companies to set greenhouse gas (GHG) emissions reductions targets in line with what is needed to keep global heating below catastrophic levels and reach net-zero by 2050 at latest.

The SBTi is incorporated as a charity, with a subsidiary which will host our target validation services.
Our partners are CDP, the United Nations Global Compact, the We Mean Business Coalition, the World Resources Institute (WRI), and the World Wide Fund for Nature (WWF).

DISCLAIMER

Although reasonable care was taken in the preparation of this document, the Science Based Targets initiative (SBTi) and contributing authors affirm that this document is provided without warranty, either expressed or implied, of accuracy, completeness or fitness for purpose. The SBTi and contributing authors hereby further disclaim any liability, direct or indirect, for damages or loss relating to the use of this document to the fullest extent permitted by law.

The information (including data) contained in this document is not intended to constitute or form the basis of any advice (financial or otherwise).

The SBTi and contributing authors do not accept any liability for any claim or loss arising from any use of or reliance on any data or information in this document. The SBTi and contributing authors accept no liability for the reliability of any information provided by third parties

All information, opinions and views expressed herein by the SBTi and any contributing authors, e.g., technical partners, are based on its judgment at the time this document was prepared and is subject to change without notice due to economic, political, industry, or firm-specific factors.

"Science Based Targets initiative" and "SBTi" refer to the Science Based Targets initiative, a private company registered in England number 14960097 and registered as a UK Charity number 1205768.

VERSION HISTORY

VERSION	CHANGE/UPDATE DESCRIPTION	Date published
0.1	A 1.5°C Pathway for the Global Buildings Sector's Embodied Emissions: Pathway Development, Draft for Public Consultation	May 16, 2023
0.2	A 1.5°C Pathway for the Global Buildings Sector's Embodied Emissions: Pathway Development, Draft for Pilot Testing	November 21, 2023
1.0	Release of the final 1.5°C Pathways for the Global Buildings Sector's Embodied Emissions: Development Description. This was published together with the final Buildings Sector Science-Based Target-Setting Criteria Version 1.0	August 28, 2024

CONTENTS

INTRODUCTION

INTRODUCTION

This document is the final report of the project "1.5˚C Pathways for the Global Buildings Sector's Embodied Emissions". It showcases the methodology used for the development of these 1.5˚-aligned pathways, the steps undertaken and the results of the analysis. The project ran from November 2022 to June 2023. It was commissioned by the Science Based Targets initiative (SBTi) and performed by Ramboll with the support of Sweco.

This document is part of a set of deliverables for a larger project launched by the SBTi consisting in developing target-setting criteria, tools and guidance for the real estate and construction sector. In addition to the decarbonization pathways for buildings' embodied emissions, the SBTi Buildings Project also includes a set of decarbonization pathways for in-use emissions, criteria and guidance for emissions accounting, reporting and target setting.

The work carried out as part of the development of the embodied emissions pathways included:

1. Developing buildings' embodied emissions pathways aligned with a 1.5˚C scenario, covering the global buildings sector, to be implemented in SBTi's target-setting methods and tools.
2. Providing global pathways for the buildings sector that apply a unified performance metric (e.g., in kg CO_2e/m^2) consistent across countries.
3. Disaggregating the pathways by building typology, covering at least residential, office and retail buildings.
4. Exploring further disaggregating the pathways for newly constructed buildings and existing buildings (i.e., the embodied emissions of the materials required for retrofit).

This report has been prepared using the feedback received from the SBTi and from the Buildings Expert Advisory Group (EAG).

This document is presented for information only. Companies and financial institutions willing to set science-based targets should refer to the SBTi Buildings Criteria Version 1.0 and the supplementary resources for GHG accounting or target setting related questions.

THE ROLE OF BUILDINGS' EMBODIED EMISSIONS IN THE SBTi FRAMEWORK

THE ROLE OF BUILDINGS' EMBODIED EMISSIONS IN THE SBTi FRAMEWORK

2.1 WHAT ARE EMBODIED EMISSIONS AND WHY DO THEY MATTER?

Embodied emissions relate to upstream emissions from sourcing and producing construction materials. Emissions from transport, construction site activities and demolition also contribute to embodied emissions. The term embodied carbon is also frequently used. In this report, both embodied emissions and embodied carbon refer to all GHGs resulting from extraction, production, transport and manufacturing of construction materials, and construction processes .

Globally, a third of all building-related emissions stem from embodied carbon.[1] This accounts for around 10% of all energy-related GHG emissions worldwide. In the EU, about 60-70% of embodied emissions stem from the materials used for the initial building construction, also called upfront embodied emissions.[2] These emissions are those derived from the life cycle stages A1 to A5 defined in the European Standards EN 15978 and EN 15804, which cover the product and construction process stages over a building's lifetime (Figure 1).

Furthermore, the importance of embodied emissions for the climate impact of a building or a portfolio of buildings is growing. So far, reducing embodied emissions of buildings has not been a priority for most corporates, industries, and policymakers. In contrast, in-use operational emissions are already receiving attention as part of policies and corporate targets for scope 1 and 2 emissions. As operational emissions are reduced, the share of embodied emissions over a building's total emissions increases, making their reduction more relevant from a GHG accounting and climate mitigation perspective.

1 https://globalabc.org/our-work/tracking-progress-global-status-report.

2 Figures based on forthcoming report prepared by Ramboll, KU Leuven and BPIE as part of a study supporting the development of a roadmap for the reduction of whole-life cycle carbon emissions of buildings commissioned by the European Commission, DG Environment.

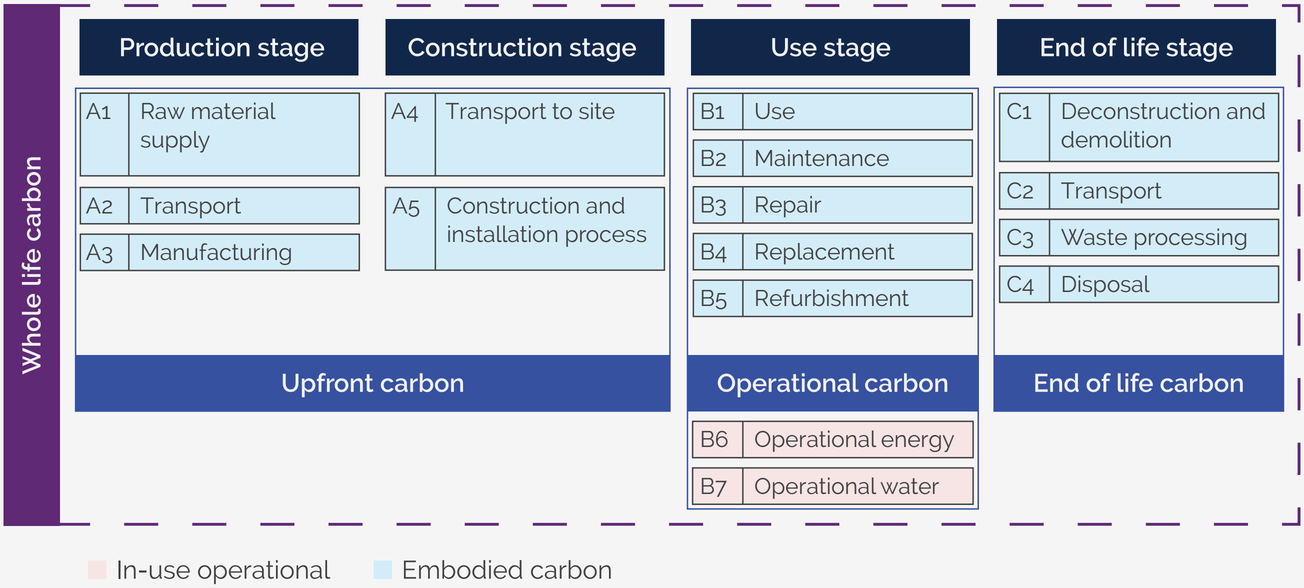
Some key material production sectors such as cement and steel have or will have sector-specific decarbonization pathways that enable science-based targets for corporates producing construction materials. However, reducing embodied emissions goes beyond decarbonizing the carbon-intensive material production industries. Strategies to decrease upfront embodied emissions also include improving the design to use less materials, relying on recycled or reused materials, or replacing conventional building materials with less carbon-intensive ones. Making use of existing buildings through renovations or transformation is another impactful strategy to decrease upfront embodied emissions.

For most actors in the construction and real-estate value chains, embodied emissions do not fall in their scopes 1 or 2. The emissions from producing construction materials occur in the respective industries, and account as part of scope 3 for users such as building designers, developers and investors. Only a generic approach for target setting is available for embodied emissions so far.

In these key features, embodied emissions differ from the operational emissions caused by energy consumption from buildings use, such as heating and cooling. Users are typically directly responsible for operational emissions, and these have long been established in the buildings sector as a significant source of emissions. Updated pathways for operational emissions have been developed by the Carbon Risk Real Estate Monitor (CRREM) and the SBTi to be aligned with the 1.5°C ambition.

