Towards embodied carbon benchmarks for buildings in Europe

#3 Defining budget-based targets: A top-down approach (updated version 1.1)

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#3 Defining budget-based targets: A top-down approach

Project name	Towards EU embodied carbon benchmarks for buildings
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In this report, the widely used terms 'embodied carbon' and 'carbon budgets' are applied. Herein it is considered synonymous with 'embodied GHG emissions' and 'GHG budgets'. These terms therefore refer to both CO2 and non-CO2 GHG emissions. The data regarding global emission budgets presented in this report do, however, differentiate between carbon- only and GHG emissions and thus refer to either GHG emissions (CO2-eq) or CO2 emissions.

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Executive summary

Rationale – Why is this important?

"Embodied carbon" consists of all the greenhouse gas (GHG) emissions associated with materials and construction processes throughout the whole life cycle of a building[1]. While past efforts have mostly focused on increasing energy efficiency in building operation, recent research on GHG emissions across the full life cycle of buildings highlights the increasing importance of embodied GHG emissions related to construction material production and processing.

The project "Towards Embodied Carbon Benchmarks for buildings in Europe" was established by Ramboll and BUILD AAU - Aalborg University with the support of the Laudes Foundation. Through four reports[2], the objective is to enhance our understanding of embodied carbon in buildings and set the framework conditions for reducing it. To do so, the project explores the concept of embodied carbon baselines, targets and benchmarks for buildings in Europe.

To drive embodied carbon emissions reduction as part of a reduction of whole-life emissions, targets for embodied carbon are needed. Targets define the number of emissions that can be emitted in line with scientific and political decarbonisation requirements to hold global warming to well below 2oC, and preferably limit it to 1.5oC, compared to pre-industrial levels, to avoid the worst impacts of the climate crisis. This report therefore outlines how a carbon budget of the remaining emissions quantity, in line with global warming limits and targets linked to this budget, can be set for embodied carbon as a reference point for policymakers and industry.

Methodology – What did we do?

This report brings together a review of existing methodologies for setting targets based on carbon budgets and a discussion of the characteristics of embodied carbon in buildings. It starts by presenting the elements needed to set a budget-based target as applied in common target-setting approaches. Building on scientific literature, it then presents the challenges that lie in applying these elements to embodied carbon.

Based on all these considerations, the report proposes a way forward for defining a carbon budget and setting targets along the budget trajectory for Paris-aligned embodied carbon levels for upfront emissions from new buildings per square metre (m2). A key challenge of this is downscaling the global carbon budget to specific numbers for embodied carbon in a global or national context. This issue is addressed by using a five-step approach that focuses on a national GHG budget and allocates a share of this budget to embodied carbon, as shown in Figure 1.

This procedure for downscaling from a global budget to an activity in a country is applied to the Danish and Finnish building sectors. In the proof of concept provided in this report, a combination of different allocation principles for the GHG budget to countries is applied. Global emissions are allocated to countries based on an equal per capita (EPC) principle. The share of embodied carbon resulting from new construction is determined in two ways. First, allocation is based on a utilitarian (U) principle that assesses the contribution to national welfare through

1. Embodied carbon therefore includes: material extraction, transport to manufacturer, manufacturing, transport to site, construction, maintenance, repair, replacement, refurbishment, deconstruction, transport to end-of-life facilities, processing and disposal.
2. Reports: #1: Facing the data challenge; #2: Setting the baseline; #3: Defining a carbon budget; #4: Bridging the gap.

multi-regional input-output (MRIO) models. Second, a grandfathering allocation (GF) based on the current share in the national emissions inventory is undertaken.

Future construction is forecasted based on national economic activity (EA) in the construction sector. As this combines all building construction activity, a differentiation between building purposes (e.g. residential, non-residential) is not possible in this approach. Rather, all buildings are included in the resulting targets.

Figure 1: Downscaling from global budget to embodied carbon in buildings - a concept to set targets for embodied impacts in new buildings per m².

Results – What did we find?

Existing methodologies for budget calculation and target setting are designed for purposes other than addressing embodied carbon. This is due to several factors that can be summarised in two points:

- First, the characteristics of embodied carbon differ from operational carbon emissions. This is because of the cross-sectoral and international nature of the value chain along which embodied emissions occur. Neither a definition of emission scopes used in corporate GHG accounting nor the territorial GHG inventories used by governments and cities are fully able to capture all relevant embodied emissions.
- Second, important elements for setting a budget-based target are not available on a commonly agreed basis. Notably, agreement on a carbon budget specific to the building sector or embodied carbon, and a decarbonisation scenario or trajectory that is aligned with the global carbon budget are needed. There is therefore a pressing need to develop a shared trajectory that contains the reference information for reducing embodied emissions.

Applying the proposed approach for downscaling the global budget to upfront embodied carbon from national construction activity in Denmark and Finland shows that the Paris-aligned budget and related targets in line with global warming of 1.5°C are substantially lower than current levels of embodied carbon and existing legislation.

Table 1 presents a comparison of the targets per m2 with the baseline established in report #2 “Setting the baseline”, which includes all life cycle stages but finds that the largest share is caused by upfront emissions. In Figure 2, the curves of the carbon budget as targets over time are shown for Denmark in comparison to the baseline and national legislation on maximum embodied carbon levels for new buildings. Both apply to new constructions, assuming a constant construction rate based on past construction trends from 2018 to 2020.

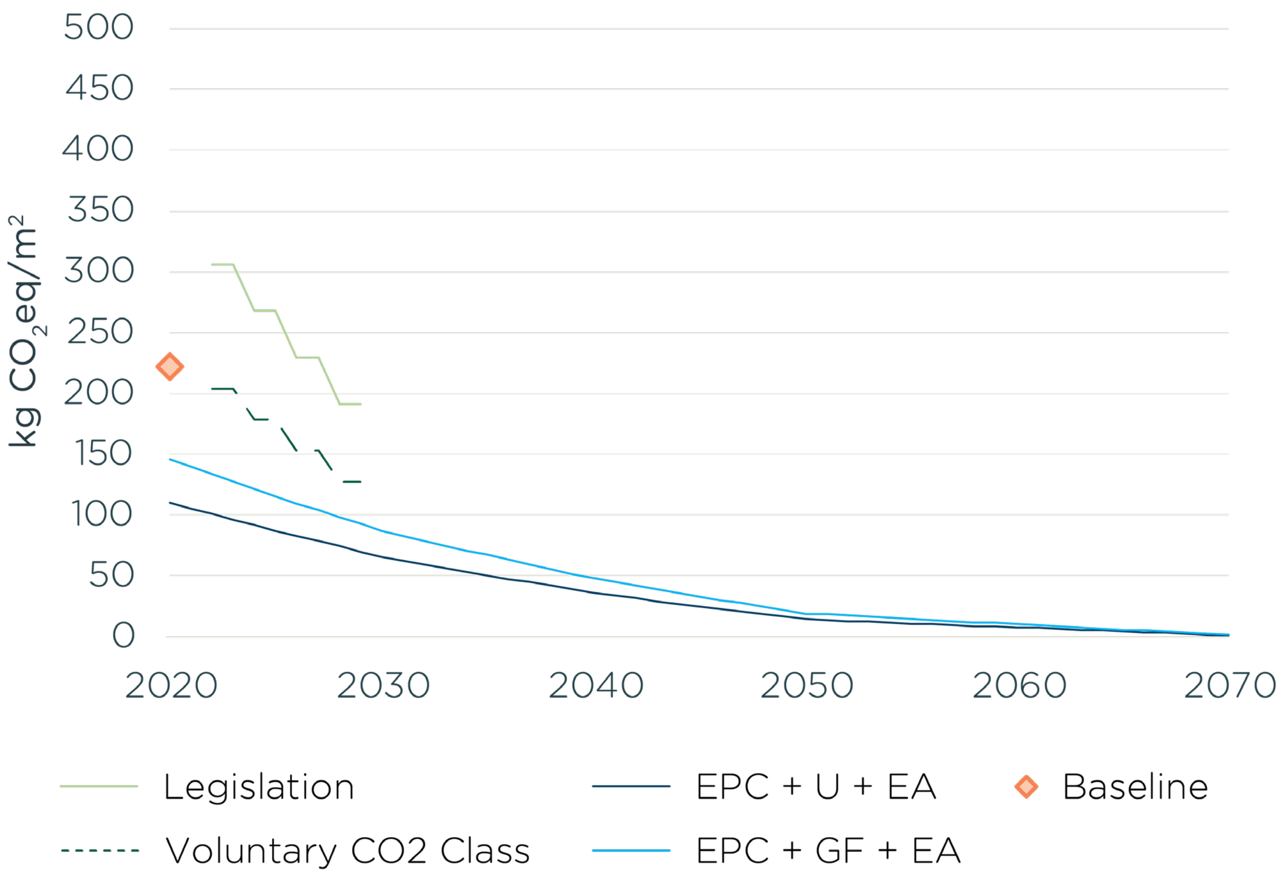
This approach, as with any allocation of the carbon budget among countries or sectors, relies on a choice of allocation principle. Depending on this choice, and because of the multitude of national or even more regional targets needed, an overshoot of the GHG budget is still a probable scenario. Additionally, the data for sectoral allocation of the budget to (upfront) embodied carbon requires data on the type of activity within the construction sector, which proves difficult to obtain. For these reasons, the concept would benefit from further progress on agreeing on allocation principles, data collection and availability, or the establishment of a global budget for embodied carbon to reduce differences between countries.

3. For these countries, the necessary data was available.

Table 1: Comparison of whole-life embodied emissions (in kgCO2eq/m²) according to empirical baseline and budget-based targets

Year	Denmark	Finland
Baseline	222	333
2025	87-116	52-213
2030	66-88	39-168
2050	15-19	8-35

Figure 2: Upfront embodied emissions (in kgCO2eq/m2) for Denmark



Conclusions – What does this mean?

Our assessment, concept and the resulting target levels highlight the following aspects:

- **Budget-based targets communicate the amount of embodied carbon that can be emitted in line with the carbon budget and are therefore consistent with the Paris Agreement on limiting global warming. Such targets set at building level are highly relevant** as a reference for the speed and scale of decarbonisation efforts in the construction sector. Considering the complexity of the value chain at play, they would constitute a strong signal for the demand side (investors, owners), and would subsequently be passed on further down the value chain (designers, producers).

- **There are challenges when defining a carbon budget and budget-based targets for embodied carbon emissions in buildings.** Fundamental elements of such targets, such as a specific carbon budget and a Paris-aligned decarbonisation trajectory needed for embodied carbon in buildings, are not yet available. Existing initiatives on GHG emissions reduction targets in the building sector have so far focused on operational carbon, and because of the specific characteristics of embodied carbon. Developing targets based on the carbon budget for embodied carbon will be crucial to more widespread target setting.

