A 1.5°C PATHWAY FOR THE GLOBAL BUILDINGS SECTOR'S EMBODIED EMISSIONS

PATHWAY DEVELOPMENT DESCRIPTION - DRAFT FOR PILOT TESTING

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A 1.5°C PATHWAY FOR THE GLOBAL BUILDINGS SECTOR'S EMBODIED EMISSIONS: PATHWAY DEVELOPMENT DESCRIPTION – DRAFT FOR PILOT TESTING

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LIST OF ABBREVIATIONS

CRREM	Carbon Risk Real-Estate Monitor
EAG	Expert Advisory Group
GHG	Greenhouse Gas (emissions)
GVA	Gross Value Added
GWP100	Global Warming Potential over a 100-year timeframe
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
I-O	Input-Output (model)
MRIO	Multi-Regional Input-Output (model)
NACE	Nomenclature of Economic Activities
NZE	Net Zero Emissions
SBTi	Science Based Targets initiative
SQM / m^2	Square Meter

1. INTRODUCTION

1.1. Overview of this study

This document is the final report of the project “A 1.5˚C pathway for the global buildings sector’s embodied emissions” showcasing the methodology used for the development of the pathways aligned with a 1.5˚C climate change trajectory and presenting the preliminary results of the analysis. The project, running from November 2022 to June 2023, was commissioned by the Science Based Targets initiative (the “SBTi”) and performed by Ramboll with the support from Sweco.

This document is part of a set of deliverables for a larger project launched by the SBTi to develop target-setting guidance for the real estate and construction sector. In addition to the decarbonization pathway for buildings’ embodied emissions, this also includes a decarbonization pathway for in-use emissions, and a guidance document for emissions accounting, reporting and target setting.

The present deliverable is aimed at describing in detail the steps undertaken to develop the pathways for the embodied emissions of the global buildings sector aligned with a 1.5˚C climate change trajectory, as well as by providing an overview of the results of the analysis.

The details of the work carried out as part of this project include:

1. Develop pathways(s) for buildings’ embodied emissions aligned with a 1.5˚C scenario, covering the global buildings sector, so that they can be implemented in SBTi’s currently approved methods and tools for corporate target-setting.
2. Provide global pathway(s) where a unified performance metric (e.g. in kg CO2eq/m2) is provided for the global buildings sector and is applied equally across countries.
3. Disaggregate the pathway(s) by building typology, covering at least the following three building typologies: residential, office, and retail.
4. Explore further disaggregating the pathway(s) 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 Expert Advisory Group (EAG).

Companies and financial institutions willing to set science-based targets are asked to refer to the separate SBTi Buildings sector guidance for their GHG accounting or target-setting related questions.

1.2. Overview of this report

This report is organised into the following chapters:

- **Chapter 1**. Introduction.
- **Chapter 2**. The role of embodied emissions of buildings in the SBTi framework.
- **Chapter 3**. Scope of a relevant embodied carbon pathway.
- **Chapter 4**. Attribution principles for downscaling.
- **Chapter 5**. Development of the embodied emissions pathways.
- **Chapter 6**. Embodied emission pathways.

2. THE ROLE OF EMBODIED EMISSIONS OF BUILDINGS 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. Additionally, emissions from transport, the construction site and demolition contribute to embodied emissions. The term embodied carbon is also frequently used. When used in this report, both embodied emissions and embodied carbon refer to all greenhouse gasses (GHGs).

Globally, a third of all building-related emissions stem from embodied carbon[1]. This accounts for around 10% of all energy related GHG emissions world-wide. 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 2-1).

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.

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 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 emissions.