Therefore, dedicated reduction targets for embodied emissions, specifically upfront embodied emissions, can provide important incentives and guidance to lowering the overall climate impact of the buildings sector, and contribute to keeping global emissions within the remaining budget for limiting global warming to 1.5°C.

Figure 1. Diagram illustrating buildings' life cycle and stages adapted from EN 15978 (2011)



2.2 HOW CAN EMBODIED CARBON BE REFLECTED IN SCIENCE-BASED TARGETS?

To incentivize the reduction of whole-life carbon emissions of buildings, setting science-based targets for embodied emissions by key actors in construction and real estate is essential. According to WorldGBC, embodied emissions are responsible for approximately 11% of global emissions.[3] Establishing the scientific foundations and guidance on the target setting requirements makes this possible.

So far, the SBTi methods do not provide specific requirements or guidelines for targets on embodied emissions. This is due to two main factors. First, while the SBTi prioritizes the reduction of emissions from scopes 1 and 2, and requires companies to set scope 3 targets when these emissions represent over 40% of their total scopes 1, 2 and 3, scope 3 targets are typically based on a more generic approach, acknowledging the complexities and lower degree of control companies have over these emissions. Second, the cross-sectoral nature of embodied emissions means that a specific reduction pathway aligned with the 1.5°C carbon budget is not yet available in global industry breakdowns. Nevertheless, the feasibility of establishing such a budget was demonstrated through scientific study and expert analysis, including contributions from some authors of this note.[4]

Setting targets in accordance with the scientifically established carbon budget requires a pathway that describes the acceptable levels of embodied carbon to stay within that budget and the necessary reduction curve over time. This is the key contribution of this work, which is presented here.

Science-based targets are most relevant if they are formulated in relation to a common output metric for the sector. Corporate targets can then be set on the carbon intensity of creating the output. For buildings, the square meter of area built represents this common metric. It is also used to determine the in-use operational emissions. However, gross floor area is the most relevant definition of floor area due to the importance of walls, foundations and other structural elements for embodied carbon.

3 WorldGBC, 2019. Bringing embodied carbon upfront: Coordinated action for the building and construction sector to tackle embodied carbon.

4 Horup, Lise Hvid, Steinmann, Jacob, Le Den, Xavier, Röck, Martin, Sørensen, Andreas, Tozan, Buket, & Birgisdottir, Harpa. (2022). Towards embodied carbon benchmarks for buildings in Europe - #3 Defining budget-based targets: A top-down approach. Zenodo. https://doi.org/10.5281/zenodo.6120882.

SCOPE OF A RELEVANT EMBODIED CARBON PATHWAY

SCOPE OF A RELEVANT EMBODIED CARBON PATHWAY

3.1 ALIGNMENT WITH THE SBTi FUNDAMENTALS

In this project, the design of the 1.5°C global pathways for embodied emissions in the buildings sector has been rooted in the SBTi fundamentals, specifically on the Sectoral Decarbonization Approach (SDA) methodology developed by the SBTi.

The SDA is a science-based method that allows carbon-intensity measures and targets to be derived from global mitigation pathways for some of the most carbon-intensive activities. Companies using the SDA to set targets can later derive their specific reduction targets based on their relative size in the sector.

The SBTi Buildings Project builds upon the SDA framework, which only covers scopes 1 and 2 of emissions, and accounts for scope 3 emissions, as well. Addressing the impact of scope 3 emissions is the main value added to this project, given that embodied emissions of a building fall into this scope for the most relevant parts of the buildings sector value chain.

For this, a global pathway has been developed that forms the overall decarbonization trajectory of the embodied emission component of the buildings sector. Regional variation is expected to be non-negligible, but data availability to formulate appropriate assumptions proved to be a strong limitation. Therefore, the refinement into regional pathways has been postponed for a potential future expansion of the work.

3.2 ABSOLUTE EMISSIONS TARGETS VS EMISSIONS INTENSITY TARGETS

A key consideration for the design of the decarbonization pathway was the choice between using an intensity target or an absolute one. Absolute targets reduce a specified quantity of emissions from a base year to a target year. In contrast, intensity targets measure emissions relative to a reference value, such as per unit of economic output.

In general, absolute targets offer a straightforward way to measure progress and provide greater certainty that the carbon budget is kept, compared to intensity targets. While absolute targets can be challenging for growing companies, by shrinking or making considerably large emissions intensity reductions, companies can improve environmental performance without compromising growth.

Emission intensity targets can overcome the challenges faced by growing companies, given that these calculate emissions relative to a measure of output, which can be a proxy for growth. Nevertheless, a decrease in emission intensity does not necessarily imply a reduction in absolute emissions. It could be the case that a company is meeting intensity targets but not absolute emission reduction targets. Moreover, some companies may be reluctant to share economic or physical output measurements which are necessary to calculate emission intensity.

Both target-setting approaches therefore have their advantages and can be considered reasonable for corporate target setting in relation to embodied emissions. As will be shown in the following sections, the projected high growth in floor area results in steep intensity reductions to stay within the global carbon budget. An absolute target can be envisaged for companies with lower projected growth rates, or a transition from new construction towards renovating existing buildings and extending their lifetime.

3.3 SELECTION OF THE PATHWAY METRIC

The pathway intensity needs to be related to a specific metric. For embodied emissions, two metrics can be envisaged to describe GHG emission intensity: per square meter (m^2) or per user (e.g., employees in an office, dwellers in housing buildings or customers in retail).

A per m^2 quantification is the most common metric used in buildings-related climate impact assessments. It is featured in standards for life cycle assessments such as EN 15978[5], commonly used in existing legislation to monitor and reduce embodied emissions, and also used in relation to operational carbon. The advantage of this metric is that data is reliably available from relatively early design stages and does not change substantially over the lifetime of a building. However, the definitions of m^2 of a building are very different around the world and would need alignment before a consistent and comparable quantification would be possible. Using floor area as an intensity metric does not address space use, which may disincentivize efficient and intensive use of buildings.

A per user quantification is less common. However, it provides the advantage of incentivizing more intensive space use, which represents a strategy to reduce embodied emissions. For all building types, density would be promoted over spacious designs which cause higher emissions for the same needs. With this approach for example, luxury apartments would have higher reduction responsibility than denser multi-family homes, for example, social housing, therefore also taking into account equity considerations. Yet, the use of per user for quantification faces important barriers. Estimating or committing to a certain number of users is not as common and the methods are even less clear than for m^2 and may vary more significantly over the building's lifetime. For this reason, also the current availability of data for different building types is lower than for m^2.

As a result, in this project a per m^2 definition of carbon intensity was used.

5 European Standard EN 15978, Sustainability of construction works – Assessment of environmental performance of buildings – Calculation Method.

3.4 EMISSIONS SCOPE

Another key consideration was related to whether the project should only address upfront embodied emissions or it should consider embodied emissions over the whole life cycle of a building.[6] Only considering upfront emissions may generate potential rebound effects, leading to undesirable outcomes. This is the case, for instance, if buildings are constructed so that upfront emissions are lower but at the expense of having to renovate the building earlier than normal. If only upfront emissions are accounted for, there is an incentive to displace those emissions into the future, for instance through shorter replacement cycles. The discussion on the disaggregation of renovation and new construction activities follows in the next section.

As mentioned, upfront embodied carbon represents the largest share of total embodied emissions and is the most quantifiable part at the point of buildings design. It is also the easiest to express in a meaningful kg CO_2/m^2 pathway or target. Moreover, the availability of data for disaggregation between use types is highest for upfront emissions. While the scope of this pathway is focused on upfront embodied emissions due to their quantifiability and data availability, the potential for rebound effects if lifecycle emissions are not considered has been recognized. To mitigate this risk, the pathway has been designed with stringent guidelines that promote durable, long-lasting construction practices, so that reductions in upfront emissions do not lead to increased emissions over the buildings' lifecycle.

The scope of emissions reflected in the upfront embodied emissions pathways includes all activities that are classified as 'construction' in a building process. Building structure, envelope, internal walls, internal finishes and technical installations are part of the scope.

3.5 APPROACH TO RENOVATION VS. NEW CONSTRUCTION

The buildings construction activity can be divided into two main areas: the construction of new buildings, and the renovation and redevelopment of existing ones. While new construction projects are usually similar in their process and types of emissions that occur,[7] renovation projects show a much larger variation among upgrading windows or insulation elements, changing the internal space allocation and deep renovation, keeping only the structural frame of the existing building. In general, renovation activities cause lower embodied emissions than the construction of new buildings.

6 Upfront embodied emissions refer to the life cycle modules A1-A5, and in this case, the whole life cycle of a building would include modules B1-B5 (use-phase embodied emissions) and C1-C4 (end-of-life) would be included, according to EN 15978. Please refer to Figure 1 for an illustration of a building's life cycle stages and modules.

7 This is not to say that new buildings are usually similar, depending on building type, location, and many more parameters; buildings vary substantially.

