Paris Proof Embodied Carbon

Background Report

experts in sustainability
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DGBC
Dutch Green Building Council

Project	Paris Proof Embodied fort he Whole Life Carbon Approach
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Glossary and Abbreviations

B&U	Burgerlijke en Utiliteitsbouw. [Residential and Non-residential construction] Abbreviation used to denote residential buildings and buildings for public and business life.
Determination method	The determination method sets out how the life cycle analysis for building materials and products is conducted in the Netherlands and which environmental impacts are calculated.
EPD	Environmental Product Declaration. A presentable and concise representation of an LCA with results such as the environmental impacts and ECI.
GWP	Global Warming Potential. See 'Climate impact'.
GWW	Grond-, Weg- en Waterbouw. [Groundwork, Road, and Hydraulic Engineering] Abbreviation used to denote civil works such as roads bridges, dikes and canals.
kg CO_2-eq.	The unit in which climate impact is expressed: kilograms of CO_2 equivalents. This unit allows the impact of different greenhouse gases to be expressed as one number. For example, the effect of 1 kg of methane is equivalent to 25 kg CO_2-eq.
Climate impact	The environmental impact of greenhouse gases, expressed in CO_2-eq.
LCA	Life Cycle Analysis. An LCA calculates the environmental impact of all the processes and raw materials required to apply a product, over the life of the product. The life cycle is defined by life stages, designated by the numbering A1 through D. A1-A3 refers to the production stage, C1-4 to the demolition and waste stage and D the recovery phase.

Environmental impact	A change in the environment as a result of an activity. There are multiple environmental impacts, such as: climate change, acidification and toxicity. Each describes a different effect with its own unit.
ECI	Environmental Cost Indicator. A life cycle assessment calculates the environmental impact of a material, product or structure. These environmental impacts (multiple numbers with different units) can be converted into one integral number: the environmental cost, in euros.
MPG	Milieuprestatie Gebouw. [Environmental Performance of Buildings calculation] A sum of the shadow costs of all products and materials used in the building divided by the period covered and the gross floor area.
NMD	Nationale Milieudatabase. [National Environmental Database] The database used to calculate the environmental performance of buildings and/or building products. The database contains a large number of profiles of materials and products commonly found in construction with their associated environmental impacts and shadow costs.
Shadow costs	See 'ECI'.

1 Introduction

The construction sector is facing a major sustainability challenge. This task goes further than just reducing CO_2 in the use stage. The construction process and the use of materials also result in a CO_2 impact. This will require a new perspective on how the construction industry is becoming more sustainable. We call this the Whole Life Carbon approach. This approach is part of the European #BuildingLife program.

NIBE was commissioned by the Dutch Green Building Council (DGBC) to research how the CO_2 impact of the building process and material use for both new construction and renovation could be included in the Whole Life Carbon approach. We also call the CO_2 impact of the construction process and material use the Embodied impact. At the heart of our research has been the question of how the impact of the Dutch construction sector can be situated within the Paris Agreement. We therefore call our study 'Paris Proof' Embodied.

Previously, the DGBC commissioned a study on emissions from the operational energy consumption of existing properties. This research has been developed as a Paris Proof built environment in the Delta Plan for Sustainable Renovation. The current study is intended to supplement this (for the embodied part of the emissions).

This background report describes the approach taken, as well as the results to date, which ultimately led to a proposal for target values for maximum climate change impact for new construction and renovation for different functions per m^2 of building.

In addition to this background report, a calculation protocol has also been prepared, describing how to perform the calculation for a structure.

1.1 Objective for Paris Proof embodied

On August 9, 2021, the IPCC independent panel of United Nations climate scientists presented the first part of a three-volume climate report to inform governments for the purpose of shaping climate policy (1). The report presents several scenarios for the predicted global temperature increase. Each of these scenarios has a cumulative global budget for greenhouse gas emissions, the maximum that may still take place to stay within the scenario.
In our study, we have focused on the global cumulative budget for the 1.5 degrees scenario (with 67% probability) and our aim was to indicate how the projected 2021-2050 construction targets in the Netherlands would be possible within a fair portion of the Dutch building sector in this cumulative global budget.

Objective: how can the Dutch construction target be achieved within the carbon budget associated with the 1.5-degree scenario of the IPCC (1)?

1.2 Structure of the study and summary

Budget
At the core of the study is the available CO_2 budget for the Dutch construction sector. This budget has not been officially set. To elaborate, a Dutch share was determined from the global budget and from this Dutch budget, a 'fair share' was determined for the Dutch construction sector.
This analysis is described in Section 2.

