I. Reduction Roadmap

Reduction Roadmap: Preconditions and Methodologies

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01 Introduction

1.1 Background

Since the Industrial Revolution, the level of carbon in the atmosphere has increased at an unprecedented rate and in May 2022 was measured at 421 ppm, the highest concentration in several thousand years (Stein, 2022). This increase is primarily due to human driven emissions of greenhouse gases and is one of the primary causes of global warming and the climate change effects we are experiencing today. If we continue emitting the same level of greenhouse gas, it will lead to catastrophic consequences for the climate, ecosystems and life on planet Earth as we know it. Therefore, we must reduce greenhouse gas emissions on a nationally and internationally (IPCC, 2021).

The limit of greenhouse gasses we can safely emit in the atmosphere is determined by Planetary Boundaries, which describe how large a human impact the planet can withstand, without risk of dangerous or catastrophic environmental changes (Petersen et al., 2022; Rockström et al., 2009). Assuming that planetary systems are in balance, the Planetary Boundaries define a safe operating space for action, which can be understood as Earth's sustainable carbon budget. Having already exceeded the Planetary Boundary for "Climate Change" in 2017, the Earth's natural environmental is under significant pressure.

The building industry is one of the major contributors to human-driven carbon emissions, responsible for 37% of total global emissions (UEA, 2017). The same goes for Denmark, where buildings, bridges and roads are responsible for 33% of Denmark's total national emissions (Klimapartnerskabet for bygge-og anlægssektoren, 2020a). Although the building industry has focused on creating more sustainable buildings in recent years, sustainability targets have been based on relative, not absolute sustainability (Brejnrod et al., 2017). When taking a relative approach to environmental construction, the climate impact of buildings is measured and compared to others similar buildings. As such, benchmarking new construction with existing construction it is possible to track progress in relation to sustainability goals. What relative benchmarking fails to do, is to document whether buildings are sustainable in terms of Earth's Planetary Boundaries, and whether new construction contributes significantly to meeting international climate goals such as the Paris Agreement (United Nations Climate Change, 2015).

To assess this, it is necessary to apply an absolute approach to construction, in which the climate impact from a building is compared to the share of Earth's carbon budget to which the building in question is allocated (Brejnrod et al., 2017). Although the allocated share may be difficult to determine, it is an approach the construction industry must learn to grapple with so that we can

be sure to limit global warming impacts from new buildings to a safe level.

1.2 Problem Definition

The problem defined above led to the Reduction Roadmap, which works to develop an operational tool for the construction industry, to translate the Planetary Boundary for "Climate Change" into a reduction target for new residential construction in Denmark, to ensure a transition from today's emissions levels, the target of absolute sustainable housing. Because we have already exceeded the Planetary Boundary for "Climate Change" we must transition to sustainable construction as quickly as possible, while accepting that the change needed will not happen overnight. To define a safe timeline for the necessary reductions, the carbon budgets defined in the Paris Agreement for a 1.5°C global warming scenario have been applied.

As such, the Reduction Roadmap has been developed to a define reduction curve, which illustrates annual reduction targets for carbon emissions within limits defined by the Paris Agreement. The goal of the Reduction Roadmap is to give the building industry a common tool and target, to make the necessary transition towards building within Planetary Boundaries.

Based on the existing statistical foundation, preeminent literature, and the latest climate science research – it is clear where the construction industry is today, where we need to go, and the speed at which we must reduce annual emissions. All building industry actors are encouraged to use the Reduction Roadmap to set sustainability targets in the development of new construction.

1.3 Scope

The scope of this project is the design of a roadmap for new housing construction in Denmark. As such, this report illustrates a reduction pathway towards target emissions levels, in relationship to new housings' share of Earth's global carbon budget. The reduction pathway outlined in this project has the objective of stopping the increase of greenhouse gas content in the atmosphere but does not define a way back to place where emission levels fall under the safe operating space for "Climate Change." Additionally, this project is does not define how large a share of Denmark's total greenhouse gas emissions should be allocated to different industries in the future. The roadmap presented in this study assumes that all industries will continue to be allocated the same share of National emissions as they do today. Finally, the roadmap applies an "equal per capita" allocation principle, in which each of individual of the world's population is allocated the same share of global carbon budget.

GLOSSARY

Several technical terms and abbreviations are used throughout the report. These are briefly defined below.

Building Industry

When we use the term Building Industry, we refer to professions who are employed with the building, rebuilding, repairing of budlings or construction works of any kind and size, such as buildings and houses, roads and railways, bridges and tunnels, ports and airports, bicycle paths and golf courses.

Carbon Equivalents (CO2eq)

There are many different types of GHGs and CO2eq is shorthand for describing different GHG in a common unit. CO2 is the common unit selected because it is the most common GHG emitted by human activities. A GHG's CO2eq can be determined by multiplying the amount of the GHG by the Global Warming Potential (GWP). In the body of this reportt, the term "carbon" and "CO2eq" are used interchangeably, both meaning carbon equivalents.

Green House Gases (GHG)

GHGs are any gas in the atmosphere which absorb and re-emit heat, thereby warming Earth's atmosphere. The predominant GHGs are water vapor, carbon dioxide, methane, nitrous oxide, and fluorinated gasses, all of which have different chemical properties but are typically expressed in carbon equivalents (CO2eq). When concentration of greenhouse gases in the atmosphere increased, the combined impact increases Earth's surface temperature, thereby changing climate on Earth.

IPCC AR6: Sixth assessment Report of the Intergovernmental Panel on Climate Change

Published in April 2021, the IPCC Report presents a comprehensive assessment about the state of technical, socio-economic and scientific knowledge on the impacts of anthropogenic climate change today, future risks, and options for slowing down climate change. The IPCC Report is internationally accepted authority on ground-breaking climate change science and is widely supported by both scientists and governments.

Life Cycle Assessment (LCA)

Life Cycle Assessment is defined as a systematic analysis of potential environmental impacts of products or services during their entire life cycle, from raw material extraction, transportation, manufacturing, to the construction process, building use, and end-of-life stages as well as, beyond the building system. LCA is used

to compare or benchmark the impacts of one product, service, or entire building composition against another in relative terms. When we talk about LCA, we refer to the Danish building industry, prescriptive method for calculating the carbon footprint of building activity which is Building LCA, EN 15978 standard.

The Paris Agreement

The Paris Agreement is a legally binding, international treaty for climate change mitigation, that was adopted in 2015 by 196 of the world's countries during COP 21 in Paris. The goal of the Paris Agreement is to limit global warming below 2°C, preferably 1.5°C scenarios (compared to preindustrial levels).

Planetary Boundaries (PBs)

Planetary boundaries is a conceptual framework which defines nine planetary systems, each having a respective boundary from within which safe operating space (SOS), humanity can continue to develop and thrive. Once Planetary Boundary thresholds are transgressed there is an increased risk of unexpected irreversible environmental changes.

Safe Operating Space (SOS)

The safe operating space refers a zone of safety in which Earth's ecological systems are in balance and can regenerate while at the same time supporting human life and related activity.

Stockholm Resilience Center

The Stockholm Resilience Center was founded in 2007 as a joint initiative between the University of Stockholm and the Beijer Institute of Ecological Economics at the Royal Swedish Academy of Sciences, founded with the mission "to advance research for governance and management of social-ecological systems to secure ecosystem services for human well-being and resilience for long-term sustainability" (Stockholm Resilience Center, 2022). Today, the Stockholm Resilience Center is leading the discourse on understanding the dynamic and complex relationship between humans and nature in Earth's biosphere.

Zone of Uncertainty

The Zone of Uncertainty is a concept related to Planetary Boundaries. When a boundary is overshot, Earth's environmental condition moves into a "zone of uncertainty", where risk for unpredictable and irreparable environmental changes increases dramatically.

02 Framework for sustainable buildings

Given the project background, purpose and delineation, the framework for the design of operational reduction curve for new housing construction is explained in the following sections. As such, the following section covers the latest knowledge from climate scientists on the status of greenhouse gas emissions, impacts of climate change, and commitments to national and international climate targets. Furthermore, there is an overview of sustainable construction today, and how Earth's "sustainable climate budget" can be scaled down to targets for new housing in Denmark.

2.1 Anthropocentric Climate Change

The increase in global temperature and resulting climate change impact is human driven. If we continue emitting the same rate of greenhouse gas emissions in the future, the results will hold catastrophic consequences for both human and natural systems. This is the concluding sentiment of the UN's sixth climate report IPCC AR6 (IPCC, 2021), reconfirming warnings of previous reports. Due to the improved climate models and data-sets developed in recent years, climate scientists have gained a greater understanding of the planet's climate system, which is why the IPCC AR6 report provides a much more detailed insights into how human actives affect climate systems. Conclusions from this improved knowledge foundation state unequivocally that human-driven greenhouse gas emissions must be significantly reduced to stop further warming. The IPCC AR6 report outlines carbon budgets for human-driven (Anthropocentric) emissions compared to pre-industrial levels (1850-1900) for 1.5°C, 1.7°C and 2.0°C scenarios.

These budgets illustrates in **Table 1** are calculated from 2020 and stretch until global emission levels hit net-zero. As pictured, the budgets are estimated with different possibilities of limiting global warming with each, a respective temperature limit. The budgets related to carbon emissions, are estimated based on global surface temperature, which is why the effect of other greenhouse gases such as Methane (CH_4) are also included. For greenhouse gases other than carbon (C_02), are covered based on their global warming potential into carbon equivalents (C_02eq).

Although the numerical difference between 1.5°C and 2.0°C global warming scenarios seems small, the difference has a massive consequence for Earth's climate, ecological systems, and global surface warming. **Figure 1** explains some of the direct and indirect consequences of the .5°C increase in global warming.

Table 1:
IPCC AR6, Table SMP.2 - Estimates of historical carbon dioxide (C02) emission and remaining carbon budgets.