Because of the differences between the two, the question arises whether a pathway for embodied emissions should be split between new construction and renovation, or include both. Both options have advantages and disadvantages, as explained in Table 1 below.

Table 1. Advantages and disadvantages of combined vs disaggregated pathways

APPROACH	ADVANTAGES	DISADVANTAGES
Combined pathway	• Because of the lower emissions and better use of resources, renovation projects need to be incentivized. A combined approach creates such incentives, as increasing the share of renovation projects in a portfolio would enable achieving the reduction targets. • Economic data on final consumption expenditure is usually not disaggregated. Therefore, the accuracy would likely be higher for an overall combined pathway.	• The wide variation of renovation projects may offer a risk of greenwashing as a strategy for target achievement. A larger share of low-effort renovation projects may be used to drive down the overall embodied carbon intensity per m^2 while new construction projects continue without substantial reductions. A minimum requirement for what constitutes a renovation could be considered as a way to reduce this risk.
Disaggregated pathways	• Because of the differences between new construction and renovation, specific pathways would be better capable of capturing the specificities of the project's nature. Disaggregated pathways would ensure that low-embodied carbon strategies and materials are used in both new construction and renovation projects. Both areas would need to decarbonize their operations. • Particularly, new constructions would likely have clearer decarbonization targets because the projects are relatively similar.	• A top-down approach, using Input-Output (I-O) models that do not provide disaggregated results but only an overall construction pathway, risks creating an inaccurate distribution between the two, as the differentiation would strongly rely on assumptions and scarce evidence. • Particularly, the renovation pathway would likely be less accurate because the variation between projects and the limited availability creates challenges in defining the appropriate share.

The availability of information regarding the number and details of renovations in the global building stock is limited. Additionally, the consistency across sources is low. A particular challenge is the variation in definitions used for renovation projects. As these projects can differ substantially, terms for sub-segments exist. Further, actor groups may have different terms and definitions, too. Retrofitting and refurbishment are terms used for renovation processes that maintain existing building structures but substantially alter the building components such as façades or internal walls. Instead, re-modelling refers to a smaller segment focused on changes to the interior, from changes of finishes in individual rooms to improving the layout of the interior. However, this does not capture the full essence of renovation. Lastly, additions and re-development projects can relate to renovation but may also include projects that result in new construction.

Furthermore, the available data is limited in its geographical and temporal scope. Data for Europe only represents an incomplete picture of the global renovation activity, while projections up until the late 2020s create a weak base for pathways up to 2050. Due to the limitations with renovation-related data, a decision to develop an upfront embodied pathway for new constructions was decided.

ATTRIBUTION PRINCIPLES FOR DOWNSCALING

ATTRIBUTION PRINCIPLES FOR DOWNSCALING

4.1 OVERVIEW OF ATTRIBUTION PRINCIPLES

Establishing a science-based reduction pathway for embodied emissions relies on a defined carbon budget for these emissions. Due to its cross-sectoral nature, such a budget is not quantified in publications by the International Energy Agency (IEA) or others who calculate emissions across sectors. Therefore, the downscaling of the global carbon budget to embodied emissions of different building typologies is an important step to identify the appropriate share of buildings' embodied emissions out of the entire global carbon budget.

Attribution principles define how this division of the total budget is performed to create tangible budgets for sub-groups such as certain economic sectors. It is worth noting that every attribution principle carries a normative implication. The selection of principles decides how the carbon budget is allocated.

Table 2 below presents the most common attribution principles and their underlying perspectives on equity.[8]

Table 2. Overview of attribution principles

ATTRIBUTION PRINCIPLES	DESCRIPTION	UNDERLYING PRINCIPLE OF DISTRIBUTIVE JUSTICE
Grandfathering	The GHG budget is allocated and spread over time based on past or current emission levels. Current high emitters also have relatively higher carbon budgets.	*Acquired rights*: No theoretical justification, as the share, is based on historical data on how large a share the system/country has previously acquired.
Equal-per-capita	All individuals in the world have an equal right to emit GHGs. The individual carbon budget is the same for all, which allows them to establish national carbon budgets.	*Egalitarianism*: All individuals should be equal in terms of welfare or resources.

8 Horup, Lise Hvid, Steinmann, Jacob, Le Den, Xavier, Röck, Martin, Sørensen, Andreas, Tozan, Buket & Birgisdottir, Harpa (2022). Towards embodied carbon benchmarks for buildings in Europe - #3 Defining budget-based targets: A top-down approach. Zenodo. https://doi.org/10.5281/zenodo.6120882.

ATTRIBUTION PRINCIPLES	DESCRIPTION	UNDERLYING PRINCIPLE OF DISTRIBUTIVE JUSTICE
Economic capability	A larger share of the remaining budget is allocated to those who have fewer means, for instance by allocating a lower reduction target to a country with a low GDP. The individual carbon budget differs and favors poorer and less developed economies.	*Prioritarianism*: A benefit has a greater moral value the worse the situation of the individual to whom it accrues.
Economic value added	Determines the total gross value added from each industry sector based on total economic activity in the world. The approach considers value added; it does not consider the need or utility that the industries provide to the final consumers.	*Financial merit*: Industry sectors with a relatively large value added are allocated a proportionally large share of the emissions budget.
Utilitarian	The global carbon budget is allocated to products and services based on their value, which is determined by assigning individual shares proportional to the final consumption expenditure of a country (i.e., economy).	*Utilitarianism*: Products and services are prioritized based on their value within an economy, in terms of their contribution to final consumer expenditure and overall welfare.
Historic responsibility	Emissions since the industrial revolution have caused global warming and depleted the carbon budget to the current levels. Therefore, emitters of the past should be held accountable and emit less in the future.	*Responsibility*: Historic action is the reason for the situation the world is facing today.

4.2 Attribution principles for downscaling carbon budget of buildings

Not all of these principles are equally suitable and appropriate for the task of downscaling the carbon budget to embodied emissions of buildings. Moreover, their level of maturity and recognition in practice varies.

Table 3 summarizes the result of a literature review, which indicates the primary principles used for buildings. It also illustrates that often a combination of principles is needed to arrive at a meaningful share of the carbon budget.

Table 3. Use of attribution principles in literature and practice

PUBLICATION/INITIATIVE	ATTRIBUTION PRINCIPLE(S) USED
SBTi – Sectoral Decarbonization Approach (SDA). Also used by CRREM	Grandfathering + responsibility
SBTi – Absolute Contraction Approach	Grandfathering
Horup et al. (2022). Towards EU embodied carbon benchmarks	Multi-step approach Step 1, equal-per-capita combined with either grandfathering or utilitarian in step 2
Hjalsted et al. (2020). Sharing the safe operating space	Multi-step approach Step 1, equal-per-capita combined with either grandfathering or utilitarian in step 2
Ryberg et al. (2020). Absolute environmental sustainability assessment	Multi-step approach Step 1, equal-per-capita combined with grandfathering in step 2
Chandrakumar et al. (2019). A top-down approach for setting climate targets for buildings: the case of a New Zealand detached house	Multi-step approach Step 1, equal-per-capita combined with grandfathering in step 2
Habert et al. (2020). Carbon budgets for buildings: harmonizing temporal, spatial and sectoral dimensions	Explores different options: Responsibility, capability, equal-per-capita
Horup et al. (2022). Defining dynamic science-based climate change budgets for countries and absolute sustainable building targets	Multi-step approach Step 1, equal-per-capita combined with utilitarian in step 2
Danish reduction roadmap 2020	Grandfathering
Dutch GBC (2022). Embodied carbon budget of the NL WLC reduction roadmap	Multi-step approach Step 1, equal-per-capita combined with grandfathering in step 2

In the literature reviewed, grandfathering or a combination of equal-per-capita and grandfathering were the predominant attribution principles used in the context of the built environment. Grandfathering is particularly relevant in the starting point of the pathways, as it means that current practices and realistic embodied carbon levels are reflected, as well as their impact on the carbon budget.

Additionally, the combination of equal-per-capita and welfare contribution also creates a promising approach. This is because data for calculating the shares of GHG emissions are accessible in economic databases and allows for the specification of detailed activities such as construction.

Yet, all principles have drawbacks in comparison to other ones. Most notably, the missing or limited integration of equity considerations in grandfathering and welfare contribution. The reliance on assumptions and modeled data also introduces considerable levels of uncertainty or inaccuracy in many of the principles.[9]

In the process of calculating and presenting the science-based pathways for reducing embodied emissions, we will primarily explore the grandfathering approach, but also perform a sensitivity analysis using other principles: equal-per-capita combined with utilitarian and economic value added.

9 It is also important to notice that the Common But Differentiated Responsibilities (CBDR) principle is not taken into account for the formulation of the pathways in this study, especially since these are not formulated for countries but at the global level.