- **It is possible to overcome these challenges.** The concept of downscaling from global budget to building leads to ambitious targets that can only be achieved through a fundamental transition of the industry. Reducing the embodied carbon per m2 is essential in the industry and at construction project level. As this is not likely to be sufficient to stay within the carbon budget, action from policymakers is needed to reduce the number of m2 built. Therefore, in addition to an embodied carbon target per square metre, a target per capita may be needed.

- **The gap between the current levels of embodied carbon (see report #2 "Setting the baseline") and the levels required by the carbon budget is substantial.** The proposed concept for targets shows that Paris-aligned values lie well below the current baseline. Existing target initiatives do not specifically capture this gap for embodied carbon, while existing legislation falls short of closing it. This calls for immediate and ambitious action to reduce the embodied carbon of new buildings.

Call to action – What should we do?

Based on these conclusions, a set of recommendations emerges:

- **Setting budget-based targets for the embodied carbon of buildings needs to become more common.** For this, accessible data is needed, together with internationally recognised initiatives to define a target-setting methodology that is based on a widely agreed Paris-aligned carbon budget for the building sector, while also developing decarbonisation pathways for the sector, including embodied carbon.

- **The targets will need to be supported by ambitious benchmarks** for new buildings to be defined in regulations. To the extent possible, these benchmarks should be aligned with the budget-based targets. A framework for establishing such benchmarks is developed in report #4 "Bridging the performance gap".

- **Closing the gap between current and required levels of embodied carbon also calls for additional policy measures.** While embodied carbon limits per m2 are one element, further instruments such as reducing the rate of new construction or support for building materials with negative emissions should be considered. In addition, these elements need to be coordinated with renovations of existing buildings and the reduction of operational emissions.

- **To enable investors, building design professionals and spatial planners to set targets at building and local level, globally appropriate standards for a budget and decarbonisation trajectory for embodied carbon could be highly beneficial.** This would reduce barriers for such actors and ensure a higher level of overall consistency with the global budget. This exercise could be undertaken by an internationally accepted body like the SBTi, as part of its work to develop corporate targets in line with the Paris Agreement and the latest climate science, and necessitates collaboration with the public sector, the industry and academia, to get access to the necessary data on buildings' life cycle assessment (LCA) and construction activities.

Contents

1. Introduction

As the effects of the accelerating climate and ecological crises are becoming evident, the need for transformational climate action is growing. Based on decades of climate science and driven by increasing pressure from civil society, policymakers in the European Union (EU) and beyond are making bold claims for reducing greenhouse gas (GHG) emissions in their respective regions and activities.

Building construction and operation are among the most significant activities driving current GHG emissions, representing 37% of global GHG emissions [1]. At the same time, increasing the energy efficiency of existing and new buildings, as well as shifting to sustainable construction practices are considered major opportunities for decarbonising the economy in the coming decades.

Altogether, the sum of embodied and operational emissions is referred to as whole-life carbon emissions. Reducing this total sum of a building's emissions is the highest priority, to which this work aims to contribute.

While past efforts have mostly focused on increasing energy efficiency in building operation, recent research on GHG emissions across the full life cycle of buildings highlights the increasing importance of embodied GHG emissions related to construction material production and processing. "Embodied carbon" consists of all the greenhouse gas (GHG) emissions associated with materials and construction processes throughout the whole life cycle of a building[4].

These embodied emissions of buildings are rarely addressed in policy strategies and instruments. However, if embodied carbon is not included in building decarbonisation targets, failure to meet global decarbonisation targets is highly likely. This is because the total climate impact of buildings would remain only partly addressed. Thus, the need and potential for reducing embodied emissions require attention and alignment as part of European and global efforts to combat climate change. It was against the backdrop of increasing efforts to understand and reduce the whole life cycle carbon of buildings that the project "Towards Embodied Carbon Benchmarks for the European Building Industry" was established.

In particular, setting a performance system for embodied emissions at building level can provide relevant guidance for policymakers and the building industry. Developing the foundations of such a performance system for new buildings has been the objective of the project "Towards Embodied Carbon Benchmarks for buildings in Europe", established by Ramboll and Build AAU - Aalborg University, with the support of the Laudes Foundation. This includes a baseline for current embodied carbon levels in new buildings, as well as considerations of the available carbon budget for these emissions. Together with a review of data availability and quality, these elements form the basis for a performance system in the form of benchmarks for reducing embodied carbon.

The focus of this project was placed on the EU. This is grounded in its position as a pioneer in GHG emissions reduction policies with instruments such as the Energy Performance of Buildings Directive, its Taxonomy for Sustainable Activities, or the EU Climate Transition Benchmark Regulation. Additionally, there is increasing policy awareness of the life cycle perspective of buildings. These instruments and initiatives will have an increasing impact on the building industry. This project seeks to inform the debate among policymakers and industry alike and stimulate the development and application of benchmarks for embodied carbon in the EU and beyond.

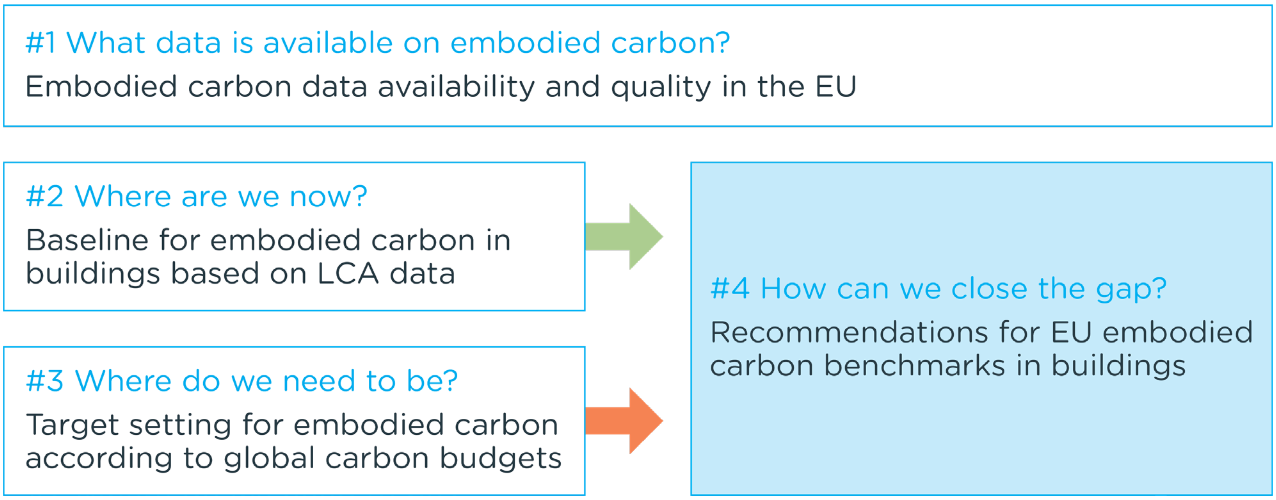
4. Embodied carbon therefore includes: material extraction, transport to manufacturer, manufacturing, transport to site, construction, use phase, maintenance, repair, replacement, refurbishment, deconstruction, transport to end-of-life facilities, processing and disposal

The series of reports produced in this project provide insights and advances on the following questions:

1. What data is available on embodied carbon in the EU?
2. Where are we now? What is the current status of embodied carbon in new buildings?
3. Where do we need to be? What level of embodied carbon is aligned with the available carbon budget?
4. How can we close the gap? How can embodied carbon benchmarks be set for reduction?

This is the third report in this series.

Figure 3: Overview of report series for the project "Towards Embodied Carbon Benchmarks for buildings in Europe"



The purpose of this report is to present a proposed concept of how a carbon budget for embodied carbon can be determined and how targets aligned with this budget can be set for buildings. To do this, the report defines the necessary elements of a target, investigates the applicability of existing approaches for target setting to reduce the climate impact of embodied carbon in buildings, and proposes a methodology for setting embodied carbon targets.

This methodology is applied and tested for Denmark and Finland. Building on the Baseline Report that calculated current levels of embodied carbon, the application of the proposed approach for budget-based targets shows a huge performance gap in efforts to mitigate climate change. Not least because of the increasing share of embodied carbon (in relative and absolute terms) determined in the Baseline Report, this calls for rapid and ambitious action on target setting and benchmark development.

2. What is needed for a budget-based target?

Defining budget-based embodied carbon targets requires that the necessary foundations are established. This section lays out the fundamental elements of targets set in a budget-based process. These elements are:

- The global carbon budget
- Pathways for future emissions, to stay within this budget
- Approaches to scaling down global emissions to countries, sectors, companies or activities

2.1 Global carbon budget

The Paris Agreement sets out a global framework for averting climate change by limiting global warming. Climate change mitigation efforts and targets have increasingly emerged since the adoption of the Paris Agreement in 2015. In the Paris Agreement, the vast majority of countries around the world have expressed the ambition to limit global warming to 1.5°C or, at most, 2°C above pre-industrial levels [2]. To stay within the limit, the end-of-century radioactive forcing must be kept at 1,9 W [3]. Variations in radiative forcing are caused by changes in the atmospheric concentrations of greenhouse gas emissions, strongly driven by CO2 and other gases emitted by human activities. The relationship with radiative forcing having been established, the number of greenhouse gases (GHG) already emitted into the atmosphere have been identified and remaining global carbon budgets have been estimated [4].

The global carbon budget determines the remaining amount of GHG that can be emitted until the targeted global warming limit is reached. Because of the different global warming targets formulated in the Paris Agreement, varying levels of ambition between 1.5°C and 2°C are possible and result in different carbon budgets. The latest IPCC report published in September 2021 [5] contains updated budgets considering emissions up to 2019. These budgets cover CO2 emissions and are presented in Table 2. A CO2-equivalent budget for non-CO2 emissions has to be added, which is taken into consideration in the decarbonisation scenarios cited and referred to in this report.

Table 2: Estimated remaining global CO2 budgets from the beginning of 2020 in GtCO2 [5]

Global warming target relative to pre-industrial levels [°C]	Additional global warming relative to 2010–2019 average [°C]	Estimated carbon budget in GtCO2 by likelihood of limiting global warming to temperature limit					Variations in reductions of non-CO2 emissions
		17%	33%	50%	67%	83%	
1.5	0.43	900	650	500	400	300	Higher or lower reductions of non-CO2 emissions can increase or decrease the values on the left by 220 GtCO2 or more.
1.7	0.63	1450	1050	850	700	550	
2.0	0.93	2300	1700	1350	1150	900	

This global budget forms the top-level consideration that any relevant target has to reflect in order to keep emissions within this budget. Through this mechanism, the target can be considered science-based and Paris-aligned.