	Approximate global warming relative to 1850-1900 until temperature limit (°C)	Additional global warming relative to 2010-2019 until temperature limit (°C)	Estimated remaining carbon budgets from the beginning of 2020 (GtCO2)				
			17%	33%	50%	67%	83%
Global budget	1,5	0,43	900	650	500	400	300
	1,7	0,63	1450	1050	850	700	550
	2,0	0,93	2300	1700	1350	1150	900

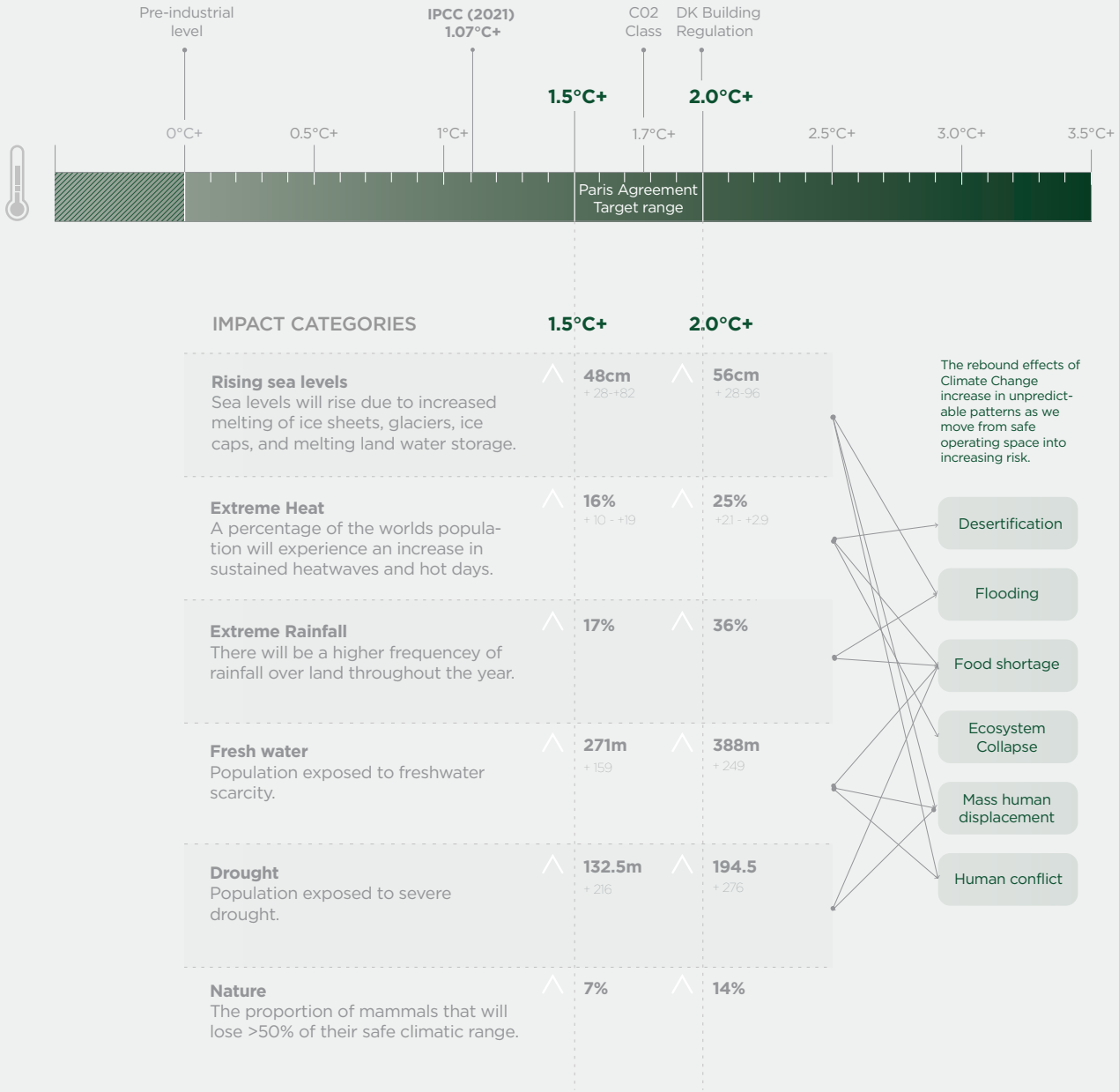

Figure 1:
Although the numerical difference between 1.5°C and 2.0°C global warming scenarios seems small, the difference has a massive consequence for Earth's climate, ecological systems, and global surface warming (Pearce et al., 2022).

2.2 The Paris Agreement

The temperature increases in **Table 1** relates directly to the Paris Agreement (United Nations Climate Change, 2015), which Denmark and 195 other member nations of the UN Climate Convention signed to in 2015. As such, participating nations committed to collaboratively limit the global temperature to 1.5°C, with a maximum overshoot of 2.0°C. The IPCC Report outlines the global carbon budgets with which work to achieve the goals set in the Paris Agreement.

In addition to the long-term objectives of global warming, Denmark and other member states are obligated to present national reduction contribution, in relation to achieving the global goal of reducing greenhouse gas emissions by 40% in 2030, compared to 1990 levels. The reductions must be distributed between the member states, and Denmark has, as part of this commitment, adopted a national climate law which demands a 70% reduction by 2030, compared to 1990 levels. Furthermore, Denmark has committed to being a climte-nuetral society by 2050, at the latest (Klima-Energi- og Forsyningsministeriet, 2020). In a climate-neutral society, more greenhouse gas emissions are emitted at the same rate they are absorbed. This is also referred to as net-zero. This objective is to stop the increase of the atmosphere's greenhouse gas content and thereafter greenhouse effect – one of the main causes of global warming. The concentration of greenhouse gases in the atmosphere is expressed in parts per million (ppm) and, like global temperature, has increased exponentially since industrialization.

In May 2022, researchers from the National Oceanic and Atmospheric Administration documented the highest concentration of greenhouse gases in the atmosphere since industrialization (280 ppm) measuring at 421 ppm (Stein, 2022). According to the Stockholm Resilience Center, the planetary limit of greenhouse gas concentration in the atmosphere is 350 ppm (Rockström et al., 2009).

2.3 Planetary Boundaries

The Planetary Boundaries were first described by a group of researchers led by Johan Rockström in 2009 at the Stockholm Resiliency Institute (Rockström et al. 2009) is a method to measure the state of global well-being. The Planetary Boundaries concept makes visible a safe operating space for human impact on nine essential planetary systems at a global scale (Figure 2). Each time a Planetary Boundary is transgressed, the planets environment well-being moves into a "zone of uncertainty" and the risk for non-linear and abrupt environmental changes significantly increases (Rockström et al., 2009; Steffen et al., 2015).

Today we have overeshot six of the nine Planetary Boundaries, as illustrated in Figure 2 (Persson et al., 2022; Wang-Erlandsson et al., 2022) including the boundary for "Climate Change" which was overshoot in 2017 (Fifth Assessment Report – IPCC, n.d.).

If we image that the Planetary Boundary for "Climate Change" had not already been exceeded, the safe operating space defines the safe level of annual anthropogenic emissions of C02eq. Because this boundary was already transgressed, the room for action can be considered as an estimate of Earth's sustainable carbon budget and / or the target C02eq emissions.

This "room for action", subsequently referred to as the safe operating space, was calculated in 2015 as 3.61 billion tons C02eq/year by Bjørn and Hauschild (2015), who applied data from the IPCC AR5 report. With the release of the IPCC AR6 in 2021 the weighing factor for different greenhouse gases in relation to C02eq has been updated, as such the safe operating space is also redefined. In addition to the weighing factor update, where for example the radiation efficiency of methane (C04) has adjusted by approximately 25%, there are also additional greenhouse gases data points "loaded" in the IPCC AR6 report. Based on these updates, Petersen et al. (2022) recalculated humanity's safe operating space, resulting in a significant reduction from Bjørn and Hauschild's

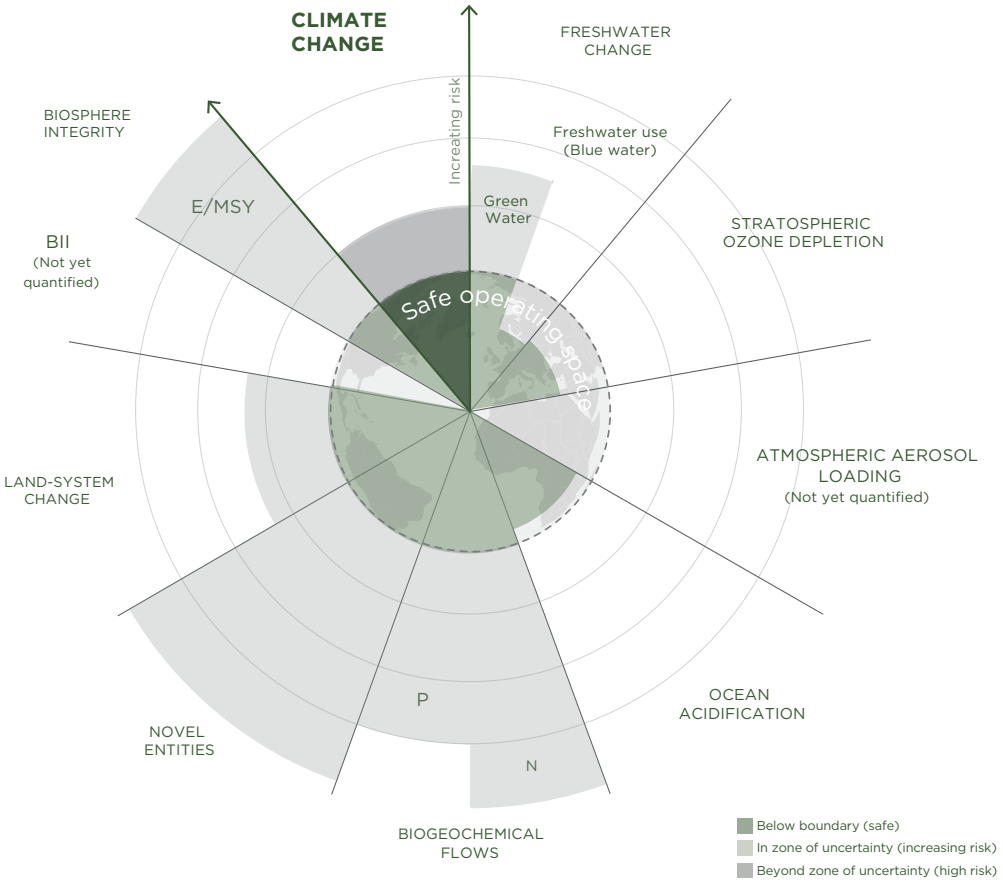

Figure 2:
Planetary boundaries Credit: Designed by Azote for Stockholm Resilience Centre, based on analysis in Persson et al. (2022) and Steffen et al. (2015)