For most actors in the construction and real-estate value chains, embodied emissions do not fall in their scope 1 or 2. The emissions from producing construction materials occur in the respective

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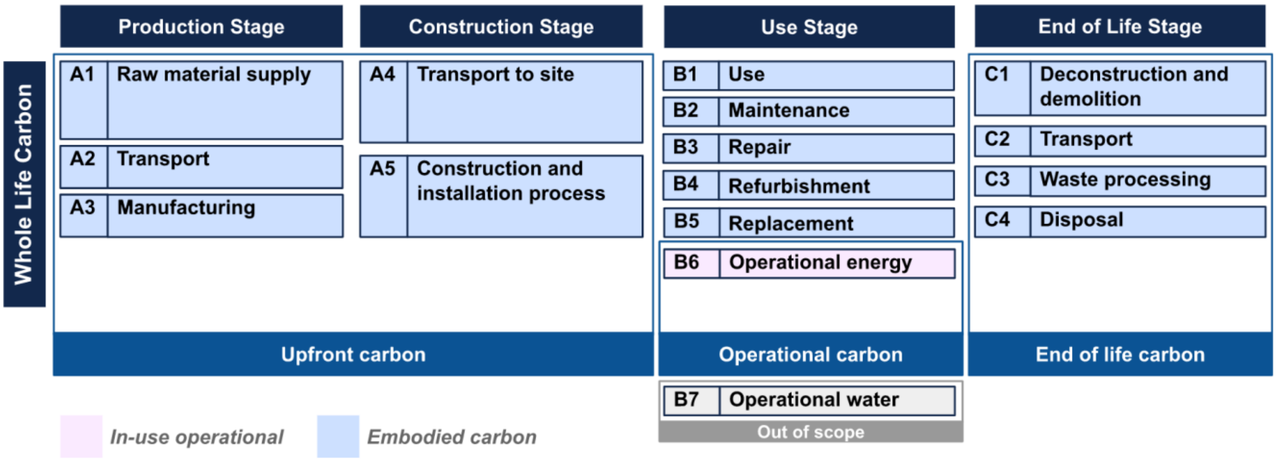
[1] https://globalabc.org/our-work/tracking-progress-global-status-report

[2] Figures based on forthcoming report prepared by Ramboll, KU Leuven and BPIE as part of 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.

industries. 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 building 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 recently been developed by CRREM 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 building sector and with that contribute to keeping global emissions within the remaining budget for limiting global warming to 1.5°C.

Figure 2.1 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 to bring down these emissions, as they account for a significant portion of total emissions. According to WorldGBC, embodied emissions are responsible for approximately 11% of global emissions[3]. Establishing the scientific foundation and explicit 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 explained by two main factors. On the one hand, the priority has so far focused on the principle of reducing emissions from scope 1 and 2, while scope 3 targets are set based on a more

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

generic approach that aims at creating action but recognizes the lower degree of control over scope 3 emissions. On the other hand, the cross-sectoral nature of embodied emissions means that a specific reduction pathway aligned with the carbon budget for the 1.5°C ambition is not available in global industry breakdowns. The feasibility of establishing such a budget was demonstrated through scientific study and interrogation by a group of experts including some contributing 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 in a preliminary form.

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.

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[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

3. SCOPE OF A RELEVANT EMBODIED CARBON PATHWAY

3.1. Alignment with SBTi fundamentals

In this project, the design of the 1.5°C global pathway for embodied emissions in the building 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 can later derive their specific reduction targets based on their relative size in the sector.

The project builds up on 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 of this project, given that embodied emissions of a building fall into this scope for the most relevant parts of the building sector value chain.

For this, a global pathway has been developed that forms the overall decarbonization trajectory of the embodied emission component of the building 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 emission intensity targets

A key consideration for the design of a 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 can be measured in a simpler way compared to intensity targets and give higher certainty that the carbon budget is kept. However, absolute targets represent a problem when a company is growing. In such a case, the only way to improve its environmental performance is by shrinking or by making considerably large emission intensity reductions.

Emission intensity targets can overcome the problem with growing companies, given that these calculate emissions relative to a measure of output, which can be a proxy for growth. Nevertheless, they also entail certain difficulties. 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 building-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 m2 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.

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[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 whether 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 carbon and is the most quantifiable part at the point of building 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. Therefore, the scope was limited to these emissions.

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 finishes, and technical installations are part of the scope.

3.5. Approach to renovation vs. new construction

The building 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 construction of new buildings.

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 the table below.

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[6] Upfront embodied emissions refer to the lLife 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 EN15978. Please refer to Figure 2.1 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.

Table 3.1. 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 m2 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 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 construction 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 base. • 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.

4. 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 divisions 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 4-1 below presents the most common attribution principles and their underlying perspectives on equity[8].