2.2 Global and sectoral pathways

In addition to the total carbon budgets, pathways are needed to define levels of emissions over time that result in a transition compatible with the carbon budget. These pathways or scenarios help to understand the necessary future development of emissions from industrial sectors and activities that ensure levels stay within the global warming target.

Pathways model the impact of expected changes to technologies, behaviour and policies on emissions reduction over time. In this way, pathways also provide a context for an emissions reduction target by illustrating certainties and uncertainties around political, economic, and technological developments. Ultimately, pathways reach an emissions level that can be sustained while staying within the global warming limit.

The IPCC Special Report identifies such mitigation pathways compatible with the 1.5°C target [6]. A set of transition pathways consistent with an increase of 1.5°C in 2100 were explored through six integrated assessment models (IAM) and a simple climate model. To systematically explore the impact of different socio-economic responses to the mitigation pathways, the IAMs have adopted the five Shared Socio-Economic Pathways (SSPs) [7]. The SSPs provide different narratives of the future world in terms of socio-economic indicators such as technological developments, and population growth and economic growth. By integrating the SSPs into the IAMs, GHG emissions scenarios can be derived for different climate policies.

The International Energy Agency (IEA) develops and updates scenarios for different global warming thresholds. The IEA report on net zero by 2050 [8] provides scenarios for limiting global warming to 1.5°C. In these scenarios, future energy emissions are divided into the following sectors: industry, transport, energy and buildings (operational energy use). The industry and transport sectors are further broken down[5] and the building sector is also further divided into direct and indirect energy use for residential and non-residential buildings respectively. The remaining sectors, including direct emissions from the construction industries, are in other IEA publications [9] summarised in "other industries", which are considered mainly non-energy intensive[6]. Using these scenarios creates a complete and consistent framework for all sectors and entities, in which all GHG emissions can be attributed to one of the sectors. **However, this division also means that transversal categories like embodied carbon in building materials cut across several sectors, and the necessary emissions reduction for this category cannot be forecasted in these tools.** This key challenge is discussed in Chapter 2 below.

2.3 Downscaling the global budget

The carbon budget presented in the latest IPCC report (Table 2) is global and therefore needs to be broken down further to be operationalised for emissions reduction targets at country and economic activity levels. Assigning a share of the global carbon budget to a country, building or any other service is a matter of subjective opinion on what is fair. Different normative principles and underlying justifications exist on this matter.

Applying "equal per capita" (EPC) is one way of dividing the budget into equal shares to all individuals that can easily be translated into a country's budget. However, some might also argue that developing countries should have a relatively larger share in the future, to make up for industrialised countries that have emitted large amounts of CO2 in the past. This would be an example of applying the "ability to pay" allocation principle. **Therefore, a distributed budget should always be communicated with transparency around the allocation principles applied,** to allow the reader to endorse or disagree with the ethical principles behind the resulting budgets. Allocation principles are also sometimes referred to as sharing principles.

Table 3 presents the commonly used and described sharing principles and their respective distributive justice principles as they are found in the literature [10–13].

5. For industry, this is cement, iron and steel, chemicals, aluminium, and pulp and paper; for transport it is aviation, maritime, rail, light vehicles, medium and heavy vehicles and two/three wheelers.
6. This category also includes the production of transport equipment, machinery, mining and quarrying, food and tobacco, wood and wood products, textile and leather, as well as miscellaneous sectors

Table 3: Sharing principles and underlying principles of distributive justice.

Allocation principles	Description	Underlying principle of distributive justice	Examples of application [14]
Equal per capita (EPC)	All individuals in the world have an equal right to emit GHGs. The individual carbon budget is the same for all.	Egalitarianism: All individuals should be equal in terms of, for example, welfare or resources.	N/A
Ability to pay, capability (AP)	Ability to pay allocates a larger share of the remaining budget 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.	EU Effort Sharing Regulation
Final consumption expenditure (FCE)	The carbon budget is split by assigning individual shares which are proportional to the final consumption expenditure of an economy.	Utilitarianism: Maximising the sum of welfare should be the priority.	N/A
Grandfathering (GF)	The GHG budget is allocated and spread over time based on the status quo of emissions. 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.	SBTi Absolute Contraction pproach, Sectoral Decarbonisation Approach

Implementing the allocation principles for the global carbon budget requires different levels of data and therefore also faces practical restrictions. For instance, to create sharing principles for a sector based on contribution to welfare, it is necessary to quantify the impact of the specific sector on welfare through available data. In general, a review of downscaling the planetary boundaries found that it appeared easier to assign shares on large scales, such as at country level or for industrial sectors, as larger scales require fewer normative decisions [11]. Setting more granular targets (e.g. at company or spatial planning level) requires more assumptions and notable efforts for data collection and quality assessment.

In practice, an allocation principle rarely stands alone as they are often applied together. An example is the most commonly applied sharing principle "equal per capita" (EPC) to scale down to country or individual level and then combined with utilitarian principles for sharing among industrial units [11]. Utilitarian sharing principles are based on currencies reflecting welfare such as economic value, contribution to happiness, or fulfilment of human needs. The share is then distributed according to the systems' contribution to utility compared to other systems. There are no commonly agreed standards for allocation, and thus it is a question of what is practically possible and ethically reasonable. A study investigated an annual carbon benchmark per m2 dwelling and applied six different allocation principles [15]. The study showed that applying different allocation principles affected the result by a factor of up to 6.2. This highlights the importance of the decision on the allocation principle and the potential ethical implications of such a decision.

Box 1 below describes the process of setting national GHG emissions reduction targets in the EU, including the allocation principles used for the division of reduction efforts between the Member States. In continuation of the work in work package 1 of this project, the same countries have been included in this overview.

Box 1: How national carbon budgets and targets work in the EU, and what they do to establish a sufficient basis for setting embodied carbon budgets and targets

The political context of allocation principles is dominated by considerations about capabilities and grandfathering. At international level, the allocation of efforts for reducing GHG emissions follows a categorisation of countries into developed, developing, and least developed countries along with their economic performance (e.g. measured in GDP per capita). This approach is referred to as "common but differentiated responsibilities" [16]. Developed countries with high economic development based on past GHG emissions should lead efforts to combat climate change. This principle paved the way for the Kyoto Protocol, in which only developed countries were obliged to reduce emissions, and is still reflected in the Paris Agreement (Articles 2 and 4). This is, however, not translated into specific pathways, carbon budgets or similar, as the contributions are self-determined.

The clearest example of allocating emissions reduction targets to a group of entities is the European Union with its Effort Sharing Regulation (Regulation (EU) 2018/842, abbreviated to ESR). The EU has been setting increasingly ambitious political targets for the reduction of emissions since 2009. As the EU has some, albeit only limited, legislative competence to regulate emitting activities in its member countries, it "distributes" the achievement of the target to the Member States and certain industrial sectors.

In response to increasing scientific understanding of the urgency of climate action, the EU has committed to a target of reducing GHG emissions by 55% by 2030 compared to 1990. This has been transcribed in the EU Climate Law and also submitted as the EU's Nationally Determined Contribution (NDC) to the UNFCCC in compliance with the Paris Agreement. The long-term objective is to reach climate neutrality for the EU by 2050 [17].

The general increase in ambition for this target was defined by the European Commission in the European Green Deal [17]. It was a result of the long-term climate neutrality commitment for 2050 that was set in response to the findings communicated in the IPCC Special Report published in 2018 [18]. To present a pathway that underlines the leading ambition of the EU, the intermediate reduction target of 55% was set after assessing the potential contributions of and impacts on society and the economy [19].

Different policy measures are put in place to achieve the necessary reductions. The measure of primary relevance to the allocation of reduction targets is the ESR. It sets the levels of national targets for the EU Member States to contribute to the overall EU target. The national targets are measured in relation to 2005 emissions levels in the EU Member States. The version of the ESR currently in force still reflects the previous level of ambition of a 40% reduction at EU level. In line with this, the Member State targets vary between reductions of 0% (Bulgaria) and 40% (Luxembourg). With the recent agreement to increase the EU target to 55%, and a proposal for a revised ESR published as part of the Fit-for-55 package, the Member State targets will also be increased. Table 3 shows the current and proposed future targets for the five countries covered in the project. These reduction targets are part of the NDCs for the EU countries as submitted in response to the Paris Agreement by the EU Commission. Further GHG reduction measures such as the EU Emissions Trading System (EU ETS) further contribute to the NDCs.

Table 4: National reduction targets for selected EU Member States by 2030

National reduction targets in accordance with the proposed revision of the Effort Sharing Regulation (COM(2021) 555 final).	
Denmark	50%
Finland	50%
Netherlands	48%
Belgium	47%
France	47.5%
For comparison	
EU	55% NB: This target encompasses all types of GHG emission sources, including those addressed by the EU, in particular through the EU Emissions Trading System (ETS), which are not part of a country's ESR reduction target. For this reason, EU reduction targets are higher than those for Member States under the ESR.

The EU also, to a large extent, bases the sharing of GHG emissions reduction efforts on the economic ability of Member States, by allocating efforts according to GDP per capita. The considerations of fairness and cost effectiveness have been key principles in the decision to set national targets. The impact assessment [20] of different options to distribute the targets describes the process and parameters in detail. Fairness reflects the economic development and abilities of Member States. Countries with low GDP per capita are allocated substantially smaller reduction targets than so-called rich Member States. Considerations of cost effectiveness are then applied to the group of rich Member States, taking the cost impacts of policies in the reduction curve of those countries into account.

In relation to embodied carbon, it is very important to understand that countries typically report on territorial emissions also sometimes referred to as production-based emissions. Territorial emissions account for activities within the country's borders, thus omitting all imported materials consumed by the country's activities. Research from **the UK** Green Building Council (UK GBC) shows that, of UK Manufacturing and Construction, 30% were related to non-territorial emissions, revealing a significant proportion of emissions coming from imported materials [21]. For the EU, with a large and diverse economy, this share may be lower. However, with high global interconnection, imports of steel, for example, still make up 20–25% of EU consumption [22]. Notable parts of embodied emissions are not therefore included in EU emissions inventories and are not addressed by the EU and national reduction targets.

3. What characteristics shape targets for embodied carbon?

Defining a relevant approach to target setting for the reduction of embodied emissions in the building sector has to reflect the characteristics of these emissions and the industry context. Applying the methods and defining the elements described above (budget, pathway and allocation principles) must address the characteristics and overcome the challenges of aligning the challenges with existing accounting practices. Chapter 3 will describe the approach of current target-setting initiatives that can be used to inspire budget-based targets for embodied carbon in buildings.