Scenario	Carrying Capacity Gt. C02eq/ year	Notes on changes
Method 1: Weighted average of substance-specific contributions (8)		
M1 - Original	3.61	-
M1- AR6	2.90	AR5 data replaced with AR6
M1 - AR6+	2.61	AR6 data + only GHG with ERF>0.001 W/m2 included, new indicator scores
M1 - AR6+ (95%)	2.51	As AR6+ but using the 95% confidence interval of GHG input from AR6 in the GTP model.
M1 - AR6+ (99.7%)	2.35	As AR6+ but using the 99.73% confidence interval of GHG input from AR6 to the GTP model.

Table 2:
Scenarios for a safe operating space for annual emissions of C02eqivalents based on Planetary Boundaries referenced from *The safe operating space for greenhouse gas emissions* by Petersen et al. (2022)

(2015) original target. The results of the Petersen et al. calculation is reproduced in Table 2, where the fully updated scenario AR+ is 28% lower and the AR6+ (95%) is 33% lower than the original value at 2.51 billion tons C02eq/year.

To move below the Planetary Boundary for "Climate Change" it is necessary to reduce the atmospheric concentration of greenhouse gases. This can be achieved through different methods described in IPCC AR6, but demands at a minimum, that greenhouse gas emissions do not exceed the defined safe operating space. Regardless of the approach, the concentration will reduce very slowly, because the effect of some greenhouse gases decreases over long periods of time. This will leave the planet in the "zone of uncertainty" for several hundred years. There are long-term global strategies which include the capture of greenhouse gases. Short-term approaches suggest the emissions of greenhouse gases should correspond to Earth's sustainable carbon budget (the safe operating space), work to slow down global warming, which means we must come to terms with the fact that Earth's surface temperature will be higher in the future, than it is today.

2.4 Emissions today

To put the safe operating space in perspective, global emissions levels were 47.9 million tons C02eq in 2019 (World | Total Including LUCF | Greenhouse Gas (GHG) Emissions | Climate Watch, n.d.) equating to an overshoot of the limit by nearly 20 times. With a global population of approximately 8 billion, this equals an average of approximately 6 tons C02eq/person/year. Despite Denmark's reputation as a sustainable leader, the average Dane emits 7,7 tons C02eq per year, approximately 25% over the global average. In connection with the Paris Agreement, Denmark reported an annual emission to the UNFCCC of 44.7 million tons of C02eq in 2020 (European Environment Agency, n.d.) Although this "merely" represents 0.09% of global emissions, in accordance with the Danish Climate Act, we must significantly reduce national greenhouse gas emissions.

Figure 3 illustrates Denmark's historical net-emissions from 1990 – 2020, according to calculation methods stipulated by UNFCCC (including Land-use, Land-use Change and Forestry - LULUCF), as well as a linear projection of Danish climate goals set for 2030 and 2050 (European Environmental Agency, n.d.; Klima-Energi-og Forsyningsministeriet, 2020).

2.5 The Building Industry's share

As part of the Danish climate action, the government has worked to form 14 public to private, climate partnerships that work to strengthen sustainable transition and support fulfillment of Danish climate goals. The result of which has been concrete proposals and recommendations on how various business sectors can reduce carbon emissions. The climate partnership for the construction sector provided a status report on the sectors emission levels as well as suggestions for reductions. Klimapartnerskabet for bygge- og anlægssektoren, (2020a) concludes that 23% of Danish national emissions are related to energy use in our buildings, and that 10% of emissions come the construction process and production of materials. The Climate Partnership suggests 27 concrete initiatives to reduce building industry emissions.

Following-up the Climate Partnerships initiatives, the Danish government adopted a "National strategy for sustainable buildings" in 2021 with five areas of action, with the purpose of setting the direction for the future regulation of sustainable construction (Boligministeriet, 2021). As such, from 2023 the building regulations (BR18) require LCA calculations on all new buildings, and set a C02eq limit of 12kg C02eq /m2/year for all buildings exceed 1000m2. Furthermore, a voluntary low-carbon class (Frivillig lavemissonsklasse - FLK) was defined, with a limit set to 8kg C02eq/m2/year. The target values in the building regulations were determined on the background of a publication released by BUILD - Whole Life Carbon Assessment of 60 Buildings: Possibilities to develop benchmark values for LCA of buildings (Tozan et al., 2021) where the carbon footprint of 60 different buildings is analyzed. Based on this study, the Climate Partnership recommended a limit of 12kg C02eq/m2/year – corresponding to the upper end of the Tozan et al. analysis with the rationale "that all must be able to participate" (Klimapartnerskabet for bygge-og anlægssektoren, 2020b). Both the requirements for the building regulations (BR18) and low-carbon class (FLK) will be sharpened between now and 2030, with reduced targets every other year.

Figure 4 illustrates how the National strategy for sustainable buildings proposes tightening the requirements overtime with a stepped, linear reduction curve.

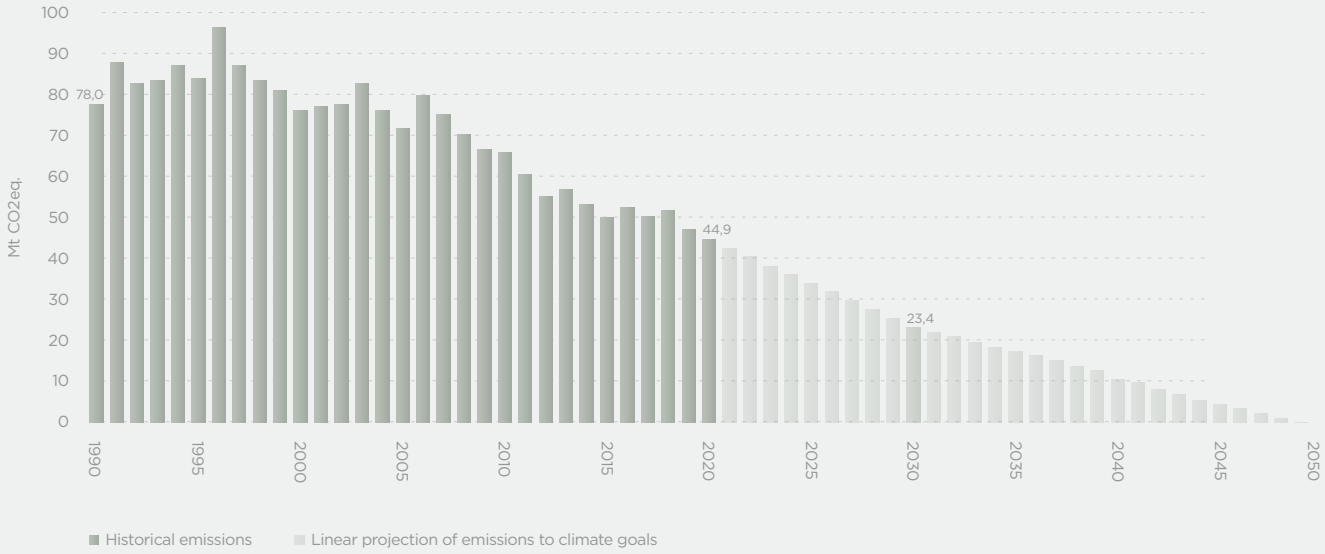

Figure 3:
Denmarks historical net-emissions and linear projects of Denmark's climate goals for 2030 and 2050.

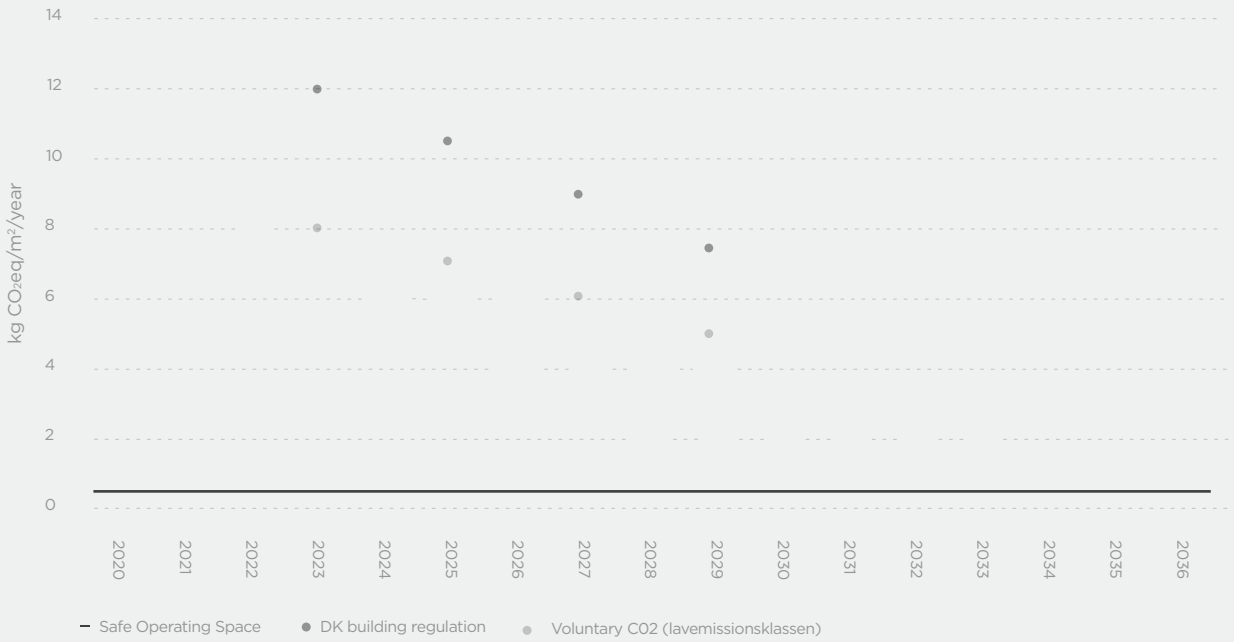

Figure 4:
Danish national strategy for reduction carbon emissions for BR18 and the low emission class.