DEVELOPMENT OF THE EMBODIED EMISSIONS PATHWAYS

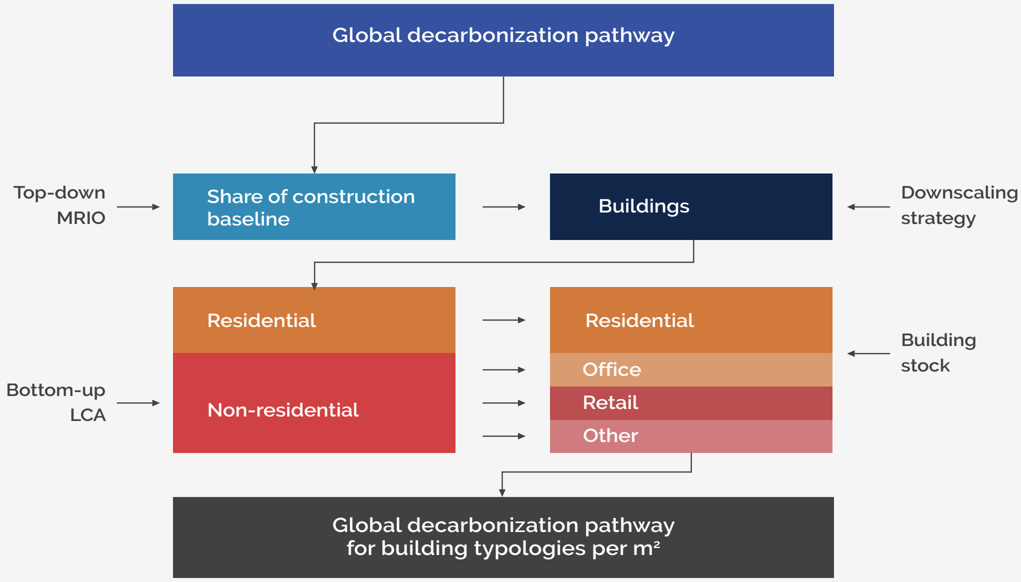
DEVELOPMENT OF THE EMBODIED EMISSIONS PATHWAYS

5.1 OVERVIEW OF THE APPROACH

The overall approach consisted in establishing a decarbonization pathway for building typologies per m^2. The first step was collecting data to define and determine a global decarbonization pathway to comply with the Intergovernmental Panel on Climate Change (IPCC) 1.5°C scenario. The next step was to project future activities of the global building stock divided by building typologies, whereafter renovation rate scenarios could be established. The share of global embodied carbon resulting from new construction was determined by three attribution principles: economic value added, equal-per-capita and utilitarian, and grandfathering.

All these considerations proposed the way to define the global decarbonization pathway for building typologies per m^2.

Figure 2. Overview of the approach to develop the global decarbonization pathway for building typologies per m^2



5.2 GLOBAL PROJECTIONS OF FLOOR AREA DEVELOPMENT

5.2.1 Establishing global floor area projections per building type

As previously mentioned, the pathway has been based on an intensity measure of GHG emissions per m^2. A differentiation per type of building in the global floor area will allow for different decarbonization pathways depending on the building type. This requires data on the overall projected development of global floor area in m^2 as well as information on the disaggregation between building typologies in the current situation and in the future.

Data on the overall global floor area development is available as part of the IEA's Net Zero by 2050 Report.[10] The projections provide data points for 2020 and the projections for 2030, 2040 and 2050, in line with the 1.5°C IPCC scenario.

CRREM's work to establish pathways for in-use operational emissions relied on the IEA data with minor adjustments as a basis for the emission intensity calculations (emissions per m^2) aligned with SBTi principles and the IPCC 1.5°C scenario. To ensure highest-possible consistency with the CRREM pathways, this dataset is used to define the development of global floor area. Figure 3 below illustrates this development.

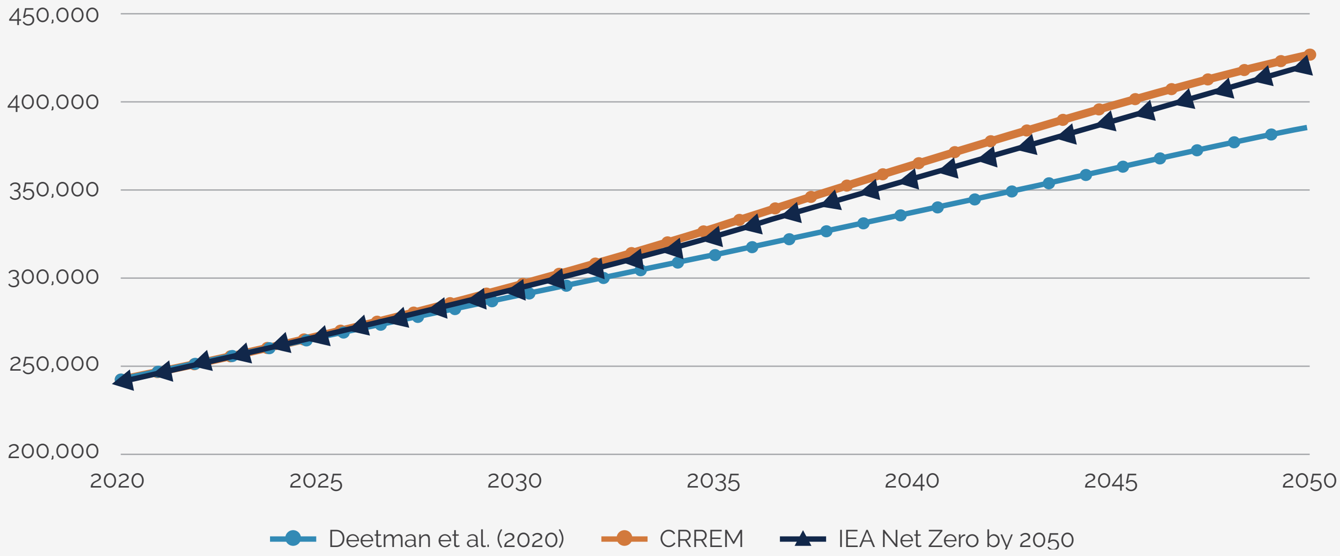
Figure 3 also shows the original projections by the IEA, as well as the model used in a paper published by Deetman et al. (2020).[11] This latter model is based on a different data source that does not cover all building types. Additionally, it assumes that its methodology underestimates the floor area development. Therefore, the data used by CRREM represents the most relevant data source. However, Deetman et al. includes a breakdown of building typologies as shares of the global floor area.

The IEA's and the aligned CRREM data expect continued growth of floor area. However, it is also assumed that the vast majority of this growth takes place in emerging markets. The underlying assumption includes an extension in lifetime of buildings by 20% on average. For these reasons, the decarbonization pathway relies on slowing floor area growth and building construction in developed economies to a major extent and to a considerable but lesser extent in developing economies, as well.

10 https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf.

11 Deetman et al (2020). Modelling global material stocks and flows for residential and service sector buildings towards 2050 – S. Deetman, S. Marinova, E. van der Voet, D. van Vuuren, O. Edelenbosch, R. Heijungs.

Figure 3. Overview of the projected evolution of global floor area (in million m²) according to the three identified sources



The definition of shares for each building typology can be obtained from a combination of IEA and CRREM projections, with the work performed by Deetman et al. This scientific publication by Deetman et al. develops a model that calculates the floor space area, up to the year 2050, and differentiated by residential, office and retail buildings.

In summary, the CRREM projections of global floor area will be used as a baseline to ensure alignment with the decarbonization pathway developed by CRREM for in-use emissions, and the relative weight of each building type on the total global floor area will be extracted for every year in the period 2020-2050 using the shares by building type from Deetman et al. (2020). In this way, there will be a floor area evolution estimate for each of the building typologies that are targeted based on the projections from CRREM, which are aligned with the SBTi approach and the 1.5°C pathway outlined in the IEA Net Zero Emissions by 2050 (NZE) Scenario. The result of this approach is captured in Table 4 below.

Table 4. Current and projected global floor area per building typology according to the proposed approach

BUILDING TYPOLOGY	2020 (MILLION m²)	2050 (MILLION m²)	CAGR[12] (IN%)
Residential	201,598	321,957	1.57%
Office	5,490	16,359	3.71%
Retail	7,197	22,788	3.92%
Other	29,813	66,069	2.69%

12 Compound annual growth rate 2020-2050.

5.2.2 Defining the newly constructed floor area along these projections

The IEA and CRREM data provide information on the net changes in the building stock per year. However, as the net changes are a function of the addition minus demolition of buildings, this shall be accounted for to correct the net change in m^2 for removals from the building stock.

Deetman et al. (2020) also provide information on additions and demolition. Based on this study, we estimate the annual net change in additions as a factor and apply this factor to the net change in the IEA NZE building stock projections.

- This factor is **1.82** and **1.42** in **2020** for residential and non-residential buildings, respectively.
- The factor increases to **2.41** and **1.87** in **2050** for residential and non-residential buildings, respectively.

This indicates that the removal of existing buildings and construction of new buildings will increase in the future.