This chapter describes key considerations that must be addressed for developing budget-based targets for embodied carbon in buildings, which have been at the core of the concept presented in Chapter 4. The characteristics relate to the multiple sources of embodied emissions, the multiple market actors that share responsibility for the amount of embodied carbon, and the limited applicability of existing emissions accounting principles to embodied carbon.

3.1 Embodied carbon is cross-sectoral and international

The emissions that constitute embodied emissions in a building's life cycle cut across several sectors [12,23]. Construction materials in the production of steel, concrete, glass, etc. would belong to the industry sector, transport of these materials to the transport sector and construction energy to the energy sector, etc. Thus, mitigating the environmental impacts related to embodied emissions cannot be linked directly to one of the sectors normally used in national emissions inventories or future emissions scenarios. Furthermore, existing policy targets like the ones mentioned in Box 1 do not cover embodied carbon in any specific sector. Rather, parts of the mentioned sectors would have to be combined. In many cases, inventories and scenarios include a sector referred to as "buildings". This category, however, describes the emissions generated during the use of the building through fuel consumption, heating, cooling or electricity. **From a building perspective, it is nonetheless important to also address the embodied emissions, as it is the responsibility of the developer or building owner to increase demand for a more sustainable design in terms of materials and the square metres needed.** Leaving the issue of decarbonising embodied impacts to the material industry would fail to address demand.

Additionally, with embodied carbon largely stemming from emission sources upstream in the supply chain, i.e. caused by the production of materials that are used in the construction project, the reporting boundaries for emissions become highly important. Key materials such as steel or cement can be produced in different locations around the globe and transported to the construction site. This may result in different levels of embodied emissions, due to varying efficiency levels in the plants and energy sources used. Most importantly, however, the national carbon inventories and reduction targets do not account for emissions caused by the production of imported goods. This distinction is often referred to as reduction targets for territorial emissions. The target formulated in the EU policy framework, for instance, includes only GHGs emitted within the EU's borders. The extent of the issue of course depends on how much each country imports, but an example from the UK found that 30-40% of embodied emissions from construction relate to non-territorial emissions, i.e. production materials and products produced in other countries and imported to the UK [24].

In the context of highly globalised supply chains, cross-sectoral and international value chains represent a challenge when setting targets for the construction sector, companies, or building projects [21]. National carbon emissions inventories and targets do not include the full scope of emissions that a company or the sector must report on as soon as imported materials are used. The territorial targets in particular become inconsistent as a reference for companies with multiple building development projects in multiple countries, as the origin of all materials would have to be reflected and accounted for separately.

Therefore, targets for embodied carbon need to be based on a carbon budget that is consumption-based and includes the entire value chain. This can be achieved either by defining a global budget for embodied carbon or by assigning parts of national budgets to embodied carbon, which by definition include the emissions of the material value chain. This second concept will be presented and applied in Chapter 4.

3.2 Embodied carbon is determined by multiple actors in a building's value chain

In addition to the multiple origins of embodied emissions, the process of planning a building and taking decisions that determine the level of embodied carbon involves multiple actors [12,23]. These actors all have different levels of influence, depending on the set-up of a specific construction project and also encounter different types of reporting when it comes to carbon emissions, including embodied carbon. The relevant features of such reports include the type of building (e.g. residential, office space, warehouses), size (from small units to high-rise or large-area complexes), development approaches, ownership and occupation (e.g. owner-occupied or tenant-occupied). These all result in different considerations regarding the importance of embodied carbon.

Decision on the factors that determine embodied carbon, ownership of a building and use may involve multiple actors, each with different priorities[7]. A balance between these has to be struck when setting a reduction target. While embodied carbon represents some specificities, lessons from existing initiatives on corporate targets and the operational emissions of buildings can be learned. Such initiatives are presented in Chapter 3.

In addition to these considerations, policymakers determine some elements of embodied carbon as well. Building codes and local planning regulations may require certain design features or material characteristics, while spatial planning impacts the amount and type of development possible in a municipality. During permitting procedures for construction processes, these parameters are assessed and requirements for building design or use can be made. The result is a complex network of actors that shape the levels of embodied carbon at building level and in a municipality or governance structure [12,23].

This means that the optimal target addresses the demand side, with a target for a specific product unit like a square metre that can be scaled to a building, neighbourhood or owner. This signalling principle would then be passed on to the rest of the construction value chain to speed up the transition.

3.3 Existing emissions accounting principles are not designed to support embodied carbon targets

Carbon emissions can be calculated and reported in different ways, for which international standards have been developed. Corporate emissions accounting is one such way and is undertaken widely according to the GHG Protocol. At the level of a specific product like a building, LCAs are used to quantify, compare and report on emissions. However, both of these accounting approaches are designed for other purposes than setting budget-based targets for embodied emissions.

The GHG Protocol establishes a globally standardised framework to measure and manage greenhouse gas emissions at a corporate or organisational level, as well as for countries and cities. The purpose of the developed standards is to enable organisations to understand the sources of their emissions, create a comparable emissions reporting structure and allow for the tracking of corporate emissions reduction targets.

The framework defines three scopes: scope 1 emissions are direct emissions that are owned and controlled by the country, city, or company; scope 2 includes indirect upstream emissions arising from purchased energy, while scope 3 refers to other indirect emissions upstream and downstream, for which the company, country or city is responsible through its activities, but whose sources are not controlled by the company, city or country [25,26].

7. For example, an investor may develop a building with the support of building design professionals (e.g. architects and engineers) in order to later sell the property – or parts thereof. The new owner may still not be the occupant, in which case the property is rented out. The level of embodied carbon in such a case would be determined by the expectations of the developer (initial investor) and formulated by the architect and engineers. However, ownership and control over the asset would later be in the hands of other actors. In contrast, a company or an individual may decide to develop a new building for their own use. In this case, the chain of actors is substantially shorter (building designers will likely still be involved) and the decision over embodied emissions and subsequent ownership and use fall into the same hands.

As a challenge for the establishment of budget-based targets, the accounting of scope 3 emissions under the GHG Protocol is difficult to link with a specific budget, as it counts emissions generated by other actors. In the case of embodied carbon, the production of materials like steel, cement or glass would generally not be undertaken by the developer, builder or final owner of the building. Rather, the construction material industries would see the emissions in their direct GHG accounts, while for all the actors in the decision and planning process of a building, these emissions fall within scope 3. This is the case for all the actors previously described, who in almost all cases do not produce the materials that are the most significant sources of embodied emissions. A specific calculation of the global carbon budget for buildings, and within that for embodied emissions, would be needed to enable the use of the existing reporting data.

Additionally, the method of continuous (usually annual) emissions accounting means that recurring emissions from processes can be captured successfully. However, embodied emissions associated with the building occur at a specific time during production and construction, as well as maintenance and replacements, and finally during disposal of materials at the end-of-life (EoL) stage. On average, 64% of the embodied emissions occur at production and construction, 22% during use, and 14% at EoL [27]. Thus, emission peaks can be misleading if they are either misunderstood as re-occurring emissions and their magnitude will be overly emphasised, or even overlooked if the peak is lost among several yearly reports. One solution that could be considered is depreciating the emissions of the asset (building) over its life span by reporting annualised emissions values, as this is the current standard today. However, this approach falls short of capturing the reduction of the carbon budget during the time the building materials are produced. The result would be an increased likelihood of overshooting the budget.

Thus, because of these different purposes, reporting according to the GHG Protocol does not specifically support setting budget-based reduction targets for the building sector. This therefore becomes a challenge, as there is a risk of not incentivising decision makers to demand low carbon solutions if they fall within scope 3.

Basing such targets on building-specific emissions data could instead be achieved through the LCA of its materials and construction processes. However, using LCAs as a basis for a top-down target setting creates a different set of challenges. Similar to emissions reporting under the GHG Protocol, LCAs serve a purpose that differs from the intention to set reduction targets. An LCA enables comparison between products such as buildings based on the function or purpose they are fulfilling. LCAs are conducted according to a standard [28–30] and the same assumptions and rules are applied to both systems to enable comparison. An example of an assumption could be applying a reference study period of 50 years for all buildings. Although this may seem like a simplification, it is necessary for practical reasons, to make the task of conducting the LCA feasible within data limitations and nonetheless consistent across the different items of comparison. Using simplifications and assumptions for these items is useful for comparability purposes but reduces the ability to measure emissions reductions over time. When conducting building LCAs, the upfront emissions (A1-A5) are based on what actually happens today, whereas the rest of the buildings' life cycle is based on standard assumptions regarding life span, replacements and waste handling. These assumptions are reasonable to use for comparability, but do not necessarily reflect a realistic scenario and cannot for that reason be compared to a global carbon budget.

Unlike standardised products for high-volume consumption, most buildings are designed individually and have specific purposes and features. Thus, setting targets for embodied emissions in line with the global carbon budget requires specific methods that can capture the wide variety of buildings and the characteristics of the industry and value chain. **Because of this unique feature, more specificity for embodied carbon is needed to define the relevant carbon budget for embodied carbon, and the part a newly constructed building plays in it.**

The budget therefore needs to reflect the specificities of emissions related to the life cycle stages included, and to clarify whether new buildings, renovations or both are addressed in the budget and therefore the target. The work in this project concentrated exclusively on the new construction of buildings. This is reflected in the concept for target setting outlined in Chapter 4, which also focused on upfront embodied carbon from material production to construction (stages covered in modules A1-A5 of a building life cycle).

4. What initiatives exist for setting budget-based targets?

Various initiatives have had the objective of enabling organisations and sectors to understand the urgency and implications of climate change. The relevance and applicability of their approaches for embodied emissions in buildings will be analysed in this chapter. The Science-based Targets initiative (SBTi) provides guidance to entities from all sectors on setting GHG reduction targets in line with scientifically determined needs. The Carbon Risk Real Estate Monitor (CRREM) translates the necessary reductions in operational emissions into financial risks for buildings and real estate management. Additionally, the method used by the UK Green Building Council (UKGBC), which quantifies carbon budgets and reduction targets, will be presented, as it undertakes a different approach to determining future targets.

4.1 Corporate target approach by the SBTi

Science-based targets are a widely known approach to setting top-down targets based on external climate factors. The Science-Based Target Initiative (SBTi) develops standards, criteria and guidelines to achieve widespread and harmonised use of such targets. The initiative was created in 2015 through a collaboration between not-for-profit organisations as a response to the Paris Agreement.

The SBTi approach is aimed at individual entities, mainly businesses, that seek to commit to reducing their GHG emissions in line with the calculated need for reduction. The target is defined by the organisation and is based on a scientifically established need for reduction. Alignment is then checked by the SBTi and the target is approved. The vision behind the SBTi's approach is to enable all organisations to reduce GHG emissions. The organisational reductions are focused on emissions in scope 1 and 2, as organisations are considered to have the most influence on these. In this philosophy, scope 3 emissions have less ambitious requirements and offer more leeway to organisations, even though it is acknowledged that such indirect emissions can often be the largest contributor [31].