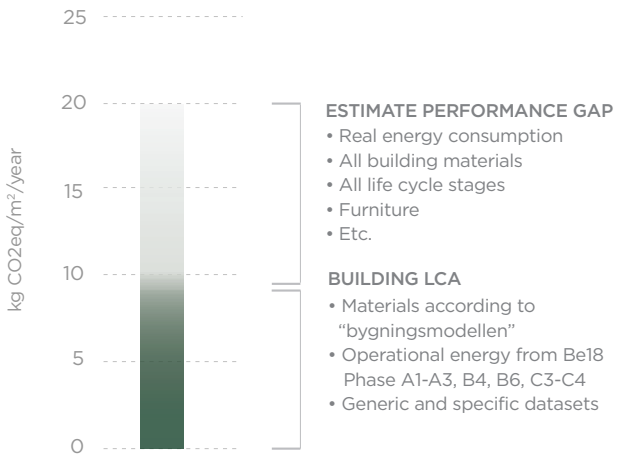

Figure 6:
Total climate impact from the building.

2.6 Building LCA

Beginning in 2023 the calculation of environmental impact of buildings (LCA) must be carried out in accordance with EN 15978 and EN 15804. As such LCA must include emissions from energy consumption calculated in accordance with the energy framework in building regulations (BR18), as well as building materials according to forth-coming data models (to be released at the end of 2022). The life cycle phases that should be included in such calculations are illustrated in **Figure 5**. The LCA calculation methods should follow those applied in the 60 Buildings study by BUILD (Tozan et al., 2021).

The future targets are based on a relative approach to construction "more sustainable" buildings, not the absolute sustainable approached outlines in Section 2.3. With a relative approach to measuring sustainability the carbon footprint of one building is compared to another like building. In doing so, it is possible to determine if the new building is a more sustainable solution, compared to the earlier building, from which method the carbon footprint of buildings can be reduced over time. This method of relative comparison does not illicit whether a building is sustainable in relationship to Planetary Boundaries or whether or not the reduction contributes to aligning with national or international reduction targets, such as the Paris Agreement.

To scale emissions with Planetary Boundaries, it is necessary to develop an absolute approach to setting targets for sustainable construction. Such an approach compares the climate impact of a building to a share of the safe operating space, that the building in question is assigned (Andersen et al., 2020; Brejnrod et al., 2017; Ryberg et al., 2018). This assigned share can be difficult to determine, in that the method requires that the environmental impact from all materials, all life cycle phases and real energy consumption throughout the lifetime of the building to be accounted for. As illustrated in **Figure 6**, LCA calculations carried out following EN 15978 assess only a portion of the total impact from a building, following a 50-year reference period.

The difference between the total environmental impact of a building over its lifetime and the phases that are included in Building LCA calculations, is called the "performance gap" and is determined by the buildings' actual energy consumption in the use phase. The scale of the "performance gap" is unique to each building and is therefore difficult to calculate precisely.

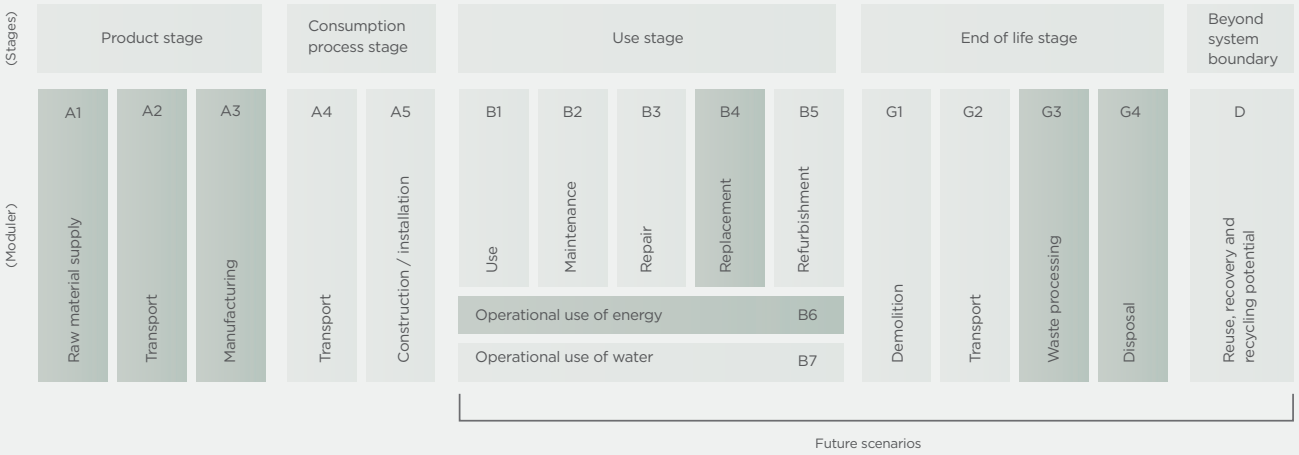

Figure 5:
The phases included in Building LCA, following EN 15978 standard. Reference: BUILD

2.7 Allocation Principles

Over the past few years there has been studies which explore how a climate budget should be allocated to a building project, each showing methods resulting in significantly different results. Allocation is always associated with subjective principles, as such, there is no right or wrong allocation method (Andersen et al., 2020; Brejnrod et al.,2017; Ryberg et al., 2018). Two of the most commonly applied methods for allocation, "Final Consumption Expenditure" and "Acquired Rights" are described below:

Final Consumption Expenditure

An economic allocation principle assumes that economic value can be considered a proxy for human well-being - namely that increased economic value leads to increased well-being. The principle distributes a share of personal carbon budget, based on how people spend their money for the consumption category in question.

On average EU residents spend 21.5% of their personal budget on "housing." The same proportion can be transferred to "housings" share of personal carbon budget. The category of "housing" includes expenses such as rent, furniture, electricity, water, and heating bills (Brejnrod et al., 2017; Ryberg et al., 2018). Therefore, the expense relates to "living" and thus the total climate impact from a home, referred to in Figure 6 as Building LCA and Performance Gap.

Acquired Rights

With Acquired Rights allocation method, the carbon budget is distributed according to the philosophy that an activity with a certain share of the budget today, retains the same budget in the future. This is regardless of whether the allocated share is large or small compared to the size of the activity (Andersen et al., 2020). This method can be applied to several different levels, relative to the allocation a share of the global climate budget down to an industry level or residential level. This distribution assumes that the historical share of the climate budget is determinable.

03 Reduction target for new housing in Denmark

The following sections describe the development of a reduction curve for new Danish housing, with respect to the timeframe outlined in the Paris Agreement and target of returning to Earth's safe operating space. In the allocation approach applied for the Reduction Roadmap the Danish share of the global carbon budget aligns with Danish commitment to the Paris Agreement. Similarly, the global value for safe operating space is allocated to a national, then industry, then housing-specific equivalent share of the target emission value.

3.1 Danish share of the IPCC carbon budget

Global warming is a global problem which must be resolved collaboratively. While the IPCC report defines both the global carbon budgets for limiting global warming to between 1.5°C and 2.0°C, and how much global emissions must be reduced from today's level, it does not stipulate what portion of the global budget is allocated to each country.

Just as the Paris Agreement is a political decision, so is deciding how the global budget is kept, and how much each country is allocated. This has yet to be decided on an international level. In this project an "equal per capita" sharing principle has been applied in which the global carbon budget has be divided equally among the world's population, regardless of individual age or income. With a population of approximately 5,8 million in 2020, Denmark represents .075% of the global population of 7,9 billion (Statistikbanken, n.d.; World Population Projections – Worldometer, n.d.). The carbon budgets stipuled by IPCC can be scaled down to Danish budget by applying this .075% factor. The budgets are reproduced in **Table 3**, which illustrates Denmark's share of the a sustainable, global carbon budget.

Based on this budget we can see how much Denmark must reduce national greenhouse gas emissions. If we continue with "business-as-usual" we have between five to fifteen years to reduce emissions within the budget stipulated by a 1.5°C target. The timeframe is determined by the amount of risk we're willing to accept when working to limit global warming. Based on the consequence of global warming described in **Figure 1** the Reduction Roadmap sets limits based on targets for 1.5°C 83%, 67% and 50% scenarios. We have excluded budgets for 33% and 17% likelihood – which are likely to lead to pathways for global warming to reach 1.7°C and 2.0°C scenarios, as illustrated in **Figure 7** as grey lines.