Based on these assumptions, the construction of new m^2 can be approximated from 2020 to 2050. The values for 2020 and 2050, split into typologies, are shown in the table below.

Table 5. Current and projected global new construction area per building typology

TYPOLOGY	GLOBAL NEW CONSTRUCTED AREA [MILLION m^2]		SHARE OF TOTAL [%]	
	2020	**2050**	**2020**	**2050**
Residential	5,150.2	8,146.4	70%	68%
Office	398.8	695.9	5%	6%
Retail	554.8	1,074.1	8%	9%
Other	1,216.4	2,047.9	17%	17%

5.3 ALLOCATING A CARBON BUDGET TO BUILDING CONSTRUCTION

5.3.1 Scaling from global budget to full construction sector

The total impact of all construction activities is estimated to be 8.5 Gt CO_2e using the EXIOBASE version 3.8.2 global multiregional input-output model (MRIO)[13] (Stadler et al. 2018). This number considers all expenses related to construction covering the full supply chain from extraction of resources up to the final construction activities. The MRIO is used to provide a comprehensive overview of the total impacts and avoiding any truncation errors that are always introduced as part of a bottom-up Life Cycle Assessment (LCA).[14] Truncation errors stem from incomplete LCA coverage of all the processes and inputs that go into e.g., the construction of a building. Cut-off rules and allocations of impacts are explicitly and implicitly included in LCA, and this truncation leads to an overall underestimation of the total CO_2e emissions. For instance, not all life cycle modules are covered by the LCA, or impacts pertaining to capital assets in the supply chain are not included as part of the LCA.

As presented earlier, we have primarily applied the grandfathering approach for downscaling to the construction sector. Moreover, the grandfathering approach is used for determining the baseline emission level of construction, which is used to determine the starting emission level of the different building typologies. While the baseline emission level is based on a grandfathering approach, the actual reduction pathway is based on the IEA NZE Scenario which should, to some extent, take into account the different industry sectors' ability to reduce its overall emission. Thus, the main downscaling approach can be characterized as a hybrid of grandfathering and ability to reduce (see more details in the sections below).

To estimate the current emission level of construction relative to other CO_2e emitting activities, the EXIOBASE model for the year 2019 was used. This showed that 19.28% of total GHG emissions in 2019 can be attributed to the construction sector. This value covers all activities related to construction covering the full supply chain from extraction of resources up to the final construction activities. With reference to the building modules presented in e.g., EN 15978 and illustrated in Figure 1, this means that the modules A1-A5 and B1-B5 are included in this value.

5.3.2 Scaling down to the buildings construction sector

Based on a review of economic productivity in the construction sector, including data for Europe, China, the US and Africa, on average about 53% of the economic productivity is related to the construction of buildings.[15]

By multiplying the share of emissions attributed to the construction sector with the productivity share for buildings construction, a total share of 10.2% of global GHG emissions is calculated, which can be attributed to the construction of buildings.

13 Multi-Regional Input Output modeling is an economic approach which tracks financial flows between countries' major economic sectors. MRIO approaches can be extended from financial flows to estimating resource flows and connected GHG emissions.

14 Antti Säynäjoki et al 2017 Environ. Res. Lett. 12 013001.

15 This number was estimated using data from Eurostat, Deloitte (Africa Construction Trends Report 2021), and from the National Bureau of Statistics of China (Table 14-9 – Total Output Value of Construction by Branch and Region, 2018).

5.3.3 Scaling down to building typologies

Further downscaling to building typologies and determining the starting point of embodied emissions reduction pathways requires values reflecting the current status quo of construction. For this purpose, bottom-up LCAs of buildings are needed. Only recently, studies compiling such information across a range of buildings, typologies and countries have started to emerge. Table 6 presents the upfront embodied carbon baselines found in recent literature.

The data availability continues to face significant challenges. Reports that attempt a large-scale overview of embodied emissions have highlighted the following major challenges[16] related to:

- The general availability of LCAs, which is limited to a very small share of all buildings constructed in a given year. In addition, data is almost exclusively based on European and, to a lesser extent, North American cases. Regions such as Africa, Asia or Latin America are almost completely absent from existing data sets.[17] Where data is available, sufficient data points are only available for residential and office buildings; other non-residential buildings, including retail buildings, are rarely featured and based on a smaller sample size.
- The comparability of assessment results, which vary substantially between methodologies, data sources and system boundaries. This limits the possibility to determine a general average value for the embodied emissions of a building in the status quo situation.
- The representativeness of the data, which often originates from buildings seeking sustainability certification or being required to have transparency over their life cycle emissions. For this reason, the results of some studies express more closely the current feasibility with available technologies and materials, rather than a general status quo.

Differences in the completeness and assessment methodology exist between most of the studies and even their underlying cases.

The first study analyzed (Röck et al., 2020) represents the most comprehensive review of embodied emissions in buildings. This study is referenced in the IPCC AR6 WG3 reports' chapter on buildings that deals with embodied emissions. It takes a global perspective, with a broad sample of buildings, while using mechanisms to mitigate differences in scope, calculation method and background data. However, the over-representation of European buildings remains, as does the challenge of representativeness arising from self-selection of buildings for which an LCA is performed. The findings from Röck et al. (2020) are shown in Table 6.

Table 6. LCA-based emission data for residential and office buildings based on the review study by Röck et al. (2020)

BUILDING TYPOLOGY	AVERAGE CO_2e EMISSION [KG CO_2e / m^2][18]
Residential	407.9
Offices (an assumed representative for other non-residential typologies)	572.4

16 Röck M, Sørensen A, Tozan B, Steinmann J, Le Den X, Horup L H, Birgisdottir H, (2022). Towards EU embodied carbon benchmarks for buildings – Setting the baseline A bottom-up approach, https://doi.org/10.5281/zenodo.5895051. Simonen K., Barbara X. Rodriguez & Catherine De Wolf (2017). Benchmarking the Embodied Carbon of Buildings, Technology|Architecture + Design, 1:2, 208-218, DOI: 10.1080/24751448.2017.1354623.sions.

17 The Rock et al 2020 study, listed in Table 1, has a few casesfrom those regions too.

18 The study defines m^2 as gross floor area.

In comparison with the other studies, the values resulting from Röck et al. (2020) work are found to be within the spectrum of baseline values, albeit on the lower end of the range. In practice, they are likely to reflect state-of-the-art building projects in which embodied emissions have explicitly been analyzed. In practice, the actual average upfront embodied emissions will be lower in some advanced countries and higher in other countries without widespread awareness at the moment. This gap to the general performance of buildings has to be acknowledged and should be closed in future research which may be used to update the pathway.

Given the benefits in global coverage and harmonization efforts made, we consider the values reported by Röck et al. (2020) to be the most relevant ones. A follow-up study on embodied emissions levels in Europe[19] found recent buildings to be very close to the range observed in the 2020 work. As the data relies on voluntary reporting, the self-selection bias of buildings with some level of sustainability consideration applies. The results can therefore be considered best available practices up to 2020, which represents a relevant baseline for the reduction pathways.

Table 7. Overview of studies presenting embodied carbon values for the status quo of buildings design and construction

SOURCE	CASE SAMPLE		UPFRONT EMBODIED EMISSIONS (KG CO_2e/m^2)			COMMENTS
	BUILDING TYPES	GEOGRAPHIES	RESIDENTIAL	OFFICES	OTHER NON-RESIDENTIAL	
Röck et al. 2020	Residential Office Other	Europe (73%) Asia (14%) Oceania (7%) South America (3%) North America (2%) Other (1%)	407.9	572.4	N/A	Dataset of 238 buildings built from global studies.
Simonen at al. 2017	Single-family houses Multi-family houses Office Educational Health care Public assembly Mixed Other	North America (62%) Europe (20%) Asia Pacific (15%) Middle East (3%) Other (<1%)	Typically less than 500	200 and 500 (50% of commercial office buildings lie between these values)	Median of 468 for mixed use	Database of 1,007 buildings for which an LCA had been performed. Overall, typically below 1,000 $kgCO_2e/m^2$ for foundations, structure and enclosure.

19 Röck M, Sørensen A, Tozan B, Steinmann J, Le Den X, Horup L H, Birgisdottir H, (2022). Towards EU embodied carbon benchmarks for buildings – Setting the baseline: A bottom-up approach, https://doi.org/10.5281/zenodo.5895051 .