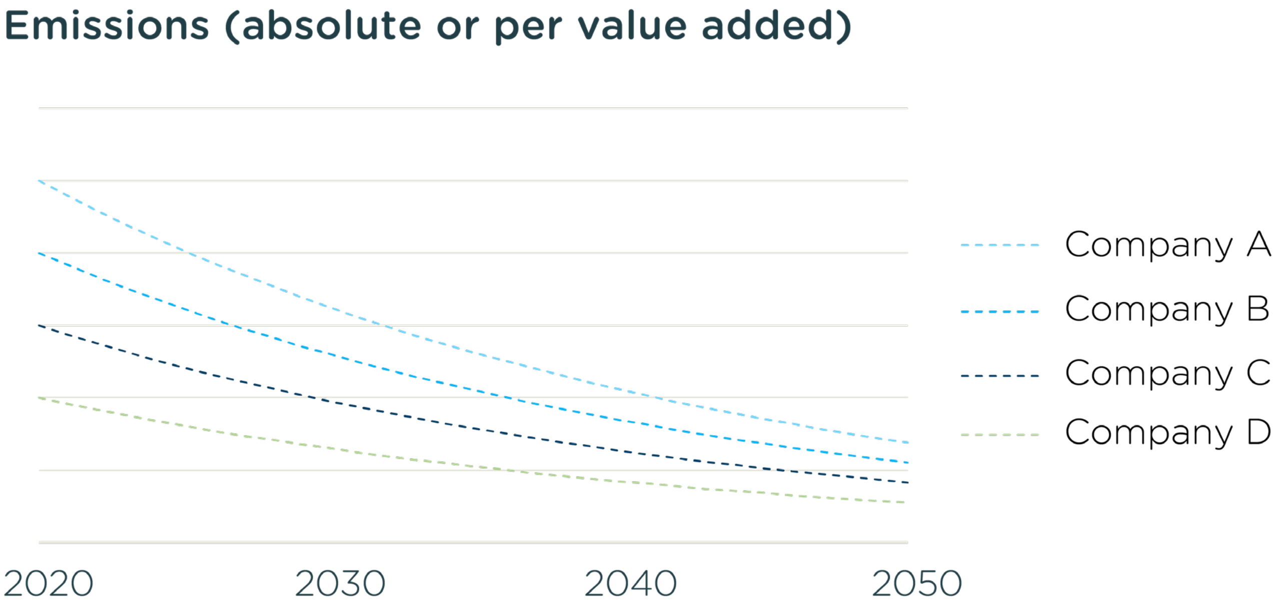
The need for reduction is determined according to three main elements, which constitute the science basis for setting the targets:

- A carbon budget defined by the IPCC (see Section 1.1)
- Scenarios on future emissions, developed by the IEA (see Section 1.2)
- An allocation approach to determining the reduction pathway of future emissions towards a target. This is connected to the allocation principles discussed in Section 1.3 but differs in the considerations it takes into account.

While the carbon budget and the emissions scenario are parameters set externally, the allocation approach determines the reduction contribution with targets and pathways for a specific organisation depending on the global warming target that is selected. Two main strands of allocation approaches are provided as options by the SBTi.

The first strand of allocation options is a contraction: a target for reducing GHG emissions that is set based on the specific emissions of the organisation and without resulting in an associated carbon emissions intensity for the sector. The contraction can be defined in terms of absolute emissions or emissions intensity per unit of value added. A graphical illustration of the emissions pathways of several organisations is presented in Figure 4.

Figure 4: Illustration of emissions reduction targets for four companies using contraction approaches.



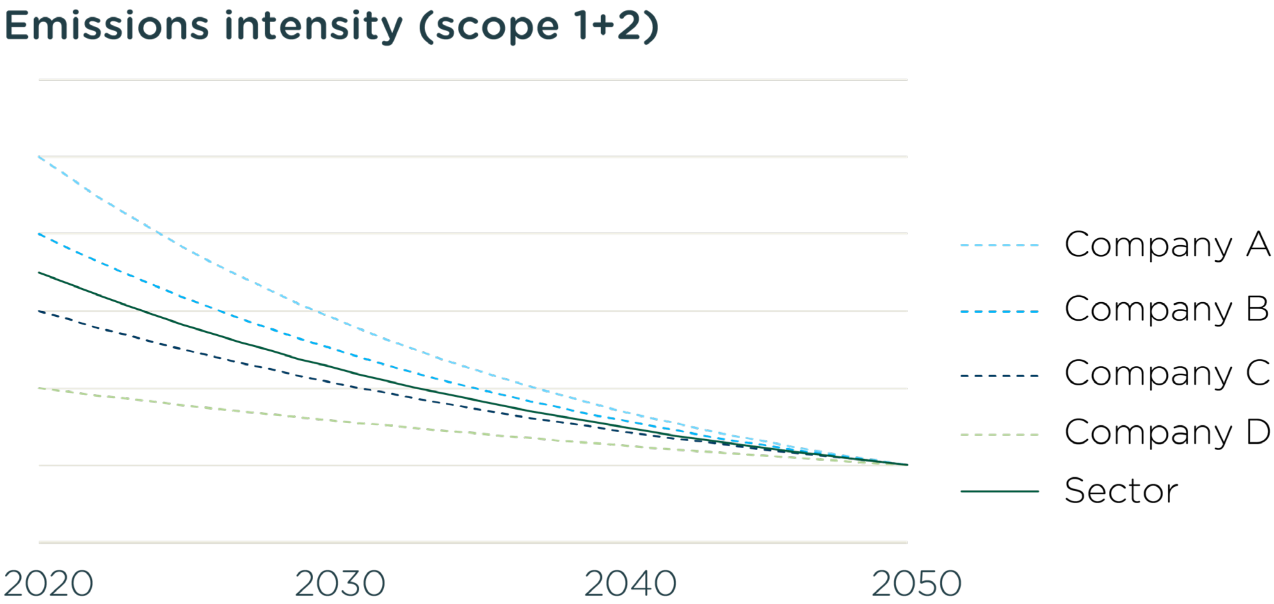
The reduction of absolute emissions is called the absolute contraction approach (ACA) and represents the least data-intensive allocation approach. Only company-specific parameters such as corporate GHG accounting are needed for a recent base year together with a target year, for which the target can be calculated according to the relevant budget and scenario from the previous steps. This results in a reduction pathway for the organisation with the same year-on-year reduction. A target under this approach has to be a minimum of 4.2% annual reductions for scopes 1 and 2 to be aligned with the 1.5°C goal.

The reduction of emissions per unit of value added is determined according to the approach called Greenhouse Gas Emissions per Value Added (GEVA). Here, the emissions intensity of the economic activities is the metric for expressing the target. This approach requires information on the value added in the base year and projections about its development up to the target year. As the relative level of ambition also depends on the economic development of a sector that is not reflected in the target, this method is considered less robust than others and considered applicable primarily to scope 3 emissions.

The second strand of allocation options is convergence. In this method, the emissions of an organisation are placed in the context of the emissions intensity of the respective sector, the so-called Sectoral Decarbonisation Approach (SDA). As a result, the emissions intensity is supposed to converge at one global level that is aligned with the long-term limiting of global warming. This is illustrated in Figure 5 below and is applicable to scope 1 and 2 emissions. To calculate this convergence target and the contributions of specific organisations, more input data is needed, including for the sector as a whole – at present and in the future. This approach is suited to homogenous sectors with common output metrics and relatively transparent output quantities. First, this is shaped by the need for a sectoral scenario, as in the IEA Energy Technology Perspectives. Second, all organisations in the sector should be able to agree on a common physical metric per which the emission intensity is measured. If these features are in place, the SDA provides valuable benchmarks for a sector to establish science-based emissions intensity, and to provide guidance for all companies in that sector in respect to their scope 1 and 2 emissions.

Setting targets following the SBTi methods includes specific normative assumptions. Firstly, even though the term allocation approach used by the SBTi is similar to the concept of allocation principles described in Section 1.3, the SBTi target methods do not consider ethical parameters in the allocation of the carbon budget across the users of carbon. The allocation principle used in the ACA is based on the current levels of emissions, benefitting high-emitting organisations. This principle is referred to as grandfathering in Section 1.3. The SDA considers the current level of emissions and reflects this in the relative contribution, but also does not differentiate between the state of economies. As such, it fails to recognise the common but differentiated responsibilities between nations depending on their historic emissions and current development status [14,23].

Figure 5: Illustration of emissions reduction targets for four companies using a convergence approach such as SDA.



Secondly, it has to be kept in mind that the resulting target of all approaches is the "fair share" contribution that assumes all companies would do the same, specifically for scope 1 and 2 emissions. In this case, the sum of all targets being reached would result in a global emissions level that respects the global warming target. Keeping within the global budget is only possible if all companies commit and reduce, otherwise, reductions by certain companies may be countered by increased emissions from others. If the range of companies that commits to targets remains limited, an overshoot of the emission budget would be the likely result.

As a result of the discussion in Chapter 2, an approach and target metric would have to be targeted to an actor in order to be relevant. Given the influential role of investors in developing large-scale construction projects and the increasing requirements to report on the non-financial impacts of their investments and assets, setting targets for institutional investors could be a relevant path for embodied carbon targets. Considering the high quantity of scope 3 emissions from purchased materials in construction, a focus on scope 1 and 2 emissions in the target neglects the importance of development decisions on overall emissions, which fall within scope 3 of the building project. The argument of the companies having less control over the scope 3 emissions does not apply to buildings, as there are multiple design and construction techniques that offer strategies for mitigating these emissions, including a priority for renovation or notions of sufficiency in spatial planning. Moreover, given the importance of scope 3 emissions for construction, it would clearly be inconsistent with national and global mitigation goals to fail to consider these [23].

Under the SBTi, target-setting methods have been developed for specific industries and types of actors, but they focus on emissions related to operational energy consumption. An SDA methodology exists for financial institutions, and this also includes real estate assets and investments [32], including scope 3 emissions from the investor's perspective. However, the criteria only require calculating emissions in scope 1 and 2 of the real estate assets and exclude embodied emissions, as they make up scope 3 emissions from the building's perspective. This existing method therefore has a different purpose and would need further refinement to create guidance on embodied emissions, too.

As highlighted before, the private sector will have difficulty staying within an emissions budget, even if targets are set at the level of developers. This is because achieving the necessary reductions also depends on other developers, some of which may not develop construction projects as their primary focus, but also construct new buildings for their own operations or use. Targets at the municipality planning level are therefore highly relevant, too. The Science-Based Target Network, a group of organisations closely linked to the SBTi, has developed a guide for GHG emissions reduction targets at city level [33]. However, the methods proposed in this guide also limit their scope to direct emissions that are included in an inventory of emissions sources located within the city's boundaries, with the result that this approach cannot be directly applied to embodied carbon either.