Construction target
In order to determine whether the Dutch construction target can be met within the budget, the Dutch construction target will have to be determined. Based on various datasets (including CBS, TNO, EIB, NIBE, DGBC), a forecast of the Dutch building target for the period 2021 to 2050 was made. This is described in Section 4.

Current construction practices
As a basis for the embodied CO_2 calculations, a dataset of building structures was generated. A structure can be included in this dataset if an Environmental Performance of Buildings (MPG) calculation is available in one of the recognized calculation tools and using the National Environmental Database (NMD) v3.0. When using a recognized calculation tool and the NMD v3.0, a breakdown of results by LCA module is possible. This is necessary for use in our study. This is described in Sections 3 (method) and 4 (dataset).

Scenarios
Embodied CO_2 emission scenarios were built based on current building practices, building targets and sustainability scenarios. These scenarios provide insight into what it will take to keep the embodied emissions of construction targets from today to 2050, cumulatively within budget. This is described in Section 6.

Target values
Finally, based on the scenarios, a proposal was made for the maximum embodied CO_2 missions per m2 of building for the different building types. If we build everything within these maximum targets, it would likely be that construction targets as a whole will remain within the budget of the 1.5-degree scenario. This is described in Section 7.

1.3 The importance of a practical perspective

Clearly, this is a tremendous challenge and we do not expect to have this all sorted out in the immediate short term. But we think it is important to provide a practical perspective that parties can relate to. It appears that the target values are ambitious, but not unachievable. With sufficient effort, we believe it should be possible to meet these values for any construction target. Parties that achieve this can then proudly call themselves Paris Proof and show that they have successfully completed their part of the challenge.

2 Our CO_2-eq. budget

The latest IPCC report (1) demonstrates several scenarios for global warming from greenhouse gas emissions. The IPCC describes scenarios using the maximum temperature increase and its probability. In our study, we use the IPCC's 1.5-degree scenario.

In the Paris Climate Accord, a large number of countries, including the Netherlands, agreed to aim to limit global warming to 1.5 degrees. This scenario involves a maximum global greenhouse gas emission budget of 400 Gt CO_2-eq. (Table SPM:2 from (1)) at a probability of 67%.

Approximate global warming relative to 1850–1900 until temperature limit *(°C)**(1)	Additional global warming relative to 2010–2019 until temperature limit *(°C)*	Estimated remaining carbon budgets from the beginning of 2020 *(GtCO₂)* *Likelihood of limiting global warming to temperature limit*(2)*					Variations in reductions in non-CO_2 emissions*(3)
		17%	*33%*	*50%*	*67%*	*83%*	
1.5	0.43	900	650	500	400	300	Higher or lower reductions in accompanying non-CO_2 emissions can increase or decrease the values on the left by 220 $GtCO_2$ or more
1.7	0.63	1450	1050	850	700	550	
2.0	0.93	2300	1700	1350	1150	900	

This global budget can be distributed to individual countries in various ways. In our study, we chose to distribute this based on population. The world currently has an estimated 7.7 billion people (source Wikipedia). The Netherlands currently has 17.5 million inhabitants (source CBS population census (2)). With this, the estimate for the budget for the Netherlands is 909 million tons of CO_2-eq.

Within the Dutch economy, construction is an important sector. No objective benchmark is available for the distribution of our Dutch budget by sectors yet. International research by IEA shows that the building materials industry has an 11% contribution to global emissions (source IEA 2019). In the absence of Dutch references, we are applying this assumption. If we take 11% of 909 M tons of CO_2-eq., this results in a budget for the construction sector of 100 M tons of CO_2-eq.

This budget of 100 M tons CO_2-eq. is therefore the budget for the total construction sector, which then includes both residential and non-residential construction (B&U) and civil engineering (GWW). In our study, we did not investigate the GWW. We also did not correct for the GWW in the budget, but looked at scenarios for the B&U and then compared them to this total budget. No estimate was made for the GWW part in the emissions of the building materials industry. A proportion of the facts and figures of Bouwend Nederland [association of construction and infrastructure companies] indicates that the GWW would amount to approximately 25% of the total.

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3 "Upfront carbon" approach

In the Dutch environmental performance of buildings (MPG) system, it is common practice to calculate the environmental performance of a building over its entire lifetime (of 50 years for non-residential buildings and 75 years for residential buildings). This also takes into account the potential for recycling and reuse after the life cycle, for which an environmental saving can be attributed.