SOURCE	CASE SAMPLE		UPFRONT EMBODIED EMISSIONS (KG CO_2e/m^2)			COMMENTS
	BUILDING TYPES	GEOGRAPHIES	RESIDENTIAL	OFFICES	OTHER NON-RESIDENTIAL	
OneClickLCA 2021	Residential Office Industrial Educational Commercial	Europe (100%)	410	510	380 (educational) – 500 (industrial)	Database of 3,737 buildings across Europe. Considers whole life carbon from modules A-C.
RIBA 2021	Residential Office Educational	Unclear, but most likely Europe	1,200	1,400	1,000 (schools)	Unclear methodology for establishing the values.
Röck et al. 2021	Single-family houses Multi-family houses Terraced house Semi-detached house Office Health care Educational Etc.	Europe (100%)	400 – 700	Around 600	400 (art and culture) – 800 (hospitals)	Dataset of 769 EU buildings for which an LCA had been performed.
LETI 2020	Residential Non-residential	Unclear, but most likely Europe		800 – 1000		Unclear methodology for establishing the baseline values.
WBCSD 2021	Office Mixed Residential	Europe (100%)		500 – 600		Based on 6 case studies for currently feasible low embodied emission construction practices.

The LCA-based emission data from Röck et al. (2020) is multiplied with the building stock data from the previous section to indicate the overall CO_2e emissions stemming from the typologies. This is done for year 2020 to capture the baseline emission levels for year 2020 for the typologies and the relative contribution of each typology to the total GHG emissions associated with new building construction.

Table 8. Estimated total CO_2e emissions per building typology

TYPOLOGY	TOTAL CO_2e EMISSIONS BASED ON EMISSION FACTOR FROM RÖCK ET AL. (2020) MULTIPLIED WITH BUILDING STOCK PROJECTIONS [GT CO_2e]	SHARE OF TOTAL CO_2e EMISSIONS BASED ON EMISSION FACTOR FROM RÖCK ET AL. (2020) MULTIPLIED WITH BUILDING STOCK PROJECTIONS [%]
	2020	**2020**
Residential	2.10	63%
Office	0.23	7%
Retail	0.32	10%
Other	0.70	21%

The shares are then multiplied with the global downscaled share of the carbon budget for buildings construction, i.e., 10.2%. Hence, the share of annual GHG emissions split into building typologies can be estimated as per Table 9.

Share of the carbon budget for buildings construction, i.e.,

10.2%

Table 9. Relative shares of global GHG budget per building typology in 2020

TYPOLOGY	SHARE OF GLOBAL GHG BUDGET
Residential	6.4%
Office	0.7%
Retail	1.0%
Other	2.1%

5.4 CORRECTING FOR RENOVATION

The share of the global GHG budget that can be attributed to the construction of buildings also includes renovation activities. The share, therefore, needs to be corrected to take this into account.

Currently, the global renovation rate is about 1% based on the IEA's Net Zero by 2050 Scenario for limiting global warming to 1.5°C (IEA, NZE Scenario). If this value is applied to the total building stock, then about 2,400 million m^2 were renovated in 2020, whilst approximately 7,300 million new m^2 were constructed. This implied that, in total, about 9,700 million m^2 were renovated or added to the building stock in 2020. Therefore, in 2020 renovation accounted for about 25% of the total area that was either renovated or added as new buildings. The share of the total area that is either renovated or added as new buildings is projected to increase in the future as renovation rates on a global scale need to increase from 1% to 2.5%. These projections are based on the IEA's Net Zero by 2050 Scenario for limiting global warming to 1.5°C (IEA, NZE Scenario).

The GHG emissions per m^2 of renovation projects are about 50% lower than the upfront emissions related to new construction. This is based on the few available studies[20] and complemented with expert knowledge from previous LCA studies comparing the impacts of renovation with impacts from the construction of new buildings. Hence, 12.5% of the budget for buildings is reserved for renovation and 87.5% is kept for construction of new buildings. This number is aligned with current efforts to model the EU building stock, including both renovations and new construction. Therefore, the final share of the global GHG emission share that can be attributed to buildings[21] in 2020 amounts to the values shown in Table 10 below. These shares evolve over time as the renovation rate needs to increase from 1% to 2.5%, and therefore the share set aside for renovation increases.

Table 10. Relative shares of global GHG budget per building typology in 2020 corrected for renovation

TYPOLOGY	SHARE OF GLOBAL GHG BUDGET
Residential	5.6%
Office	0.6%
Retail	0.8%
Other	1.9%

20 Empirical studies find a wide range of GHG reductions when comparing refurbished to new buildings. These range from 30% to 90%. (https://doi.org/10.1016/j.buildenv.2019.106218; https://doi.org/10.1016/j.buildenv.2019.106449), Ongoing, unpublished modeling work in the European context finds a 35% reduction on average across different archetypes for renovation and new buildings.

21 This is upfront embodied emissions from construction of new buildings, as a portion of the emissions is set aside for future renovation interventions.

5.5 APPLYING THE DOWNSCALED SHARES TO FORM A GLOBAL 1.5˚C PATHWAY

Cement and steel, two common and carbon-intensive construction materials, are responsible for a significant part of buildings' upfront embodied emissions. The SBTi has defined sector specific decarbonization pathways for both of these materials. In the short term, these two sector-specific pathways are less steep than the generic decarbonization pathway due to the challenges in immediate reduction of GHG emissions from processes and energy needs in these industries.

This factor has been reflected in the pathways for upfront embodied emissions. The data obtained from multi-regional input-output tables allowed us to define the shares of specific materials out of the total of upfront embodied emissions. For cement, these are 26%, while steel is linked to 9% of upfront embodied emissions of the buildings sector. Using this data as well as their science-based pathways for absolute scope 1 and 2 reductions up to 2050, correction factors for the original absolute upfront embodied carbon pathway were calculated and applied. This absolute pathway is the basis for establishing the sectoral decarbonization pathways for different building types.

This correction factor means that the absolute reduction pathway of upfront embodied emissions is slower in the short-term and becomes steeper in the longer term. However, when applying the SDA approach with its growing floor area reference unit, the SDA pathways are substantially steeper than the absolute ones.

> Additionally, it should be noted that relying on decarbonized cement and steel production represents only one measure to reduce upfront embodied emissions. Design strategies, re-use and recycling of materials and alternative materials can be used to achieve reductions in the short, medium and long run, way beyond material sector pathways.

The downscaled shares are multiplied with a global pathway for aligning with 1.5°C, with little or no overshoot (referred to as "C1"). The pathway is derived as the median value of 97 different models for achieving the target developed by AR6 Scenario Database, hosted by the International Institute for Applied Systems Analysis (IIASA).[22]

22 doi: https://zenodo.org/record/7197970#.ZDqkWHbP1PZ.

The pathway for buildings has been specified to take into account the differentiated reduction rates of different CO_2 emission contributors, which have different reduction rates. Using the EXIOBASE database, the contribution of different emission contributors was determined and coupled with reduction data from the IEA's NZE Scenario to estimate a weighted reduction pathway for buildings. Table 11 below provides an overview of the considered emission contributors and their contribution to current emissions from buildings, as well as the reduction targets in 2030 and 2050. The reduction pathway for each emissions contributor is based on the absolute reductions of the contributor. Hence, changes in e.g., production amounts to comply with the IEA's NZE Scenario are implicitly taken into account.

Table 11. Absolute emissions reduction pathways for industries contributing to total CO_2e emissions from the construction sector

EMISSIONS CONTRIBUTORS	SHARE OF TOTAL CO_2e EMISSIONS FOR CONSTRUCTION 2019	PERCENTAGE REDUCTIONS IN 2030 RELATIVE TO 2020 LEVEL	PERCENTAGE REDUCTIONS IN 2050 RELATIVE TO 2020 LEVEL
Industry, cement[23]	26%	-19%	-94%
Industry, steel[24]	9%	-24%	-91%
Industry, other sectors	29%	-15%	-96%
Electricity and heat generation	33%	-57%	-103%
Transport activities	3%	-20%	-90%

Table 12. Weighted absolute reductions percentage for construction relative to 2020

	2025	2030	2035	2040	2045	2050
Reduction percentage	-15%	-31%	-52%	-73%	-85%	-97%

Finally, the downscaled shares are divided for each building typology with the projected new building addition to estimate the target CO_2e emissions per m^2 for embodied emissions, split into the four typologies as shown in the next section.