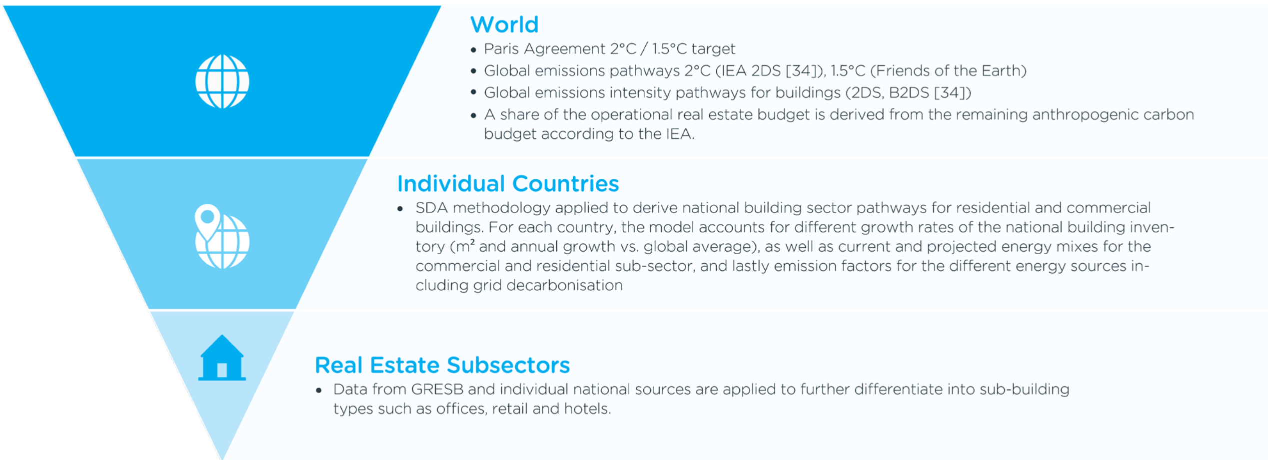
In conclusion, this is an approach that considers scope 3 emissions as secondary, falls short of the relevance of building development decisions on embodied emissions and the potential for savings from renovation, design and material choices. This underlines that a specific approach for target setting is needed for this type of emission.

4.2 Carbon risk approach for operational emissions for the real estate sector by CRREM

The Carbon Risk Real Estate Monitor (CRREM) has proven that a budget-based approach can be applied to a building perspective in relation to indirect emissions in scope 2. CRREM offers a tool for investors and property owners to estimate the risk and uncertainty associated with commercial real estate decarbonisation, with a focus on operational emissions related to a building's energy source and energy efficiency. To do so, CRREM has developed decarbonisation pathways (both in kWh and CO2e) that translate the ambitions of the Paris Agreement into pathways specific to countries and building types. The results enable investors with real estate portfolios to benchmark their real estate assets and use the pathways as proxies for "transition risk" that increase the chances of market obsolescence of an individual building, becoming a stranded asset. By illustrating the risk, the property owners are encouraged to renovate buildings to reduce operational energy use and/or switch their energy sources to renewables to stay below the decarbonisation targets.

"Paris-proof" pathways are established by downscaling from global mitigation pathways to property level, as illustrated in Figure 6.

Figure 6: CRREM pathways calculated by top-down downscaling



To scale down from global to building sector level, CRREM utilises the global emissions intensity pathways for buildings set by the IEA [34]. By applying the SDA at country level, the overall carbon intensity of each country's building sector converges gradually towards the global averages figure in the defined target year of 2050. All trajectories start at the actual emissions intensity of each country's building stock and converge around the same decarbonisation target. Pathways are calculated by taking country growth rates into account, which in practice means stricter target intensities for countries with larger floor area growth relative to the global floor area growth. Pathways for residential and commercial buildings are respectively based on the two baselines and the assumption of a constant ratio of carbon intensity for residential and commercial. Currently, CRREM covers the majority of global real estate markets – residential as well as commercial real estate. CRREM is aligned with other major initiatives such as SBTi, PCAF, and GRESB.

The initiative covers operational energy in buildings, but does not account for embodied carbon emitted in order to achieve the reduction in operational energy in the existing buildings. Through the SDA methodology, carbon intensity pathways converge around the global target (see Figure 5), which is suitable for tracking re-occurring emissions, such as operational carbon. However, it is not ideal for capturing peak emissions from new construction and renovations. Furthermore, the overall global target is based on the pathway for global buildings outlined by IEA, which only covers operational carbon and not embodied impacts in buildings. As previously described, embodied carbon is cross-sectoral and the IEA has no single pathway which describes the decarbonisation pathway needed for embodied carbon. Therefore, applying the approach developed by CRREM for embodied carbon is not currently possible.

4.3 National carbon budget for the built environment by the UK Green Building Council

The UKGBC released a pathway to net zero for whole-life carbon for the UK built environment in November 2021. The vision is to present "A Net Zero Scenario" with a calculated emissions budget and trajectory to 2050 for the UK built environment [21]. **The aim is to identify the role of the UK's built environment in complying with the Paris Agreement. The initiative covers both embodied and operational carbon for buildings and infrastructure.**

The UKGBC refers to the Paris Agreement as the basis for the budget and follows the recommendations of the Climate Change Committee (CCC). The overall UK target recommended by the CCC is to reduce emissions by 78% by 2037 compared to 1990 levels. The CCC recommendations build on the NDC of a 68% reduction by 2030 compared to 1990 levels. In April 2021, the UK adopted the recommendation and made this legally binding.

Furthermore, the CCC sets out pathways for carbon reductions across sectors, and while some sectors need to decarbonise completely, Manufacturing and Construction are not projected to reach full decarbonisation but are left with some residual emissions, which will then need to be offset by GHG removals. Moreover, it should be noted that the CCC targets refer to territorial emissions, and imported materials are therefore not included. **In its report, the UKGBC acknowledges the large proportion of non-territorial emissions in the UK's Manufacturing and Construction sector (c. 30%) and therefore reports on a consumption basis.**

Pathways are therefore calculated by identifying the lowest possible residual emissions by mapping historic emissions, identifying future demand and analysing mitigation potentials. To estimate the contribution from each activity, a comprehensive analysis including a multi-regional input-output (MRIO) model combined with an emissions model was used. The work involved mapping existing building stock, operational energy demand and the supply system, anticipated construction and renovation activities, while also identifying potentials from mitigation strategies within each area.

In the UKGBC report, GHG emissions reduction targets are set through a joint effort between all emitting activities: construction of new buildings, operational energy use, as well as renovation and maintenance of existing building stock. The result of the project reveals a trajectory for total GHG emissions for the built environment from 2018 to 2050. The total GHG emissions are shown as contributions from operational and embodied emissions from buildings (domestic and non-domestic) and infrastructure.

The trajectory is highly relevant as a roadmap for policymakers at national level, as it defines the necessary and possible contributions of the building sector as a whole, including specific targets for embodied emissions. Extensive efforts are needed to calculate and align the current activity levels of industrial sectors with elements of the embodied carbon and the climate change scenarios.

With a high level of aggregation, the trajectories do not, however, provide operational information for building developers and designers, because the trajectories do not give specific information at building level for embodied carbon. Specific targets on operational carbon at building level are, however, are provided. Rather, policymakers have to take the intermediate role of defining the measures for achieving the necessary reductions (e.g. targets for reduction through renovations, material efficiency, GHG targets for new buildings, etc.) for developers or investors, designers, and material manufacturers.

In summary, Table 5 presents the key characteristics of the target-setting approaches by the three initiatives.

Table 5: Summary comparison of existing target-setting initiatives

	SBTi	CRREM	UK GBC
Geography	Global	44 countries, with a focus on industrialised countries in Europe and North America	UK
Target group	Corporate and other organisations in all industries and sectors	Investors and property owners	All built environment stakeholders
Scope	All emissions, with a focus on scope 1 and 2 emissions according to the GHG Protocol	Building sector (operational energy)	UK built environment (infrastructure and operational and embodied impacts from buildings)
Trajectory	Depends on the selected method. Trajectories are generally based on Energy Technology Perspectives by the IEA	Global emissions intensity pathways for buildings set by the IEA	Climate Change Committee (CCC) trajectories for Manufacturing and Construction
Contribution to embodied carbon targets	Broadly recognised methodologies for corporate target setting with different emissions allocation principles Sectoral coverage, including material-producing industries and the financial sector as important building developers	Establishment of a carbon budget and Paris-aligned targets for indirect operational emissions addressed to building owners and developers Downscaling global emissions budgets for national targets	Creation of a national budget for the whole-life carbon emissions of buildings, including embodied emissions Input-output quantification of sectoral emissions contribution
Limitations in relation to embodied carbon targets	Priority is given to scope 1 and 2 emissions, where the influence of the target-setting actor is greater Embodied carbon not considered for financial institutions	Focus on operational emissions, as these create future carbon-related risks	Policy trajectories require further formulation for actors in the building value chain

The main requirement for such targets on embodied carbon would be a specific budget and trajectory that provide operational metrics to actors of building projects along the entire value chain. This specification can be undertaken at global or national level, depending on the targeted group of actors. The necessary steps to undertake will be outlined in the next chapter.

5. How can targets for embodied carbon in buildings be developed?

The previous chapters of this report have highlighted the ways in which embodied carbon in the building sector differs from other types of emissions, including operational emissions, that are often described in sectoral overviews of the building sector. The three initiatives presented in Chapter 3 pursue different purposes and approaches that each point to important features of the required elements for a budget-based target for embodied carbon in buildings.

This section presents a possible way forward for setting targets and discusses how the necessary elements can be developed. First, the lack of a science-based budget and trajectory for embodied carbon needs to be overcome. Second, these elements have to be applied at the relevant level in order to make them relevant and useful for policymakers, developers and building designers in specific geographical contexts. For this, exemplary calculations in the form of a proof of concept are undertaken for Denmark and Finland.

5.1 Develop a budget and emission reduction trajectory for embodied emissions based on the carbon budget

While the existing target-setting mechanism such as CRREM or the SBTi manual for financial institutions apply to operational emissions, specific methods and calculation tools need to be developed for the purpose of embodied emissions in buildings.

As discussed in this report, embodied emissions are a result of complex value chains, both in terms of products and in terms of decisions. Essentially, most buildings are unique in their size, material composition, intended use and ownership structure. Around the world, these features differ notably, as do the planning requirements and climatic conditions in which the building will be used. However, all building projects deplete the global carbon budget and therefore need to be aligned with the global carbon budget.