Table 3:
Estimates of remaining carbon budgets for Denmark based on IPCC AR6, Table SPM.2

Danish budget

Approximate global warming relative to 1850-1900 until temperature limit (°C)	Additional global warming relative to 2010-2019 until temperature limit (°C)	Estimated remaining carbon budgets from the beginning of 2020 (GtCO2)				
		17%	33%	50%	67%	83%
1,5	0,43	672	486	374	299	224
1,7	0,63	1083	784	635	523	411
2,0	0,93	1718	1270	1008	859	672

Table 4:
Estimates of years remaining to consume entire C02 budgets if we continue with “business-as-usual” based on IPCC AR6, Table SPM.2

Approximate global warming relative to 1850-1900 until temperature limit (°C)	Additional global warming relative to 2010-2019 until temperature limit (°C)	Years of emissions remaining to consume the entire budget from beginning of 2020 (at 2019 emissions levels)				
		17%	33%	50%	67%	83%
1,5	0,43	15.0	10.8	8.3	6.7	5.0
1,7	0,63	24.1	17.5	14.2	11.7	9.2
2,0	0,93	38.3	28.3	22.5	19.2	15.0

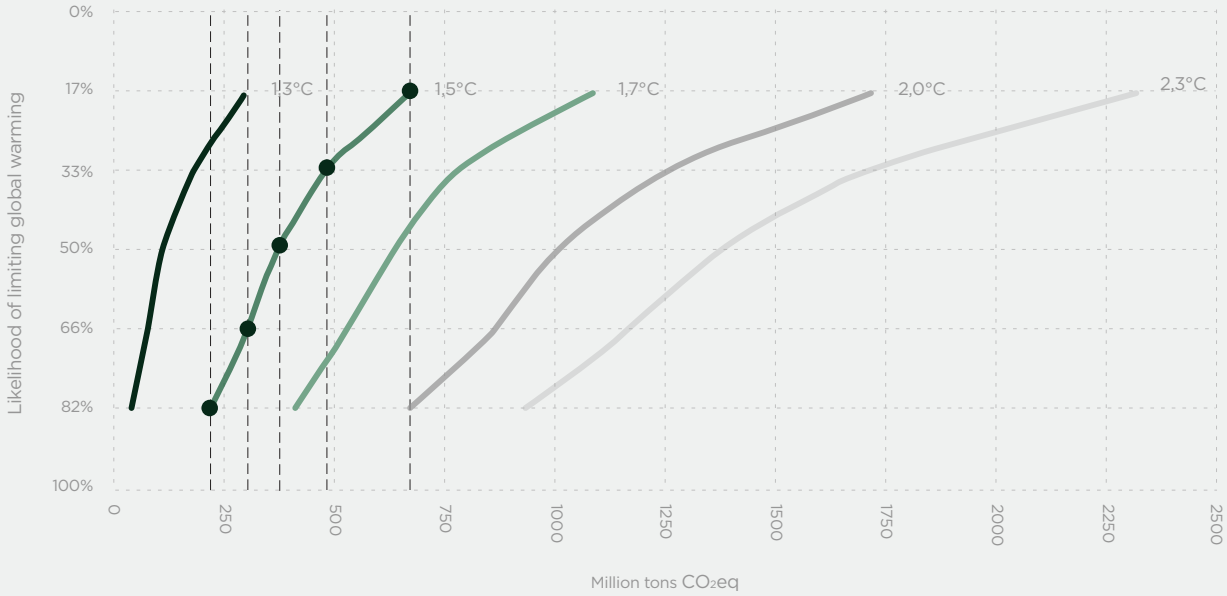

Figure 7:
The relationship between the Danish carbon budget and the likelihood for limiting global warming.

Safe operating space for planetary boundaries	
Global, AR6+ high confidence	2.51 billion tons C02eq / year
Denmark	1.9 million tons C02eq / year

Table 5:
Safe operating space based on planetary boundaries

3.2 Danish share of the safe operating space

The Earth's safe operating space for human-drive emissions has been described in an earlier section, can be determined with more, or with less uncertainty. To reduce the risk of continuous climate change the Reduction Roadmap has applied the updated value for AR6+ with a 95% confidence interval – which minimizes the uncertainty for which we can reach a 1.5°C target. In the same way that we've determined Danish share of the carbon budgets outline in the IPCC report, the Earth's safe operating space can be scaled down to Danish share, based on Danish percentage of global population. With a share of .075% Denmark should limit carbon emissions to 1,9 million tons C02eq/year, as show in **Table 5**. In contrast to this limit, Denmark emitted 44,99 million tons C02eq in 2020 (European Environmental Agency, n.d.) and therefore must reduce emissions by 96% to stay within the Danish share of the safe operating space.

3.3 The timeframe for necessary reductions

Once the Danish carbon budget aligned with Paris Agreement is defined, and the Danish reduction emission targets defined in relationship to Danish share of Planetary Boundaries, it is possible to calculate the timeframe for when Denmark must reach the aforementioned reduction targets. There are many pathways to the defined target level, but to outline specific strategies to reach said target, is an innately political task that is outside the scope of this study.

Figure 8 shows the reduction curve relative to 83%, 67%, and 50% likelihoods of limiting global warming to 1.5°C. As illustrated, the reduction pathway to a safe operating space should be reached in 9 – 16 years (from 2020), which is a shorter deadline than defined by Denmark's climate goals for 2030.

3.4 Reduction Roadmap for new buildings.

The Reduction Roadmap assumes a linear reduction towards the safe operating space, from which all human-driven greenhouse gas emissions must be reduced by 96%. It is outside the scope of this study to determine other industries share of the reduction – however the allocation principle assumes that each industry's share is the same as today. There is, therefore, no distinction made on whether some industries should reduce emissions more than others.

In Denmark there are on average 3 million m2 of new housing built each year. Considering the housing cases studied in Tozan et al. (2021) report, we can deduct that the average emissions from new housing following Building LCA standard calculations is 9,63kg C02eq/m2/year. This do not account for the total emissions of such buildings, but accounts for the phases of LCA Danish building regulations have adopted. These accounted for

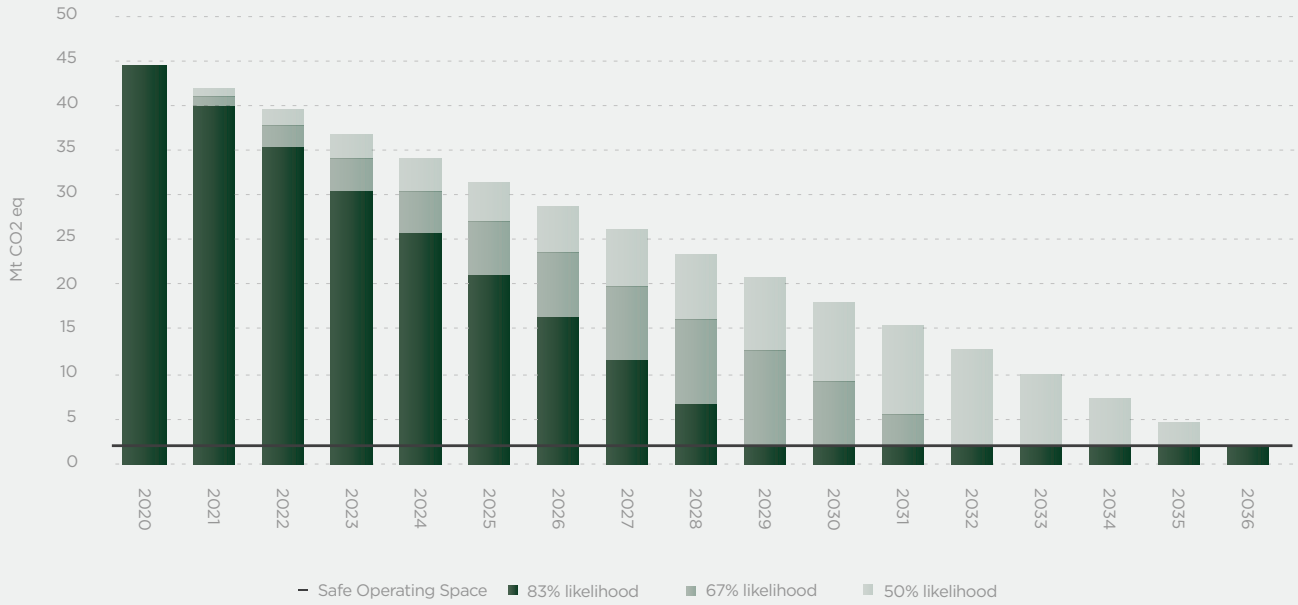

Figure 8:
Linear reduction of Denmark's greenhouse gas emissions from 2020 to the safe operating space.

building phases and their respective emissions is where the construction industry can benchmark future housing construction.

Assuming we continue with a constant rate of construction (approximately 3 million m2/year) a 96% reduction of 9,63kg C02eq/m2/year corresponds to a target emission level of 0,4 kg C02eq/m2/year. The reduction follows the same speed and framework as Denmark's national reduction curve, meaning the safe operating space for housing should be reached between 2029 – 2036.

Figure 9 illustrates the reduction pathways for new Danish housing following a 85%, 67% and 50% likelihood for staying with the global warming target of 1.5°C. The targets set for Danish building regulation (BR18) and the voluntary low emission class are illustrated as a reference point.

The reduction pathway assumes emissions reductions have already begun in 2021 and continue until new housings share of the safe operating space is reached. As illustrated, the future carbon limits set by the low emissions class roughly correspond to the budget for 50% likelihood, whereas Danish building regulation (BR18) exceed this budget. The Reduction Roadmap illustrated in **Figure 10** shows annual reduction targets for new housing in Denmark.