23 Absolute reduction pathway, scope 1 emissions.

24 Absolute reduction pathway, scope 1 emissions.

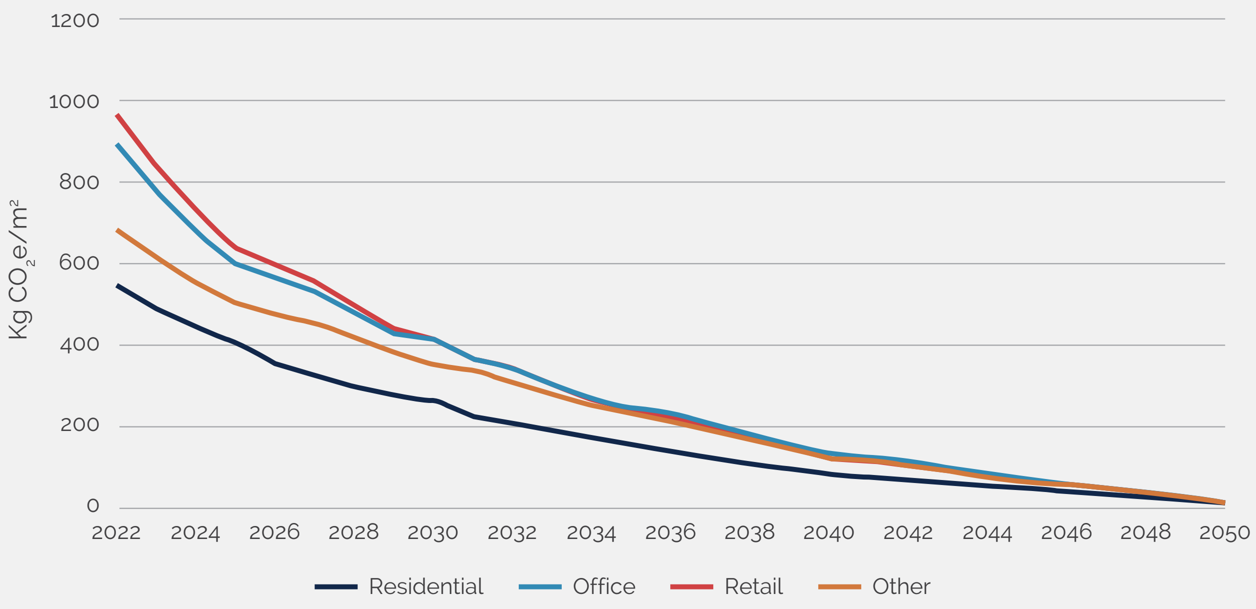
EMBODIED EMISSIONS PATHWAYS

EMBODIED EMISSIONS PATHWAYS

6.1 DEFAULT PATHWAY FOR NEW BUILDINGS USING A GRANDFATHERING-BASED DOWNSCALING APPROACH

The default pathway for new buildings using a grandfathering-based downscaling approach, includes a correction for future renovations. This means that a portion of the emissions is set aside to take into account for the renovation of the new building construction. This approach is illustrated in Figure 4 below.

Figure 4. Decarbonization pathway for upfront embodied CO_2 emissions in buildings: scenario AR6 IPCC C1, grandfathering, corrected for renovation



The represented GHG emission intensities per building type, expressed in kg CO_2e/m^2, are also reported in Table 13 below for representative years (2025, 2030, 2035, 2045, 2050) and by building typology.

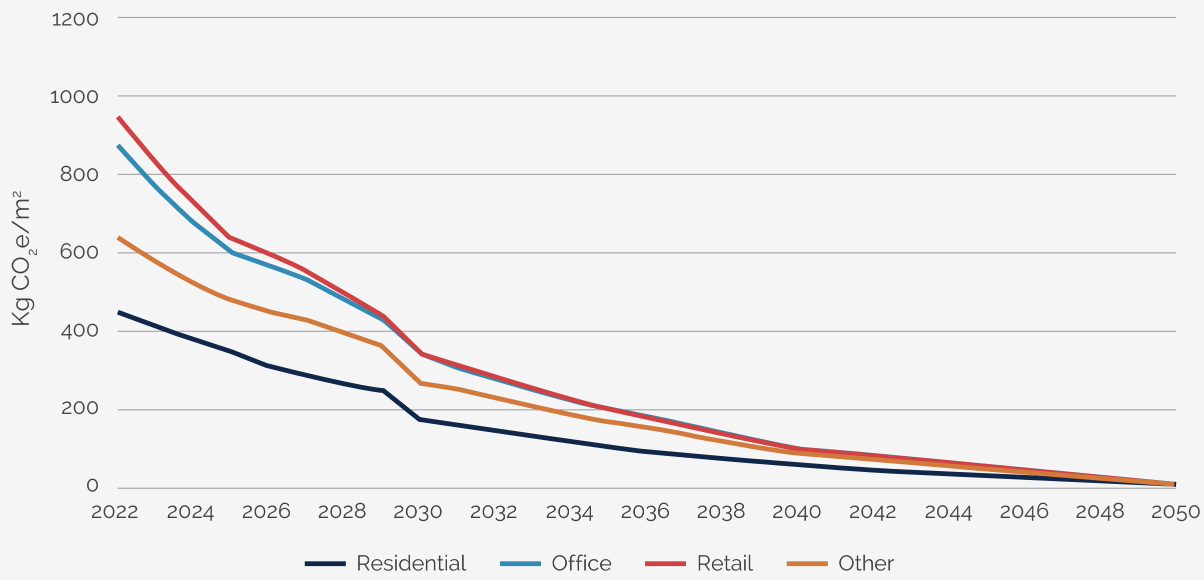
Table 13. Upfront embodied GHG emissions intensities using a grandfathering downscaling approach, corrected for renovation (kg CO_2e/m^2)

TYPOLOGY	2025	2030	2035	2040	2045	2050
Residential	406.8	264.0	154.1	84.2	49.0	11.3
Office	598.6	410.0	247.1	129.9	70.3	14.3
Retail	638.1	414.9	239.2	121.7	64.2	12.9
Other	504.0	350.6	230.3	124.0	69.4	14.9

6.2 PATHWAY VARIATION: ALL BUILDINGS USING A GRANDFATHERING-BASED DOWNSCALING APPROACH

The variation of the default pathway for new buildings, using a grandfathering downscaling approach and without a correction for renovation, is shown in Figure 5 below. Both renovation and new buildings are included in this case, and the overall pathway is reduced due to the increased number of m² affected.

Figure 5. Decarbonization pathway for upfront embodied GHG emissions in buildings: scenario AR6 IPCC C1, grandfathering, no correction for renovation



The represented GHG emissions intensities per building type, expressed in kg CO_2e/m^2, are also reported in Table 14 below for representative years (2025, 2030, 2035, 2045, 2050) and by building typology.

Table 14. Upfront embodied GHG emissions intensities using a grandfathering downscaling approach, no correction for renovation (kg CO_2e/m^2)

TYPOLOGY	2025	2030	2035	2040	2045	2050
Residential	348.0	174.1	105.5	56.5	31.2	6.5
Office	598.2	339.7	201.7	103.0	53.5	10.3
Retail	637.6	348.0	199.4	99.2	50.5	9.6
Other	478.8	265.4	169.3	88.7	47.4	9.4

6.3 PATHWAY VARIATIONS USING ALTERNATIVE DOWNSCALING APPROACHES

As already stated, a grandfathering approach was used as the general approach for downscaling. The equal-per-capita, combined with utilitarian and economic value added downscaling approaches, are implemented as an additional layer to the grandfathering approach. The sensitivity of the final pathway to this choice is shown in the figures below.

The equal-per-capita combined with utilitarian approach was calculated by applying the MRIO model EXIOBASE using the approach described by Oosterhoff et al. 2022.[25] The MRIO model includes 49 world regions. The direct (as final consumption) and indirect (upstream from final consumption) demand for real estate (i.e., building construction) activities was estimated and related to the total demand within the region for other activities. This allowed for allocating a share of the global emission budget to each activity within each world region. As the attribution was generally based on the final demand from private and public end-users, this is considered utilitarian as the relative demand of private and public end-users is assumed to indicate the relative valuation of different activities based on the overall wellbeing (or utility) that they provide to the end-users. A global share of the emissions budget was estimated by calculating a weighted average among all world regions using population as the weighted factor (i.e., application of the equal-per-capita approach).

The economic value added approach was estimated similarly to the grandfathering approach. However, instead of estimating the contribution of construction activities to global CO_2e emissions, the MRIO model was used to estimate the contribution of construction activities to global gross value added in 2019.

The following downscaling percentages were calculated for the three approaches.

25 Oosterhoff, H.C., Golsteijn, L., Laurent, A., Ryberg, M.W., 2023. A new consistent framework for assignment of safe operating space to B2C and B2B industries for use in absolute environmental sustainability assessments. J. Clean. Prod. 399, 136574. https://doi.org/10.1016/j.jclepro.2023.136574.

Table 15. Estimated allocated share for the construction sector embodied GHG emissions intensities using a grandfathering downscaling approach, no correction for renovation (kg CO_2e/m^2)

DOWNSCALING APPROACH	ALLOCATED SHARE OF THE ANNUAL EMISSIONS BUDGET (2019) TO BUILDINGS
Grandfathering, CO_2e emissions 2019	10.2%
Equal-per-capita combined with utilitarian	6.6%
Economic value added, 2019	9.2%

The baseline expressing the average emissions of the buildings, which was based on a grandfathering approach (i.e., 10.2%), remains the same regardless of the selected downscaling approach. However, the emission pathway has been altered to linearly converge towards a different emissions level in 2050 depending on the selected approach, thereby affecting the slope of the decarbonization pathway, as well as the end emission level in 2050. The different emissions level in 2050 was estimated by dividing the allocated share of emissions budget to buildings using the grandfathering approach with the allocated share of emissions budget to buildings using equal-per-capita combined with utilitarian and economic value added, respectively.