A Paris-aligned carbon budget and a decarbonisation trajectory for buildings that are aligned with this budget need to be established and must include specifications for the amount of embodied carbon emissions. This is a key challenge that needs to be overcome to enable setting budget-based targets for the reduction of embodied emissions from building projects.

A carbon budget serves as the basis for decarbonisation trajectories and also illustrates the climate impact of each building project or year of activity as the budget depletes. The First Report of this project has established a baseline of current levels of embodied carbon in building projects. Ensuring that global warming stays within the limits defined by political agreements and emphasised by scientific evidence necessitates a total amount of emissions that can be emitted this way. This has been highlighted in Chapter 1, by defining the carbon budget as a fundamental element of a reduction target that creates an adequate contribution to climate change mitigation.

A global trajectory for the decarbonisation of buildings that reflects the carbon budget serves as a reference point for the speed and extent of decarbonisation. As for other industrial sectors, the possible levels of GHG reduction and the necessary steps to take to limit global warming in line with the Paris Agreement need to be determined. There are existing reports on trajectories for the building sector or parts thereof. For example, the International Resource Panel has developed a climate trajectory for residential buildings [35]. However, agreement on a global emissions trajectory for the building sector and specifications for a broader range of building types is needed, to formulate a standard for the target setting. Ideally, such a scenario is aligned with the other trajectories and scenarios used in the methodologies for corporate bodies, municipalities, or countries. An established trajectory would then also enable effective communication of benchmarks as proposed in the third report of this series and the assessment of building projects over time against the remaining carbon budget.

This task will not be easy, as a highly heterogeneous sector would have to agree to the standards. In particular, the question can be raised of what effect the different demands and needs for buildings around the world have on embodied emissions, and how these differences may be reflected in the methodology. Nonetheless, considering the increasing urgency of reducing global emissions, this should be considered and is considered worthwhile by this study.

5.2 A concept for downscaling carbon budgets to national embodied emissions budgets

In the following section, a concept of how country-specific, top-down targets can be determined for embodied carbon in new buildings is presented. The concept of downscaling through sharing principles (allocation principles) is widely used in literature, and often follows the structure of scaling to a per capita budget, which is then translated to a national budget and then further down to a specific sector or activity [11]. At building level, there are also multiple examples of top-down targets for buildings [36–40], however, these still lack consensus around the global budget, sharing principles, the scope of life cycle stages included, etc. [12].

In this section, the concept of downscaling is presented step-by-step and the concept is then applied to Denmark and Finland as a proof of concept. Figure 7 illustrates the concept of downscaling from the global GHG budget to building level. The methodology can, in theory, be applied to any country with available data. The work presented in this study is based on a larger study on defining science-based targets for buildings. Thus, this section provides an extract of the approach used for downscaling, as well as the example applied to Denmark and Finland. Specific details can be retrieved in the planned publication of the larger study [41] or by contacting the authors of the study.

Figure 7: Downscaling from global budget to embodied carbon in buildings - a concept to set targets for embodied impacts in new buildings per m2.

The intended uses of the top-down targets are to enable developers and building designers to set ambitious climate targets for their new buildings, as well as to guide policymakers influencing legislation on GHG limit values and other measures to limit GHG emissions from construction.

The targets calculated in the proof of concept are consumption-based, thus include the imported materials consumed by the building. This is in line with how an LCA of a building is calculated. However, as previously mentioned, it is not in line with national budgets or NDCs declaring on a territorial basis.

1. Global budget and budget distribution

The global carbon budget depends on the level of temperature increase tolerated. The agreed limits in the Paris Agreement suggest 2°C, or preferably 1.5°C. The total budget (given in GHG emissions) is then distributed over the years by applying mitigation pathways calculated, for instance, in the IPCC report and which have been proven to keep warming below 2°C or 1.5°C by applying IAMs and climate models. The mitigation pathway used in this concept is based on the average of 13 Paris-aligned decarbonisation scenarios and expressed as net emissions [3]. The work of the referenced study is aligned with the IPCC Special Report [18] and the referenced article is produced by the same lead author as the chapter on mitigation pathways in the IPCC report. The pathways rely on net negative emissions from 2070 and comprise an average net total budget of 791Gt CO2eq over the 2020–2100 timeframe.

2. Defining a country share

The country share determines the budget for consumption-based emissions that the country can emit and should stay within. Determining the budget for a country can be based on EPC, allowing countries a share based on the population share relative to the global population. Other possible allocation principles take historical development and ability to reduce into account. This is applied, for example, by the EU Calculator [42], where it is possible to choose "capability". In the EU Calculator, applying capability means that, because the EU has an above-average GDP, the share of the budget is halved compared to an EPC distribution [43].

3. Defining a share for embodied impacts in buildings

The share for embodied impacts in buildings can also be determined in different ways, depending on the allocation principle applied. A grandfathering (GF) principle would base the share on historical emissions shares. In practice, this requires representative data from the respective country on the contribution of embodied emissions from materials relative to total emissions. Another example would be determining the share based on the direct and indirect contribution the buildings have on peoples' welfare, i.e. taking a utilitarian perspective. This requires estimating how construction affects peoples' welfare directly and indirectly. The method applied in this concept utilises a MRIO model of linking the global economy that considers flows between industries across supply chains. The method estimates direct and indirect contributions of the utility of the construction sector and was originally developed at DTU as part of a master's thesis [44].

4. Apply projections for future building activity

The budget share determined in steps "01-04" accounts for all construction activity. This means that if a country builds "x" new buildings in year "y", then the budget for embodied impacts in buildings in year "y" is divided among "x" buildings. Furthermore, the budget for embodied impacts in buildings needs to account for maintenance and renovation of the existing building stock. The projected future construction activity therefore needs to be mapped, to be able to create a budget for new buildings. For the proof of concept exemplary application for Denmark and Finland, construction activity is based on past construction trends from 2018 to 2020. However, it is acknowledged that realistic market projections could be beneficial to the accuracy of the targets.

5.3 Exemplary application of the concept for new construction in Denmark and Finland

The following graphics illustrate the process and results of applying this concept to Denmark and Finland. The countries selected are based on the availability of the data required to perform the downscaling. The procedure for downscaling presented in 4.2 requires country-specific data on population and construction activities, regarding both the amount of material that goes into new construction as well as the amount of new square metres. This data, especially the contribution of new construction, rather than the construction sector as a whole, has proved challenging to collect.

Budget-based targets for upfront embodied carbon

Downscaling global climate targets to embodied carbon of new buildings

01 Global GHG budget is identified and distributed over the years

The global budget was defined as the average of mitigation scenarios consistent with the 1.5OC target [3]. The work of the referenced article is in line with the work of the IPCC Special Report [18].

02 Defining a **country share**

To define a country budget, equal per capita (EPC) was applied, accounting for future population projections by the UN [48]

03 Defining a share for **embodied impacts** in buildings

The allocation to embodied impacts in buildings were based on two principles:

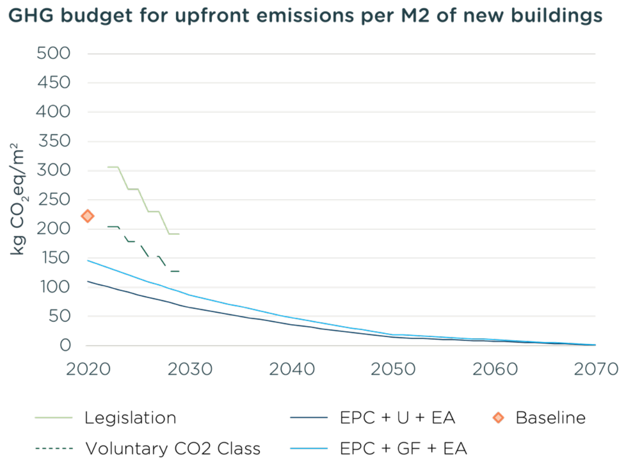
1. A grandfathering principle (GF)
2. A utilitarian (U) principle considering the utility the construction industry in Finland provides to people.

04 Apply projections for **future activities of the building stock**

To estimate the activity level of new buildings, maintenance and renovation, the study assumed status quo in construction activity, applying past construction trends from 2018 to 2020 [47]. For the distribution between activities, economic activity (EA) was used.

Budget-based targets for upfront embodied carbon emissions in Denmark

Figure 1: Budget for upfront embodied GHG emissions in Denmark.



To enable comparison between the national strategy and the calculated values of this study, the average contribution of upfront emissions according to a Danish study of 60 cases was applied [45].

The following numbers represent the targets for upfront embodied GHG emissions in Denmark in line with the established carbon budget.

[kgCO2eq/m2]	2020	2030	2040	2050
GHG Budget (EPC+GF+EA)	146	88	48	19
GHG Budget (EPC+U+EA)	110	66	36	15

In 2021, a national strategy was proposed for new buildings in Denmark. The strategy consists of limit values for legislation and "a voluntary sustainability class". Under the assumption presented, this study indicates that in 2023 the limit values of the legislation will exceed the carbon budget by between double and triple the amount, depending on the allocation principles applied.

Budget-based targets for upfront embodied carbon

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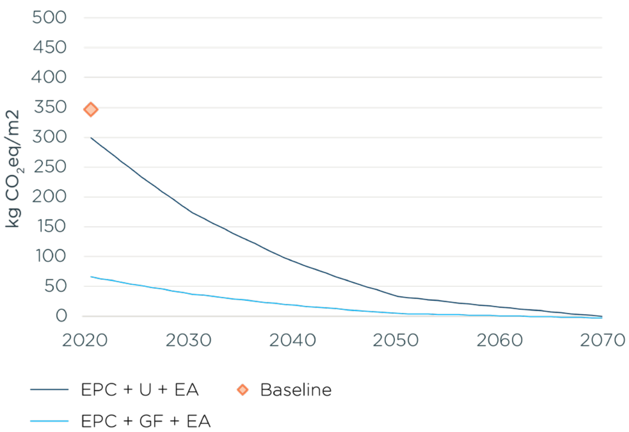
Budget-based targets for upfront embodied carbon emissions in Finland

Figure 1: Budget for upfront embodied GHG emissions in Finland.

GHG budget for upfront emissions per M2 of new buildings



The following numbers represent the targets for upfront embodied GHG emissions in Finland in line with the established carbon budget for the two sharing principles presented.

[kgCO2eq/m2]	2020	2030	2040	2050
GHG Budget (EPC+GF+EA)	288	168	89	35
GHG Budget (EPC+U+EA)	67	39	21	8

The proof of concept for the Danish and Finnish building sector outlines pathways for targets for up-front embodied emissions for the construction of new buildings. The calculated targets are the results of a downscaling procedure that first applies EPC to get a national budget and then assigns a share of the national budget to the construction sector by applying either the relative share of GHG emissions to total emissions (GF) or the results of an MRIO model, estimating the construction sector's direct and indirect contribution to the global economy (U). Lastly, the downscaling procedure applies past construction trends to estimate the budget for the construction of one new m2.