Table 4.1. 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 to establish national carbon budgets.	*Egalitarianism:* All individuals should be equal in terms of welfare or resources.

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[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 favours 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 4-2 summarizes the result of a literature review, which indicates the primary principles used for buildings in the literature that were reviewed. It also illustrates that often a combination of principles is needed to arrive at a meaningful share of the carbon budget.

Table 4.2. Use of attribution principles in literature and practice

PUBLICATION / INITIATIVE	ATTRIBUTION PRINCIPLE(S) USED
SBTi – Sectoral Decarbonization Approach (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	Multi-step approach: Step 1: Equal-per-capita combined with Utilitarian in Step 2

PUBLICATION / INITIATIVE	ATTRIBUTION PRINCIPLE(S) USED
budgets for countries and absolute sustainable building targets	
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 pathway 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.

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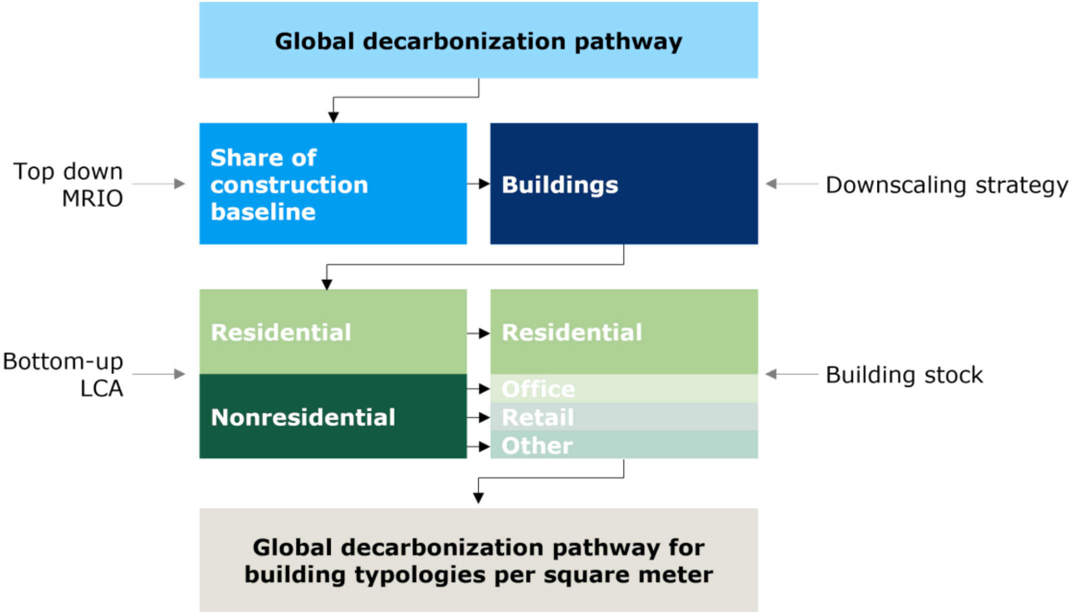
[9] It is also important to notice that the Common But Differentiated Responsibilities (CBDR) principle is not taken into account for the formulation of the pathways in this study, especially since these are not formulated for countries but at the global level.

5. DEVELOPMENT OF THE EMBODIED EMISSIONS PATHWAYS

5.1. Overview of the approach

Figure 5-1. Overview of the approach to the development of a global decarbonization pathway for building typologies per square meter



The overall approach is establishing a decarbonization pathway for building typologies per square meter. The first step is collecting data to define and determine a global decarbonization pathway to comply with the IPCC 1.5°C scenario. The next step is to project future activities of the global building stock divided by building typologies, whereafter renovation rate scenarios can be established. The share of global embodied carbon resulting from new construction is determined by three attribution principles: Economic value added, Equal per capita and Utilitarian, and Grandfathering.

All these considerations propose a way to define a global decarbonization pathway for building typologies per square meter.

5.2. Global projections of floor area development

Establishing global floor area projections per building type

As previously mentioned, the pathway will be based on an intensity measure of GHG emissions per square meter. 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 the year 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 in line with 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. The figure 5-2 below illustrates this development.