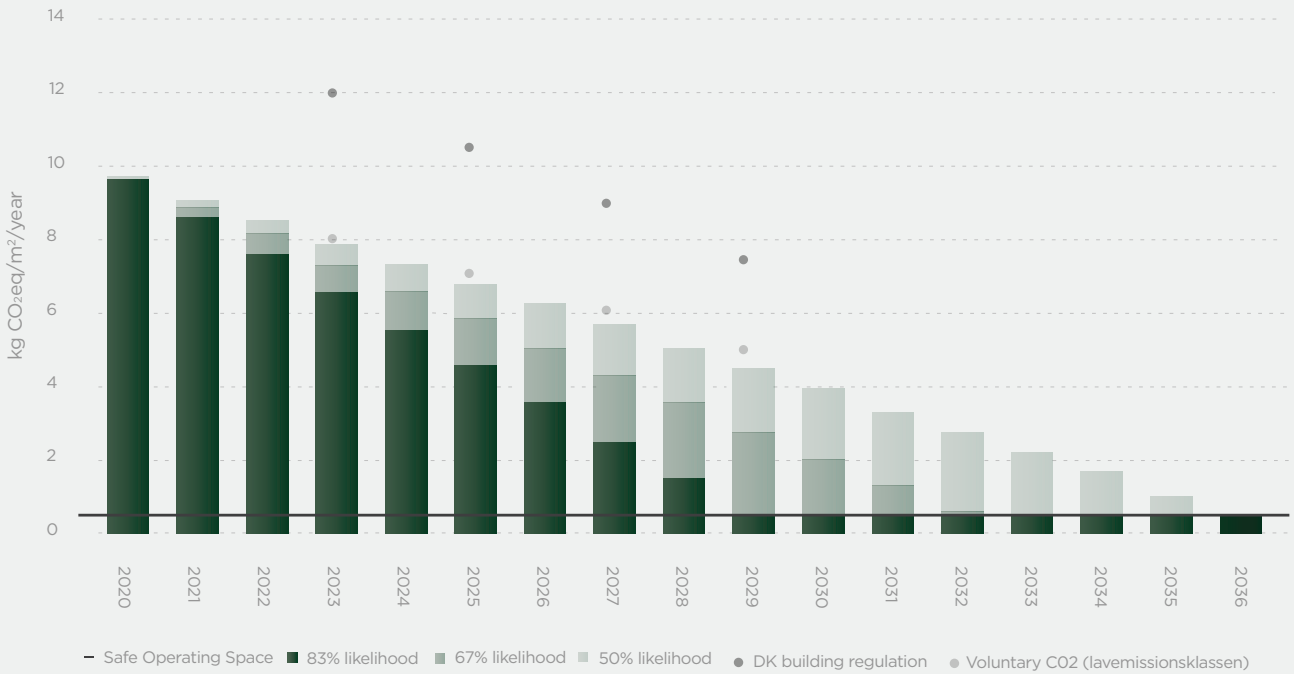

Figure 9:
The reduction curve for new Danish housing and the future carbon limits according to Danish building regulation.

3.5 Alternative reduction pathways

A linear reduction of new housing emissions expressed in kg C02eq/m2/year is only one way to the target of a safe operating space and assumes that the Danish building industry continues building approximately 3 million m2 of housing each year. The reduction curve illustrate in Figure 10 can be translated into reduction targets at different levels and ultimately to a different share of Denmark's overall emissions, resulting in alternative reduction pathways.

Applying a 50-year reference period for Building LCA – calculations of impact expressed as kg C02eq/m2/year are calculated into an kg C02eq/m2. From which it can be calculated into an environmental impact of kg C02eq so long as you know the area of new housing each year. Such calculations are shown in Table 6 and indicates that annually new housing accounts for 1.5 million tons of C02eq emissions, accounting for approximately 3.3% of Denmark's total C02eq emissions.

With this knowledge, a reduction curve can be carried out for the building industry in the same way as at a building level. In Figure 10 the linear reduction curve is based on the C02eq budget to limit global warming within 1.5°C, following a 83% likelihood. This reduction curve can be adopted to reflect other environmental impacts expressed as kg C02eq/m2/year and other built areas. Some of such alternative examples are visualized on the following pages, all of which are based on the C02 budget for limiting global warming to a 1.5°C, with 83% likelihood.

- **Figure 11**: business-as-usual
- **Figure 12**: 50% reduction of the built area
- **Figure 13**: 75% reduction of the built area.

Method 2: Charecterisation factors (15)

Level	Today's emissions	Target emissions	Unit
1 Housing m2 per year	9,63	0,4	kg C02eq/m2/year
2 Housing m2	482	20	kg C02eq/m2
3 Sector	1.479.168	61,440	tons C02eq/year
4 Share of total Danish emissions	3,3%	3,3%	%

Table 6:
Emissions for housing on different levels

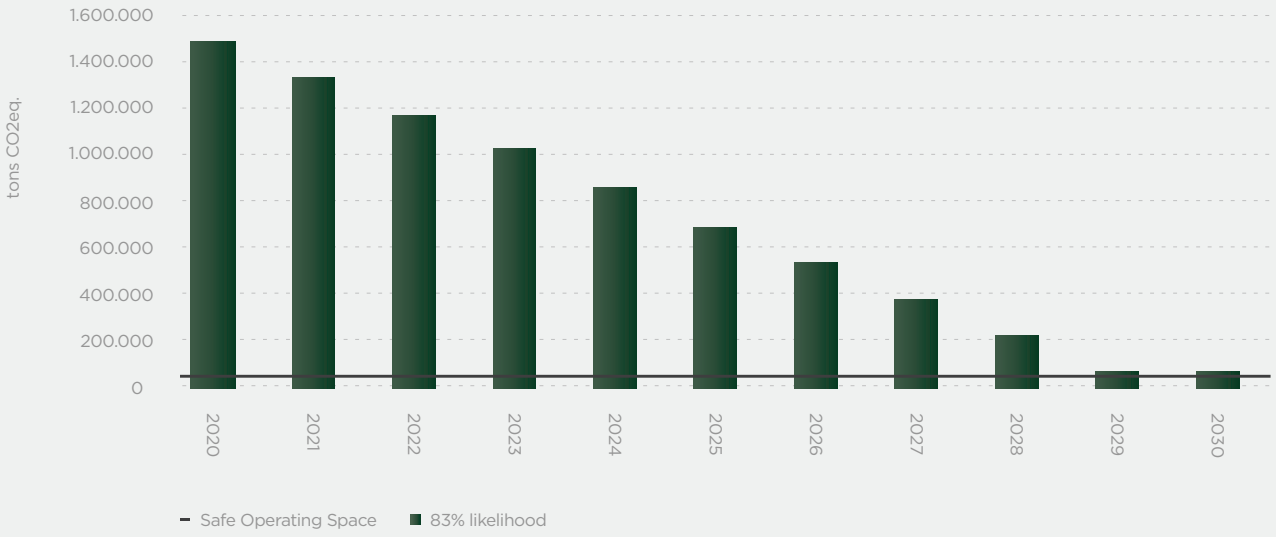

Figure 10:
Reduction curve for new Danish housing at an industry level.

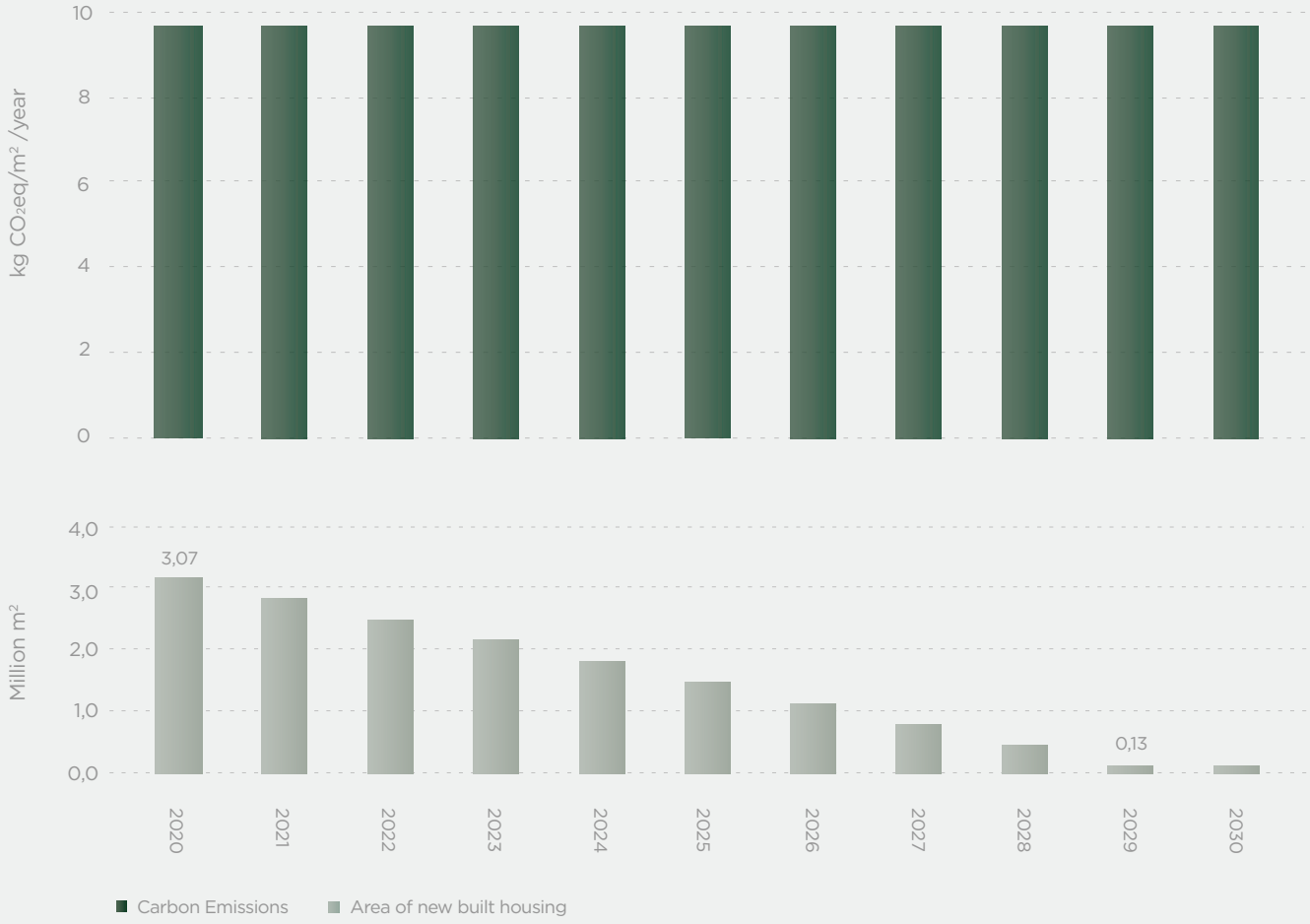

Figure 11: Business-as-usual

If we continue with building housing with an average environmental footprint of 9,63kg C02eq/m2/year it is necessary to significantly reduce the amount we build, from around 3 million m2 annually to around 130,000 m2 annually. Instead of reducing the environmental footprint of the building by 96%, we reduced the built area by 96%.