To answer the question whether Dutch construction targets in terms of greenhouse gas emissions will remain within the Paris Agreement, the MPG system is not as adequate. On the one hand, because future effects, which are beyond the time horizon, are included and, on the other hand, because potential savings are accounted for as negative emissions. The latter does not work for a budget approach, after all, saving does not remove greenhouse gases from the atmosphere, it only prevents new emissions.

For the Paris Proof analysis, we therefore use a method that is also used in the United Kingdom, called 'Upfront Carbon' there. This method only looks at greenhouse gas emissions from source to building realization and shows them per m^2 of building.

3.1 LCA source data

The Dutch National Environmental Database records source data from the Life Cycle Assessments (LCA) of building products. This data is modular, which means that each life stage of a building product is named separately. The adjacent overview shows which stages are identified in this database. For our study, we want to limit ourselves from source to realization of construction; in terms of LCA modules, that means that we then limit ourselves to modules A1 through A5.

module	life stage
A1-A3	Production
A4-A5	Construction
B1-5	Use
C1-4	Demolition & waste processing
D	Recycling, reuse and energy recovery

For this we can therefore use the National Environmental Database (NMD) and the calculation tools connected to it. A calculation protocol for the 'embodied carbon calculation for Paris Proof' has been prepared. This protocol indicates how the calculation should be set up and reported.

3.2 Use stage B

Some of the environmental impact in the use stage could fall within our time horizon (2021-2050). Unfortunately, the MPG software does not report the year in which maintenance and replacement take place. So, from an MPG calculation, it is not possible to make those interventions time-dependent without looking at the underlying life span of each of the products.

Currently, it appears that replacements in MPG calculation tools, according to the calculation rules, are factored into modules A1-A3. This means that they end up in our calculation for the entire building lifetime. This is not what we want. In our opinion, the replacements should go into module B4.
Discussing this will take a little longer. For the moment, our proposal is to then calculate with the application of a building life of 30 years, so that the replacements until 2050 are included in the calculation. These then fall under A1-A3 and are thus included in our embodied CO_2-eq. calculation.

3.3 Plant-based greenhouses gases

The LCA data in the National Environmental Database have been compiled according to the Determination Method for the Environmental Performance of Construction Works (3). This method is based on the European standard EN 15804+A2:2019. This 2019 European standard replaces an older version of the standard from 2013

The 2019 version of the standard uses a new set of environmental impacts. In this new set of environmental impacts, Global Warming Potential (GWP) is reported in three underlying contributors, where we did not do so before.

One of those three contributors is GWP-Biogenic, or the contribution to climate change from greenhouse gases from plant sources.

When we start working with the new set of environmental impacts in the MPG tools (expected in 2022), GWP-Biogenic in module A1 for biobased products will have a negative value (equal to the CO2 uptake by growth). If we then use that in our Paris Proof calculation as we currently use it, it would lead to negative values for biobased products in module A1. At the moment this does not seem desirable to us, because EN 15804:A2 explicitly states that for biobased products not only uptake, but also release of biogenic CO2 at the end of life should be considered and there should be a balance over the entire life span. A study of this principle is currently being conducted in the Netherlands. It is our recommendation that, pending the study, we keep in line with current practice and EN 15804:A2 and also when using the new dataset (should it come into effect in early 2022) stored Biogenic CO2 will not count as a negative emission in module A1.

For reference, we are referring to the English method of 'Upfront Carbon' (4), in which the same method was used and stored CO2 is not included (in English: Sequestered Carbon).

3.4 Scope of the calculation

The Paris Proof embodied value is calculated over all materials and products used. So as the building is designed or realized, so should the MPG[1] calculation be constructed for the Paris Proof analysis. This applies to both new buildings and renovation. In renovation, the parts of the existing structure, which are not being modified, do not need to be included in the MPG calculation.
Again, we only look at the materials and products used.

For the scenario analyses in our study, we used existing MPG calculations for structures. This means that in our dataset, the scope of the building code has probably been retained by the compiler. We have not been able to ascertain the scope of the MPG calculations for all the data we have used (see later). We must therefore assume that the building code was used as the scope determination of the MPG calculations.

This means that our target values, which are presented at a later stage in this report, are probably based on MPG calculations with the scope of the building code as the foundation. It is our recommendation to maintain and expand the MPG dataset so that its quality will increase.