The figure 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 therefore 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. Moreover, 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.

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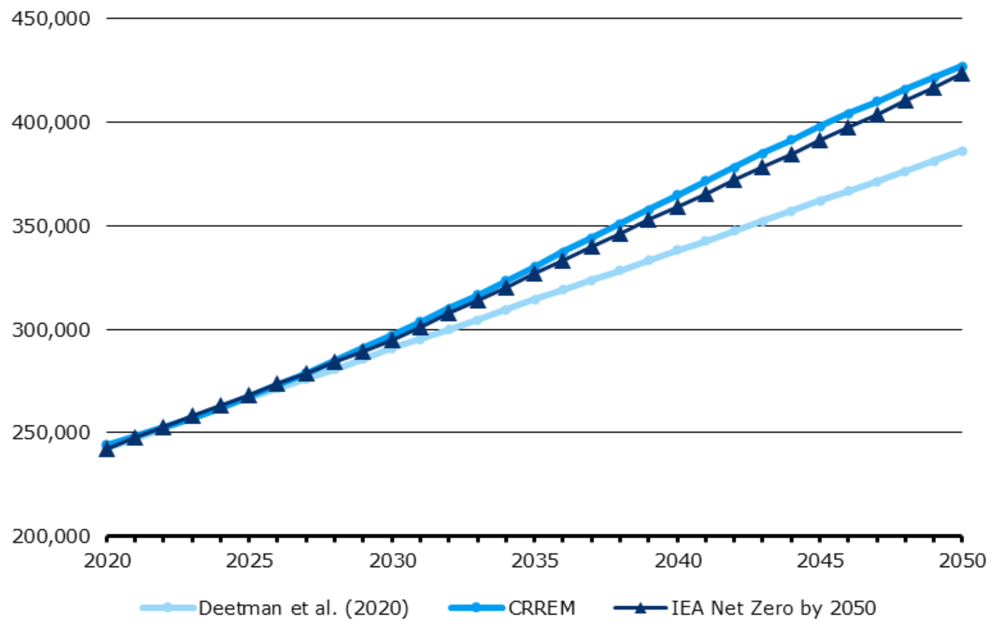
[10] https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf

[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 5-2. Overview of the projected evolution of global floor area (in Million m^2) 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 develops a model that calculates the floor space area up to year 2050 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 NZE scenario. The result of this approach is captured in the table below.

Table 5.1. Current and projected global floor area per building typology according to the proposed approach

BUILDING TYPOLOGY	2020 (MILLION M^2)	2050 (MILLION M^2)	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%

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 must be accounted for to correct the net-change in m^2 for removals from the building stock.

However, 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 (Net Zero Emissions) 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.

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[12] Compound annual growth rate 2020-2050

Table 5.2. 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

Scaling from global budget to full construction sector

The total impact of all construction activities is estimated to be 8.5 GtCO$_2$-eq 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 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$_2$-eq 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 will primarily apply 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

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[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

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_2-eq 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. EN15978 and illustrated in Figure 2.1, this means that the modules A1-A5 and B1-B5 are included in this value.

Scaling down to the building 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 construction of buildings[15].

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

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 life-cycle assessments (LCAs) of buildings are needed. Only recently, studies compiling such information across a range of buildings, typologies and countries have started to emerge. Table 5.4 below presents the upfront embodied carbon baselines found in recent literature.

However, 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

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[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).

[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

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 lifecycle 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 entry (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 the table below.

Table 5.3. LCA-based emission data for residential and office buildings based on the review study by Röck et al. (2020)

BUILDING TYPOLOGY	AVERAGE $CO_{2\text{-EQ}}$ EMISSION [KG $CO_{2\text{-EQ}}$ / M^2] [18]
Residential	407.9
Offices (an assumed representative for other non-residential typologies)	572.4

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 the state-of-the-art for 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

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[17] The Rock et al 2020 study, listed in Table 1, has a few cases from those regions too.