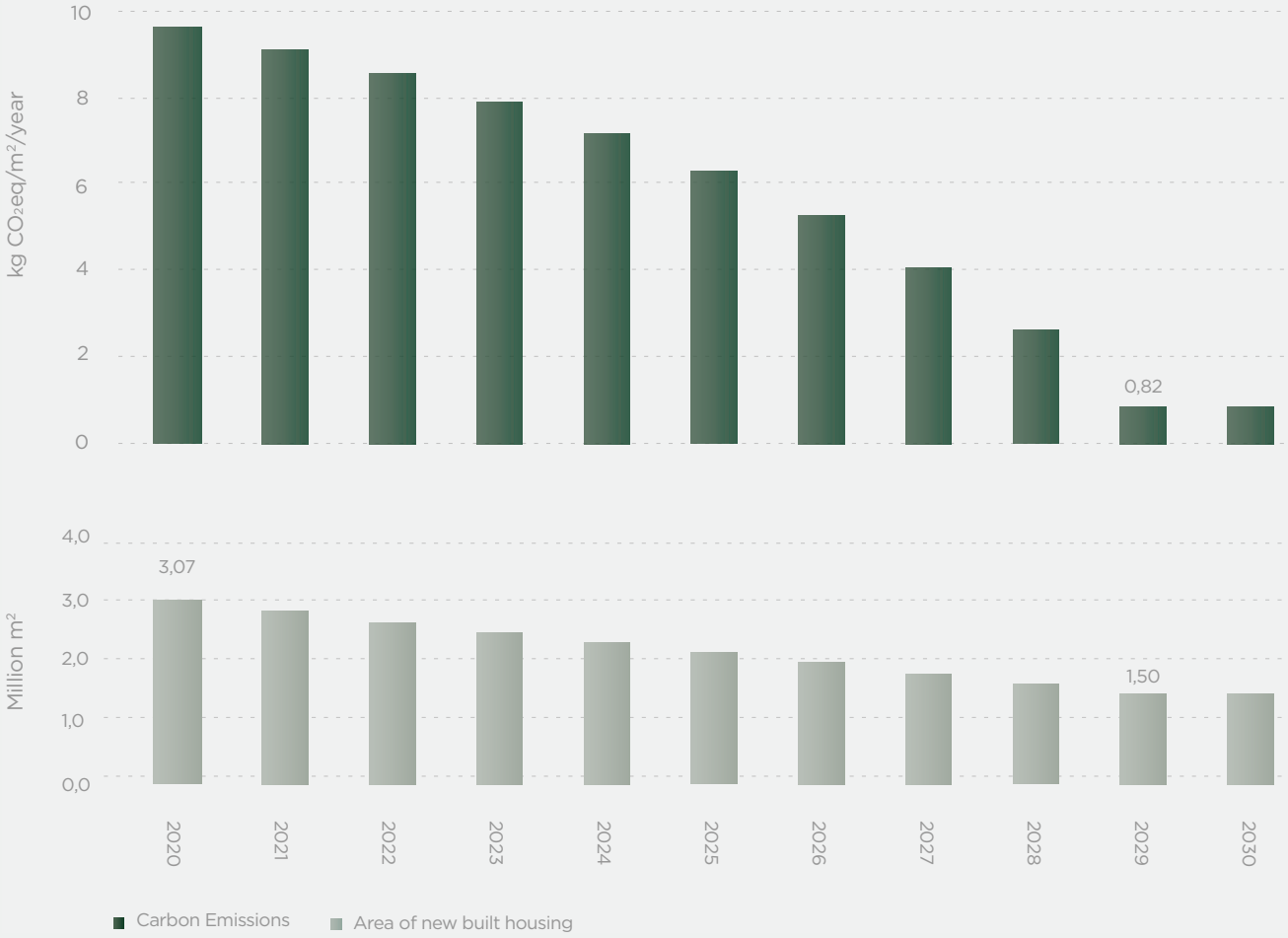

Figure 12: 50% reduction of building area

Instead of exclusively reducing the carbon footprint or the building area, it is possible to reduce both parameters simultaneously. For example, if we reduce the built area linearly from approximately 3 million m2 down to 1.5 million m2 it is “only” necessary to reduce the carbon footprint 0,82kg C02eq / m2 / year. The result of this approach, where both parameters are reduced simultaneously, is a reduction curve from carbon footprint that is a bit slighter.

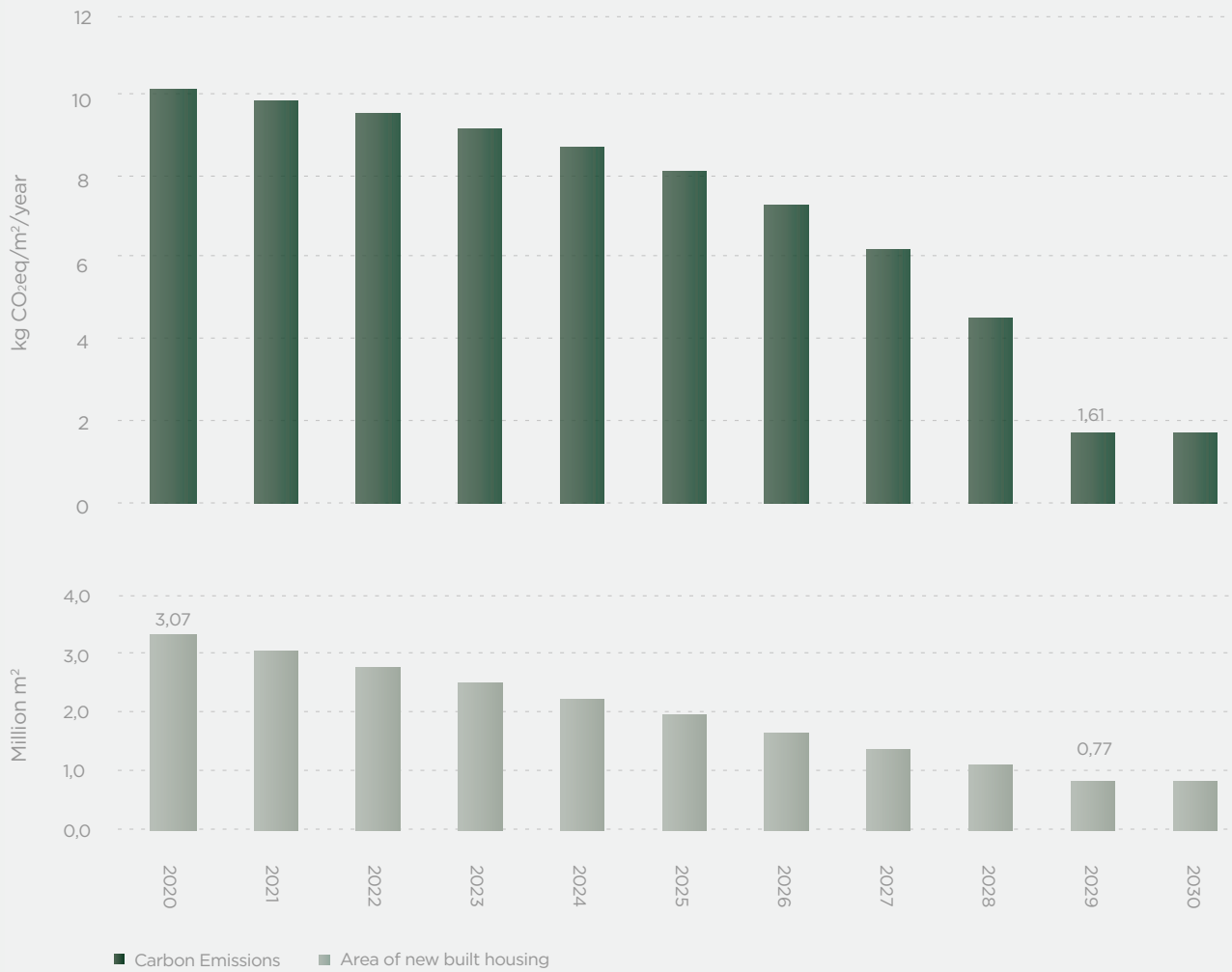

Figure 13: 75% reduction of the building area

In a similar way the building area can be reduced from approximately 3 million m2 to 770,000 m2, resulting in a 75% reduction. This mean that that the carbon footprint should reduce to 1,61kg C02eq/m2/year. The result of this approach, where both parameters are reduced simultaneous, is a reduction curve for carbon footprint that is a bit slighter.

04 Discussion

The global focus on climate change and emissions of greenhouse gases has never been bigger, and it clear that now, more than ever that further global warming must be limited. This can only happen if we all participate. For this reason, it is critical that industries with highest emission levels, such as the building industry, established defined reduction targets based on Planetary Boundaries.

The Reduction Roadmap is an attempt to develop a tool for this very purpose, but the prerequisites and the methods for translating Planetary Boundaries into reduction targets for new housing can and must be discussed. The basic principle of Planetary Boundaries and the safe operating space as an expression of greenhouse gas emission limits, assumes that Earth is still within Planetary Boundaries. As described, this is not the case for the Planetary Boundary for "Climate Change" and in order to stabilize Earth's systems, we have to move below the boundary again. To achieve this, we must reduce the atmospheres greenhouse gas content – a task which is out of the scope of the proposed Roadmap. The targets defined in this study stops development within the framework of C02eq budget, which accepts global warming of 1.5°C. As such, when targets defined in this study are reached, Earth remains in the "zone of uncertainty" with on-going climate changes as a result (Petersen et al., 2022).