Thus, the final allocated share of the emissions budget to buildings was reduced by 35% in 2050 when using the economic value-added approach as the value-added contribution of the construction sector is lower relative to other sectors compared to its relative contribution to CO_2e emissions. The final allocated share of emissions budget to buildings was reduced by 9% in 2050 when using the equal-per-capita combined with utilitarian approach, this being very similar to the results using the grandfathering approach.

Figure 6 and Figure 7 showcase how the designed pathway for upfront embodied carbon in new buildings changes depending on the applied downscaling approach. Besides grandfathering, the alternative downscaling approaches considered in the analysis are economic value added and equal-per-capita combined with utilitarian.

Overall, the pathways do not significantly change when a different downscaling approach is applied. When looking at the relative reduction in GHG intensity by 2050, the adoption of the economic value-added approach leads to a slightly more ambitious reduction compared to the other two approaches across all building typologies.

Independently of the downscaling approach applied, the developed upfront embodied emissions pathways project a steep reduction in the kg CO_2e/m^2 measure, ranging between 59% and 63% by 2030 and approximately 99% by 2050. The highest reductions are expected for retail and offices, which start at a higher GHG emissions intensity compared to residential buildings.

One of the factors determining the steepness of the curve is related to the projected expansion in m^2 being built in the future, especially in developing economies, as per the CRREM projections of global floor area.

Figure 6. Decarbonization pathway for upfront embodied GHG emissions in buildings: scenario AR6 IPCC C1, economic value added, corrected for renovation

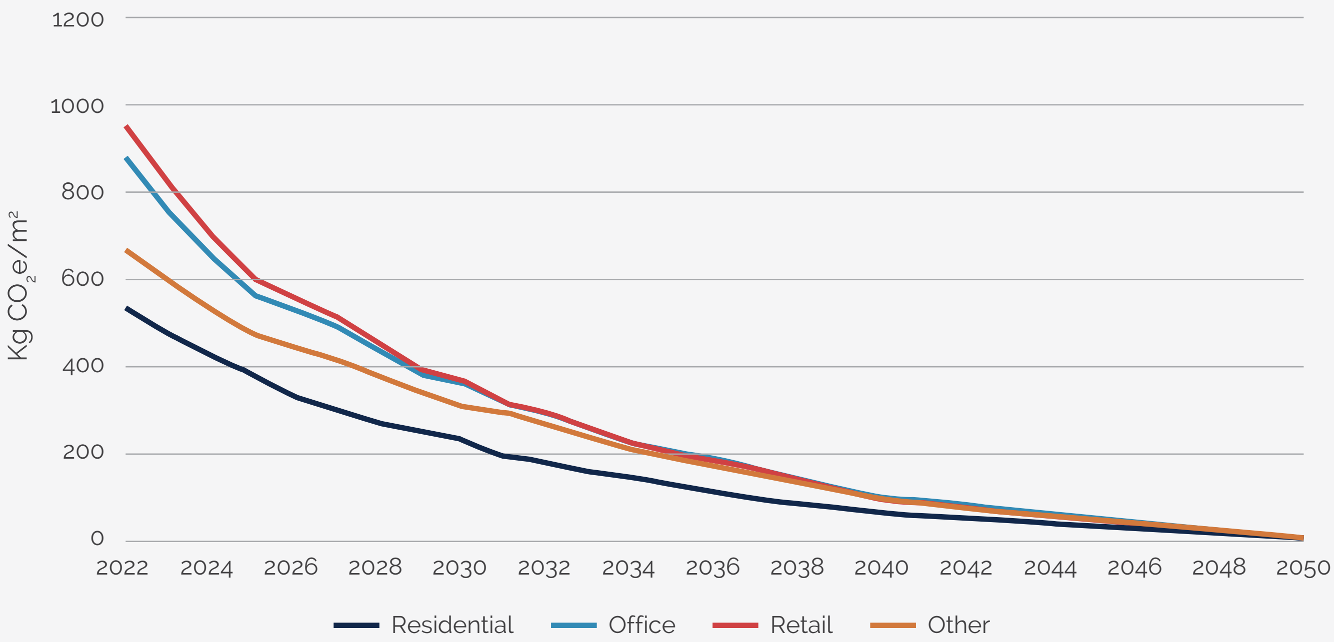


Table 16. Upfront embodied GHG emissions intensities using an economic value added downscaling approach, corrected for renovation (kg CO_2e/m^2)

TYPOLOGY	2025	2030	2035	2040	2045	2050
Residential	383.1	233.2	127.2	64.6	34.7	7.3
Office	563.7	362.2	203.9	99.6	49.8	9.3
Retail	600.9	366.5	197.4	93.3	45.5	8.4
Other	474.6	309.7	190.0	95.1	49.2	9.7

Figure 7. Decarbonization pathway for upfront embodied GHG emissions in buildings: scenario AR6 IPCC C1, equal-per-capita and utilitarian, corrected for renovation

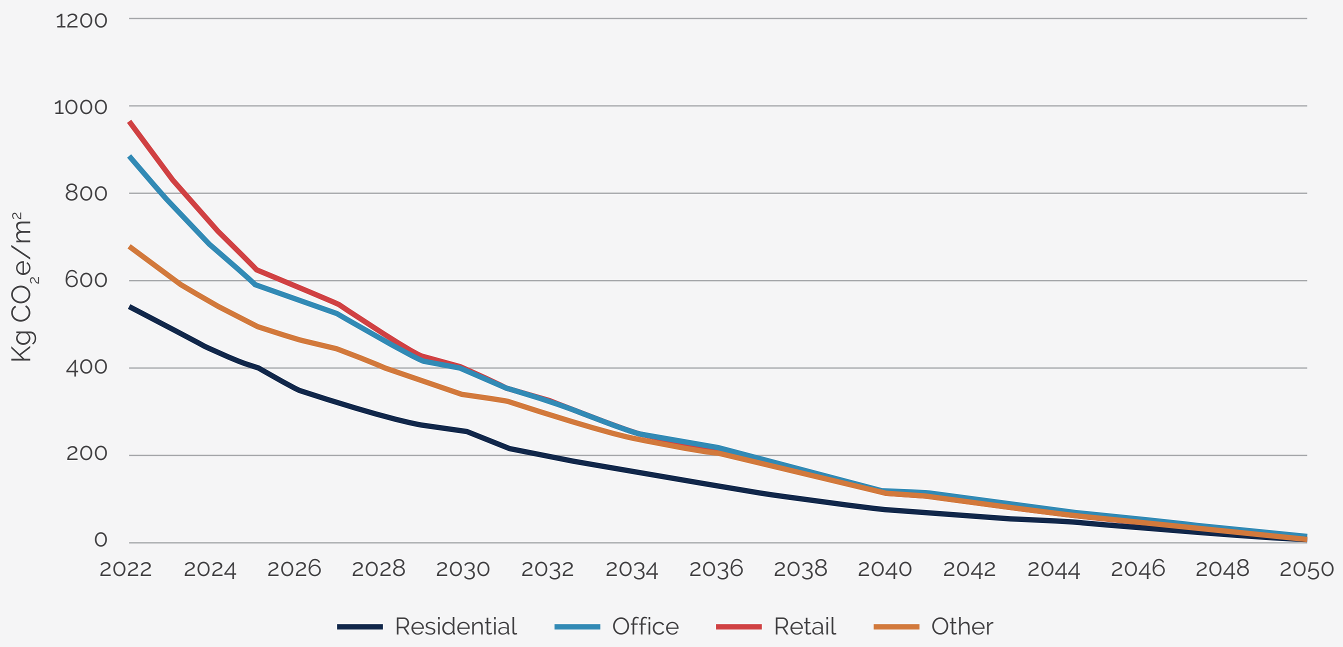


Table 17. Upfront embodied GHG emissions intensities using an equal-per-capita and utilitarian downscaling approach, corrected for renovation (kg CO_2e/m^2)

TYPOLOGY	2025	2030	2035	2040	2045	2050
Residential	400.7	256.1	147.2	79.1	45.3	10.3
Office	589.6	397.7	236.0	122.1	65.0	13.0
Retail	628.5	402.4	228.4	114.3	59.4	11.8
Other	496.4	340.0	219.9	116.5	64.2	13.5

ACKNOWLEDGEMENTS

ACKNOWLEDGEMENTS

Partners in developing the pathways and this document

The SBTi developed the embodied emissions pathways and this document in technical partnership with Ramboll, a global engineering, architecture and consultancy company. The SBTi would like to extend sincere gratitude to the entire team for their dedication and hard work in creating this document. We would like to acknowledge the SBTi technical review team for their time and support to review the pathway development method and this document.

Contributing authors

Xavier Le Den, Ramboll

Matteo Caspani, Ramboll

Jacob Steinmann, Ramboll

Morten Ryberg, Sweco

Klara Lauridsen, Sweco

SCIENCE BASED TARGETS

DRIVING AMBITIOUS CORPORATE CLIMATE ACTION

For general information and technical queries contact us at:
info@sciencebasedtargets.org