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

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 5.4. Overview of studies presenting embodied carbon values for the status quo of building design and construction

SOURCE	CASE SAMPLE		UPFRONT EMBODIED EMISSIONS (KG CO_2EQ/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	SFH MFH Office Educational Health care Public assembly	North America (62%) Europe (20%) Asia Pacific (15%)	Typically less than 500	200 and 500 (50% of commercial office buildings lie between	Median of 468 for mixed use	Database of 1007 buildings for which an LCA had been performed Overall, typically below 1,000 $kgCO_2e/m^2$ for foundations,

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[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_2EQ/M^2)			COMMENTS
	BUILDING TYPES	GEOGRAPHIES	RESIDENTIAL	OFFICES	OTHER NON-RESIDENTIAL	
	Mixed Other	Middle East (3%) Other (<1%)		these values)		structure and enclosure
OneClickLCA 2021	Residential Office Industrial Educational Commercial	Europe (100%)	410	510	380 (educational) – 500 (industrial)	Database of 3737 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	SFH MFH 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

SOURCE	CASE SAMPLE		UPFRONT EMBODIED EMISSIONS (KG CO_2EQ/M^2)			COMMENTS
	BUILDING TYPES	GEOGRAPHIES	RESIDENTIAL	OFFICES	OTHER NON-RESIDENTIAL	
						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_2-eq 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 5.5. Estimated total CO_2-eq emissions per building typology

TYPOLOGY	TOTAL CO_2-EQ EMISSIONS BASED ON EMISSION FACTOR FROM RÖCK ET AL. (2020) MULTIPLIED WITH BUILDING STOCK PROJECTIONS [GT CO_2-EQ]	SHARE OF TOTAL CO_2-EQ 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 building construction, i.e. 10.2%. Hence, the share of annual GHG emissions split into building typologies can be estimated as per the table below.

Table 5.6. 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 building construction 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 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 global scale need to increase from 1% to 2.5%. These projections are based on the IEA's net zero 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 the table 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.

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[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.

Table 5.7. 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%

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 building 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 the 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].

The pathway for buildings has been specified to take into account the differentiated reduction rates of different CO2 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. The table 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 emission 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 5.8. Absolute emission reduction pathways for industries contributing to total CO2-eq emissions from construction sector

EMISSION CONTRIBUTORS	SHARE OF TOTAL CO$_2$-eq EMISSION FOR CONSTRUCTION 2019	PERCENTAGE REDUCTION IN 2030 RELATIVE TO 2020 LEVEL	PERCENTAGE REDUCTION 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%

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[22] doi: 10.5281/zenodo.5886911

[23] Absolute reduction pathway, scope 1 emissions

[24] Absolute reduction pathway, scope 1 emissions

Table 5.9. Weighted absolute reduction percentage for construction relative to 2020

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

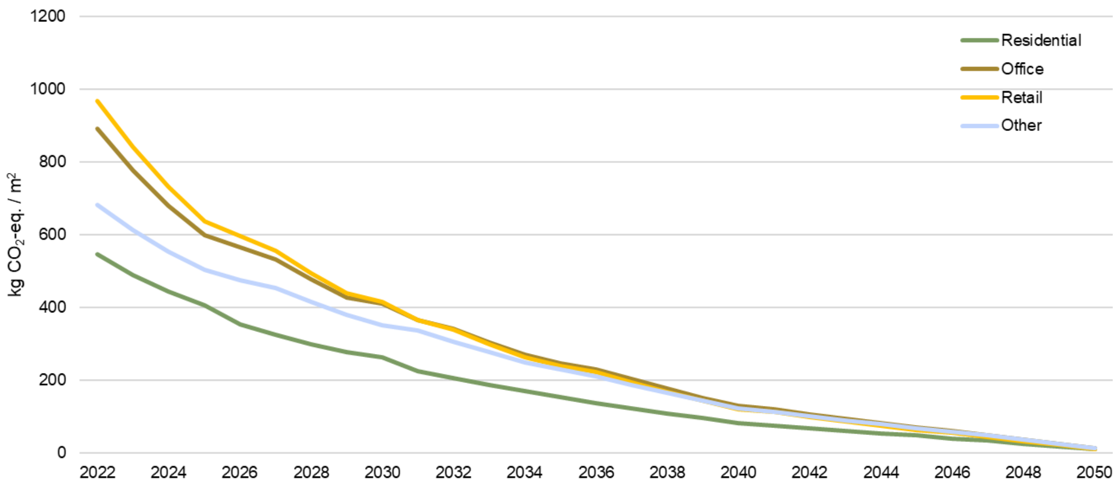
Finally, the downscaled shares are divided for each building typology with the projected new building addition to estimate the target CO_2-eq emissions per m^2 for embodied emissions, split into the four typologies as shown in the next section.