Differences in the budgets for the two countries can be observed and explained. As a result of the proposed downscaling procedure, the GHG budget depends on the population size as well as construction activity within the country. For Finland, the result is a lower budget per m2 than the Danish budget when applying the utilitarian principle. This is because the input-output (IO) model reveals that overall spending on the Danish construction sector relative to other industry sectors was higher than that in Finland. By using an IO model, a country's total GHG budget is distributed to the construction sector according to the money spent in that sector relative to other sectors, which is thus a proxy for prioritising what contributes to welfare within each country. Furthermore, the Finnish population is slightly smaller than the Danish, whereas the amount of new square metres built every year is almost the same for the two countries. When applying the grandfathering principle, Finland receives the largest budget per m2; this is because the GHG contribution from the Finnish construction sector relative to Finland's total consumption-based emissions is higher than that of Denmark.

Comparing the targets with the baselines calculated for Denmark and Finland in the Baseline Report shows a performance gap. The targets for 2020 are already significantly lower than the baseline. This means that buildings today create embodied emissions that exceed the carbon budget resulting from the Paris Agreement. As this depletes the budget even more and faster, the target becomes more relevant and urgent.

Several limitations apply to the concept as presented here. These concern the choice of allocation principles, the lack of granularity regarding building types, as well as data availability.

- First, the proof of concept applied to Denmark and Finland relies on the **choices of allocation principles** applied. As the results show, different allocation principles will result in different GHG budgets. As highlighted earlier in this report, the application of allocation principles has so far been a matter of subjective opinion. Since there is no broad agreement on the principles of a fair allocation of emissions, the choice of principles requires justification and the results must be interpreted with the principle in mind. The choice for EPC, for instance, builds on an equal right for all humans. This avoids grandfathering in the global allocation step, but also falls short of accounting for historic inequalities. The differences in historic emissions and development statuses of the building sector around the world call for further research to introduce global equity into carbon budgets, particularly for a sector as essential to basic needs as housing. Given this limitation of the downscaling method, it is also important to acknowledge that there are multiple ways of applying allocation principles, and that this report exemplifies two possible methods for a sectoral allocation but acknowledges that the targets cannot be interpreted as objective final results. Thus, the method also comes with a risk of overshoot if every target-setting actor (e.g. national government, municipality, investor) chooses the allocation principle most beneficial for their case.
- Secondly, the proposed method does not allow for **granular budgets for specific building types**. The sectoral data comprises all building construction activity, without specifying the type of building (e.g. residential, non-residential). As these buildings have different requirements and use patterns, which again vary substantially between different types of non-residential buildings – more specific budget calculations and related targets could have benefits. Such advances should be considered and could be based on combinations of building stock models combined with material flow data for different building types. Bringing together the sectoral pathways for key building materials may be another alternative approach to calculating more specific budgets. However, these approaches need to consider that embodied carbon comprises a wider range of emissions than those of materials.

- Lastly, the method **relies on data** that has proved difficult to obtain in this project – especially data describing the proportion of activities that contribute to embodied impacts, i.e. renovation, maintenance, and new buildings were difficult to obtain. Therefore, the application of this approach needs to be preceded by ensuring that this data is available and accessible.

The results of this report need to be read with these limitations in mind. Another major limitation is future uncertainty. It is the purpose of this report to set targets per m2 for new buildings, however, as the overall goal is not to overshoot the total GHG budget, the targets per m2 depend on the number of m2 to be built. Likewise, will renovation and maintenance activities of the existing building stock also consume embodied carbon, and it could be argued that if renovation activity increases, the share for new buildings should be lower. For this proof of concept, status quo for construction activities, including the number of newly built square metres has been assumed. However, the method would greatly benefit from applying projections for future activities in the building stock.

5.4 Target audiences and metrics

Approaches to top-down target setting for buildings also require consideration of the target audience. In existing initiatives, different examples of the target audiences addressed are investors and other actors that commission and oversee construction projects for the SBTi, portfolio owners for CRREM, as well as policy recommendations for central and local governments by the UKGBC. In this proof of concept, an example has been developed of a budget-based target set at building level for a specific country.

From a real estate developer or investor perspective, budget-based targets inform the climate impacts of investment decisions in new assets. In a context of increasing awareness among stakeholders as well as requirements for non-financial disclosure, the closest possible alignment with the carbon budget becomes a highly relevant consideration. With assets often dispersed over different countries, a global budget and related pathways would be highly beneficial to defining the budget share of an investor, similar to the approach used by the SBTi.

From a policymaker's perspective, budget-based targets can be used to guide ambitions for a combined strategy for implementing GHG limit values in regulations, in combination with other measures to limit GHG emissions from embodied impacts in buildings. For this, a local budget is highly appropriate as it informs the overall reduction need from embodied carbon. The assessment of the proposed target approach for Denmark in comparison with existing Danish legislation makes it clear that either the impacts per m2 need to be substantially reduced or the total new construction activity will have to decline, which requires planning efforts at public levels. In the context of deciding on scenarios for the future building stock, it is therefore relevant to discuss mitigation strategies for the built environment. While there is a need to reduce impact per m2, it might also be necessary to build fewer new square metres than has been done in the past.

While targets meant to guide developers and building designers should reflect society as it is, targets for policymakers can reflect other measures which can be taken in addition to reducing the impact of embodied carbon per m2. These measures can be a vital element of efforts to reduce the overall climate impacts from buildings – existing as well as new construction. Here there is a need for a **discussion on the sufficiency and utilisation of the existing building stock**. This would involve discussions on utilising the existing building stock better, to avoid new construction. Examples could be to transform a vacant office building into residential use, to offer less living space per person, or to introduce flexible use of building space (for example, utilising school facilities for evening classes). Embedding these kinds of outcomes as results of policies should then be reflected in step 5 of the proposed concept, where projections for future activity in the building stock are applied. The target values for new construction would thus reflect the combined effort of optimising existing buildings as well as reduction targets for new buildings.

Lastly, it is important to keep in mind that, since the targets set in this report relate to a country perspective, they are not directly comparable to the accounting principle applied in the NDCs. This is because NDCs cover territorial emissions only, while the proposed concept for target setting in this project takes a consumption-based approach, to account for all emissions, including those from imported materials.

Combining the two levels of asset portfolios and the policy mix, the budgets and corresponding target pathways can be used to guide the level of ambition for the design of new buildings and have practical relevance for building designers. The budget pathway represents benchmarks for embodied carbon that are Paris-aligned and define the scientifically necessary need for decarbonisation. To enable operable and comparable targets for buildings across use types, the targets are given per m2. However, targets could also be set according to the purpose that it is fulfilling – kgCO2eq per full-time employee, per resident, etc., to incentivise designing efficient square metres. This has to be considered in a benchmarking system. A concept for such a system is developed and presented in report #4 “Bridging the performance gap”.

6. Conclusions and recommendations

6.1 Conclusions

Existing example initiatives by the SBTi, CRREM and the UKGBC have all developed approaches to climate targets in buildings. However, with the exception of the UKGBC, these have all focused on operational emissions. This is primarily the case because these emissions were considered more relevant in the past, can be measured more directly and, for those and other reasons, decarbonisation pathways have already been developed.

Furthermore, developing targets for embodied emission that are in line with the reduction needs as expressed in the global carbon budget is a complex exercise. This is due to the nature of embodied carbon as indirect emissions, the multitude of sources for the relevant actors, the shared responsibility between these actors, and difficulties in calculating embodied emissions accurately with common GHG accounting standards because of the different purposes of these standards.

However, with additional efforts to develop the elements necessary for budget-based targets, in particular a Paris-aligned decarbonisation trajectory, it is possible to set targets that reflect the available carbon budget. This paper demonstrates that a budget can be determined by applying allocation principles and current market trends. This, however, requires a line of normative assumptions on how the budget could be split and allocated to an activity.

By applying the proposed concept to Denmark and Finland, this paper finds that the budget-based target for embodied emissions is substantially lower than the baseline established in report #2 of this project "Setting the baseline" and lies far below current legislative targets (where existing). This result calls for increased action across the EU and beyond to focus attention on embodied carbon, determine Paris-aligned targets for these emissions and accelerate the decarbonisation of this sector.

Targets will have different audiences: developers and investors can use the targets to guide the level of ambition for the design of one new m2. The targets can be used to set Paris-aligned targets for upfront embodied GHG emissions in new construction projects and offer relevant information for building designers such as engineers and architects. **Policymakers** at local, national, or supranational levels can use the calculated targets to guide ambitions for a combined strategy in implementing GHG limit values in regulations, in combination with other measures to limit GHG emissions from embodied impacts in buildings. In the strategies, policies and local plans, consideration of the total embodied carbon per individual building project will also be needed to stay within the carbon budget.

As a consequence, multiple metrics will be needed as benchmarks for building design and to ensure that mitigation efforts are driven both by reducing the embodied carbon per m2 and by building fewer but more efficient building spaces per capita. This also calls for discussion on the current demand for new buildings and a need for rethinking how we meet society's needs with an increased focus on sufficiency through better utilisation of existing buildings as well as on the material side, applying reuse or recycling possibilities.

6.2 Recommendations

Setting budget-based targets for buildings' embodied carbon needs to become more common and be reflected in a benchmarking system. This need to close the gap between current and required levels of embodied carbon also calls for additional policy measures.

Targets per square metre are a relevant metric to enable investors, building design professionals and spatial planners to make decisions at building level that ensure staying within the global budget. This would reduce barriers for such actors and ensure a higher level of overall consistency with the global budget. This exercise could be undertaken by an internationally accepted body like the SBTi as part of its work to develop corporate targets in line with the Paris Agreement and the latest climate science.

Work is needed on the creation of the necessary data that would allow for allocating the carbon budget to industry sectors and thus to embodied carbon. Efforts should be undertaken to produce more granular data on construction activities in relation to different building types. In addition, future projections of construction activity scenarios are strongly recommended, to improve the accuracy of carbon budget pathways, reducing the need to frequently revise such pathways and ideally limiting budget overshoot. Similar to recommendations in the Baseline Report and the Benchmark Report, a combined effort is needed from public institutions such as statistical offices, building sector associations and observatories and academia, along with a common language and shared methodological foundations.

Further policy instruments such as a reduction in new construction rate or support for building materials with negative emissions should be considered. For this, additional metrics to define targets per capita may prove relevant to ensure staying within budget at local and regional spatial planning levels.

Appendix 1- REFERENCES

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