In addition to this conundrum, it is assumed in the development of the reduction curves, that he emissions of greenhouse gases has already been reduced in the year 2021, which is very unlikely to have happened. We are currently in second half of 2022 and have likely consumed a larger share of the permitted C02eq budget than assigned. As such, we have even less time to act before the remaining C02eq budget is spent. We are on a trajectory towards a 2.0°C scenario.

Throughout this study we have aimed to be as apolitical as possible. In order to do so we have applied a decision-making framework in which we've:

- Invited scientific experts to offer criticism throughout the process
- Applied data points that reflect limits and allocation methods set in the Paris Agreement
- Chosen scenarios most compatible with life on Earth (1.5°C - 83% and 67% likelihood scenarios)
- And modelled a stepped, linear reduction roadmap.

In terms of selection an allocation method, it is an on-going and never-ending discussion, to decide which method is "most fair." There are arguments for and against all allocation methods, which is why this study has stayed out of this discussion by choosing an "equal per capital" sharing principle, which stipulates that all emissions should be reduced by the same precent. The "equal per capita" principle is applied based

on the Danish share of global population in 2020, however projection models of the global and Danish population show that Denmark's share with fall from the current .075% to .065% by 2050 (Statistikbanken, n.d.; World Population Projections – Worldometer, n.d).

During the development of the Reduction Roadmap different allocation methods were studied to determine what share of Danish C02eq budget is for new housing. Some of the methods described in the literature, do not directly benchmark with the Danish building industry standard for LCA on a building level, and do not put responsibility to change on the building industry, as show in Table 7A and 7B. Based on this analysis an allocation method "Acquired Rights" was modelled because it can be used as a benchmark for the way we measure building impact today and can be applied to other building typologies in the future.

"Acquired Rights" is based on the philosophy that the share (of carbon budget) one has, for better or for worse, usurped today, also applies in the future. From the perspective of welfare for example, it is not certain that housing in the future should have the same share as today... We (on a society level) might decide to allocate a larger share of the budget to shared building typologies which are central to education and public health, such as schools and hospitals. The Reduction Roadmap can act as a starting point for public debate on such political decisions that we must take in the future. Regardless of the allocation modelled, the reduction rate is consistent - we must reduce emissions for new homes by 96%.

Similar to selecting an allocation method, it is also a political decision to choose a global warming scenario and likelihood scenario – each having a resulting carbon budget. As shown in illustrations throughout the report, Danish reduction targets for 2030, and the national building codes sit above the reduction curve presented in the Reduction Roadmap. As such, these targets will result in a slower reduction.

From a computational point of view, the necessary reduction of Denmark's greenhouse gases is based on the calculation method used for the UNFCCC including LULUCF. This is a territorial inventory method, which looks exclusively at net emissions within Denmark's borders (European Environment Agency, n.d.). This method is not comparable with the calculation method for safe operating space, which is determined at a global level and is dependent on LULUCF, among other things. As such, it may have more accurate to exclude LULUCF from Danish emissions. We've included LULUCF, because it's consistent with what is reported to the UNFCCC.

There are notable inconsistencies in relationship to comparing the 96% reduction target to the result of a LCA calculation at the building level. The result of an LCA calculation does not relate to country specific emissions, but rather emissions from Danish consumption of materials globally. The result of an LCA calculation should therefore be compared with a consumption-based data point that looks at Danish consumption beyond borders (Energy Agency, 2022). Doing so however, would make it difficult to allocate the safe operating space to Denmark, which is why another calculation method has been chosen.

Finally, it is important to note that the Reduction Roadmap is based on the calculation method Building LCA, consistent with the Danish building regulation requirements. When Building LCA is updated to include a larger share of the "performance gap" (which will only strengthen the calculation) the reduction targets will be updated accordingly.

Allocation Method	Final Consumption Expenditure (FCE) (Ryberg, 2021)	Acquired Rights Building Industry (ARB) (Brejnrod et al., 2017: Horup et al., 2022)	Reduction Roadmap (RR) (Reduction Roadmap, 2022).
	Based on a percentage of individual spending. 21.5% of GDP goes to housing in the EU.	Based on industry level allocation 30% of Danish total emissions are allocated to the building industry.	Allocation principle based on the existing shares remaining the same in the future. 3.3% of Danish emissions are allocated to new housing.
Reduction Targets	FCE	ARB	RR
	Today: 1.650 kg CO2eq/person/year Target: 69 kg CO2eq/person/year Reduktion: 96%	Today: 13,5 mio. tons CO2eq/year Target: 0,56 million tons CO2eq/year Reduktion: 96%	Today: 3 million. m² new housing annually with a median footprint of 9,36 kg C02eq/m2/year. Target: 3 million. m² new housing annually with a median footprint of 0,4 kg CO2eq/m2/year Reduction: 96%

Table 7a:
Comparing Allocation Methods

Criterias	FCE	ARB	RR
Distribution of global carbon budget is distribution based on Equal Per Capita sharing principle?	YES Divides global target by global population to define individual limits	YES The building industry's share is defined out from the Danish share of the global carbon budget, which is based on Danish share of global population (.075%)	YES The building industry's share is defined out from the Danish share of the global carbon budget, which is based on Danish share of global population (.075%)
Responsibility Does it place responsibility on building industry actors to make change?	NO The allocation method has a per person/m2 target.	YES Allocation has a kg C02eq/m2/year target	YES Allocation has a kg C02eq/m2/year target
Building Typology Is the allocation method transferable to building typologies other than housing?	NO This method is only looking at housing. Does not differentiate between new and existing.	YES We have a thorough breakdown of the percentages for different buidling typologies	YES Once we have better LCA median data on other building typologies the method can apply to other typologies.
Benchmarking Is the target metric compatible with Building LCA? (C02eq/m2/year)	NO No we cannot base LCA calculations on per person allocation, because it is a matter of occupancy numbers.	NEJ The target has the right target value but does not relate to the existing Buidling LCA method.	YES This method is designed specifically to align with how we benchmark for Building LCA.
Data Sufficiency Do we have sufficient data in Denmark to apply this allocation method?	YES Kind of – the 21.5% of spending is an EU statistic. We're not sure if this figure covers all operation and embodied energy, new and existing building for example.	NO There isn't enough information about what is baked into the 30%. The data is constructed from many places outside of Denmark and no one has the "background" on this calculation.	YES We do today for bencmarking in connection with new buildings, not but for other typologies.

Table 7b:

Comparing Allocation Methods

05 **Conclusion**

The purpose of the Reduction Roadmap was to design an operation tool for the building industry that translates The Planetary Boundaries for Climate Change into industry-specific, annual reduction targets for new housing in Denmark. During this process, it became clear that the building industry currently operates far outside the Planetary Boundaries and must reduce carbon emissions significantly if we are to build within the Paris Agreement 1,5°C scenario for global warming.

Six out of nine Planetary Boundaries have already been transgressed. If we continue with "business-as-usual" there is an increased risk of it having catastrophic consequences for climate and ecosystems, with a planetary collapse as the ultimate consequence. As a building industry, we must act now to ensure the transition towards sustainable construction is in an absolute sense. Reduction Roadmap has identified today's levels and the reduction target for carbon emissions for new housing in Denmark. If we continue to build at the same rate as today, we must reduce our emissions from 9,63 to 0,4 kg/CO2eq./m2 year, equivalent to a 96% reduction.

This reduction must happen as quickly as possible to stop global warming from increasing even further, but we must also accept that the change will not happen tomorrow. Therefore, based on the Paris Agreement, we can allow the transition toward a safe operating space for Danish housing projects to take place between 2029 and 2036. The Reduction Roadmap is the first version of a shared tool for setting reduction targets that creates a basis for discussing allocation principles and calculation methods. Thus, the study is far from perfect it provides a starting point to initiate the needed change. We do not have the time to wait for perfect, but we must be willing to learn and ready to adapt as we go. The ambition for the Reduction Roadmap is to be a tool that is continuously developed with new knowledge and better data and, through this, contributes to a political reassessment of the industry emission targets.

06 Moving Forward

Through the development of the Reduction Roadmap, it became clear that we lack qualitative data to allocate and estimate the exact figure for the Planetary Boundary of the building industry. However, this project rests on a solid scientific basis, which has made it possible to create a linear reduction path for new housing.
In the future phases of the initiative, the focus will be on four key aspects, which should be discussed internally within the industry and on a higher political level.

1.Providing better and more precise data
The process has shown that we need better and more precise data to improve the current version of the Reduction Roadmap. Therefore, we intend to collaborate with public institutions, actors within the building industry, foundations, policy institutes, and municipalities to create new and more precise data. With this, the Reduction Roadmap will become more robust and set reduction pathways for not only housing projects but also offices, schools, hospitals, and infrastructure.

2.Development of a charter
The purpose of the Reduction Roadmap is to promote a joint commitment to ensure a reduction of the climate impact from the building industry so that we can work within the Paris Agreement and the Planetary Boundaries. We wish to develop a "charter" that, through a common platform for the building industry, should inspire joint action based on a shared commitment. A "charter" where we, as an industry, can exchange ideas, show "best practice" examples, and benchmark all new building projects against the reduction targets to follow our collective progress. We will never reach our goal alone, but if we work together and have a common goal in mind, we still have time to achieve it.

3. Facilitate a discussion on allocation methods and reduction rates
Although we have tried to be apolitical in developing the Reduction Roadmap, large parts of the project are based on the assumptions that, due to ethical and moral dilemmas, should be discussed within the industry and political level. We hope this project can help facilitate the discussion and thus move the industry towards a common goal.

4. Expand to other sectors
The methodology behind the Reduction Roadmap can be applied to other industries and therefore forms the basis for further dissemination. We hope and believe that this project can inspire other sectors to follow in the Reduction Roadmap's footsteps and work together follow through with Paris Agreement commitments.

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