6. EMBODIED EMISSION 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, corrected for renovation, meaning that a part of the emissions is set aside to take into account future renovation of the new building construction, is depicted in the figure below.

Figure 6.1. 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_2-eq/m^2, are also reported in the table below for representative years (2025, 2030, 2035, 2045, 2050) and by building typology.

Table 6.1. Upfront embodied GHG emission intensities using a grandfathering downscaling approach, corrected for renovation (kg CO_2-eq/m^2)

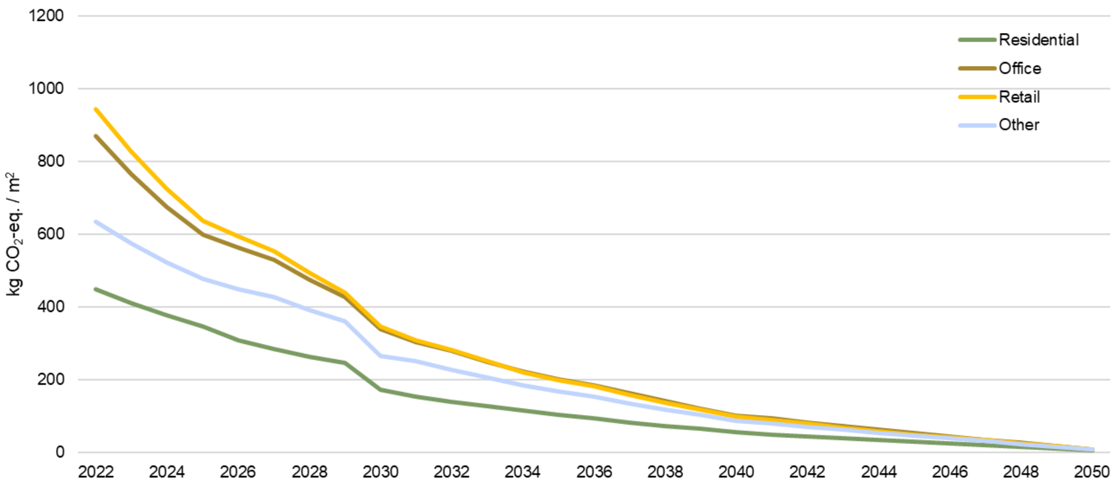
TYPOLOGY	2025	2030	2035	2040	2045	2050
Residential	406.8	264.0	154.1	84.2	49.0	11.3
Office	598.6	410.0	247.1	129.9	70.3	14.3

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 the figure below. Both renovation and new buildings are included in this case, and the overall pathway is reduced due to the increased number of m^2 affected.

Figure 6.2. Decarbonization pathway for upfront embodied GHG emissions in buildings: scenario AR6 IPCC C1, grandfathering, no correction for renovation



The represented GHG emission intensities per building type, expressed in kg CO_2-eq/m^2, are also reported in the table below for representative years (2025, 2030, 2035, 2045, 2050) and by building typology.

Table 6.2. Upfront embodied GHG emission intensities using a grandfathering downscaling approach, no correction for renovation (kg CO_2-eq/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 and 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 emission 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 CO2-eq 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.

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[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 6.3. Estimated allocated share for construction sector embodied GHG emission intensities using a grandfathering downscaling approach, no correction for renovation (kg CO_2-eq/m^2)

DOWNSCALING APPROACH	ALLOCATED SHARE OF THE ANNUAL EMISSION BUDGET (2019) TO BUILDINGS
Grandfathering, CO_2-eq emission 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 emission 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 emission level in 2050 was estimated by dividing the allocated share of emission budget to buildings using the grandfathering approach with the allocated share of emission 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_2-eq 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.

The figures below 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_2-eq/m^2 measure, ranging between 59% and 63% by

2030 and ca. 99% by 2050. The highest reductions are expected for retail and offices, which start at a higher GHG emission 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 6.3. Decarbonization pathway for upfront embodied GHG emissions in buildings: scenario AR6 IPCC C1, economic value added, corrected for renovation

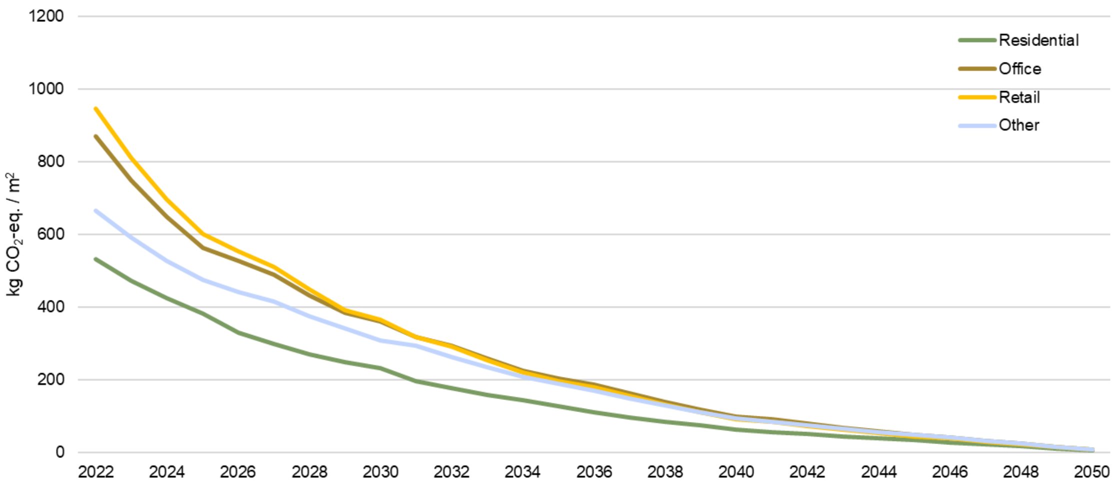

Table 6.3. Upfront embodied GHG emission intensities using an economic value added downscaling approach, corrected for renovation (kg CO_2-eq/m^2)

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

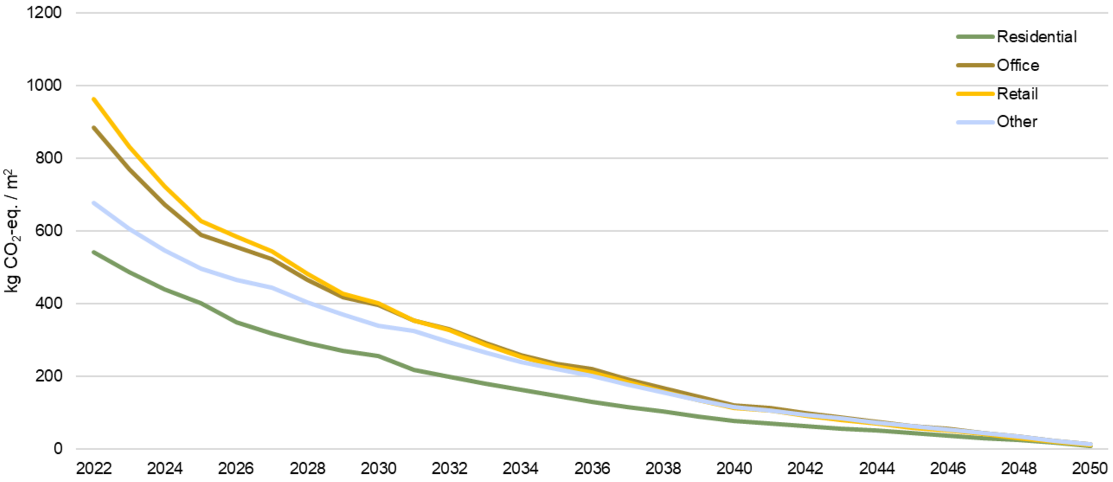

Table 6.4. Upfront embodied GHG emission intensities using an equal per capita and utilitarian downscaling approach, corrected for renovation (kg $CO_{2\text{-eq}}/m^2$)

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