3.5 Heat and electricity generation

Paris Proof has an operational energy use target value, which will soon be enhanced by an embodied carbon target value.
All measures necessary to meet the operational energy use target should also be included in the embodied carbon calculation. For now, it is therefore also our decision to include these energy measures in the MPG calculation. If this is going to happen more often in practice, then our advice would be to examine this more closely and to make a more thorough assessment.

[1] For an MPG calculation for the building code, it is now requested to include only those parts of the structure which are mandatory according to the building code. This was done because the MPG system is designated in the building code and the building code may only set obligations that are part of the building code and not outside of it.

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4 Dutch construction data

To calculate the scenarios, we use a number of datasets. These are briefly explained in this chapter.

4.1 Current inventory

For the current inventory of housing, we have included CBS data in our model. This data represents the stock of current housing by floor area. Table 1 shows the dataset for single-family homes as an example. The same set is available for multi-family homes.

Table 1. CBS data for current inventory of single-family homes

Name	Number
Residence (single-family home) 2m² - 15m²	329
Residence (single-family home) 15m² - 50m²	22913
Residence (single-family home) 50m² - 75m²	165307
Residence (single-family home) 75m² - 100m²	920904
Residence (single-family home) 100m² - 150m²	2588842
Residence (single-family home) 150m² - 250m²	1106543
Residence (single-family home) 250m² - 500m²	215602
Residence (single-family home) 500m² - 10000m²	39113

The information on the current inventory is used in our model to calculate the volume of renovation (see Section 5).

For the current stock of non-residential buildings, we used an assumption that the total stock in the Netherlands is currently 600 million m2 (reference: Martin Mooij, DGBC).
The distribution across building types in this group is quite diverse. There is an overview from a 2012 study that we have not used yet. For now, we have made the simple assumption that of non-residential buildings, 50% are office or office-like environments (a building in which people work, often in combination with some other function). In our model, in addition to office, we now only consider retail and industry[2] as types and for now we have assumed both to be at 25% of the volume. This distribution certainly has its flaws, but since only limited data is available in the dataset we are currently using, and in terms of CO2 impact for the three non-residential building types, it does not make much difference to the outcome of the scenarios at this time exactly how the distribution is made. However, this is a great opportunity for further development in making the model more accurate.

4.2 Building volume 2020-2050

In addition to the current stock, our model also needs a forecast of building volume. We added this for new construction and renovation.
For new construction, we use the following estimates:

Residential construction 70,000 homes per year of which 2/3 single-family homes and 1/3 multi-family homes evenly distributed among the different m² classes

Non-residential construction 6.2 million m² per year 50% offices, 25% industrial and 25% retail.

For renovation, we have assumed that all current housing is to be renovated and that 50% of the current stock of non-residential buildings will still be renovated. For the time of renovation, we use an S-curve distribution over the period, see section 5 for further explanation.

[2] For industry, we now use MPG calculations for logistical properties in the dataset.

4.3 New Construction CO_2 footprint 2021

To have an estimate of the CO2 footprint module A1-A5 for the current method of construction (our 0-point), a dataset of MPG calculations of existing structures and reference buildings was compiled. This dataset was developed in collaboration with W/E Adviseurs and the DGBC and it is included in Annex 1. From this dataset, we determined the lowest, average, and highest value for each type of structure and this table has been included in our model. In addition, the user of the model can choose whether the lowest, average or highest value is used as the 0-point in the scenario model.

Table 2. Summary of the lowest, average and highest value of CO_2-eq. per m^2 for new construction of the different building types in the model.

Code		*Low*	*Average*	*High*
WE	Residence (single-family home)	190	286	373
WM	Residence (multi-family home)	190	286	373
KAN	Office	205	275	333
RV	Retail real estate	292	294	296
IND	Industry	228	253	271

4.4 Renovation CO2 footprint 2021

We have insufficient MPG calculations available for renovation and renovation projects differ greatly in character. In order to obtain a workable dataset for renovation, we have made an estimate. For this purpose, we separated all MPG calculations in our dataset (for new construction) by building floor and assumed that renovation of such a structure is equivalent to the sum of new construction of the shell and systems. This is a practical assumption and we can apply it to any MPG calculation. Based on this, for renovation we also made a low, medium and high analysis on the dataset and this is the basis for our scenario model for the CO2 impact of renovation.

Table 3. Summary of the lowest, average and highest value of CO_2-eq. per m^2 for renovation of the different building types in the model.

Code		*Low*	*Average*	*High*
WE	Residence (single-family home)	88	167	321
WM	Residence (multi-family home)	88	167	321
KAN	Office	58	131	229
RV	Retail real estate	170	171	172
IND	Industry	74	115	149

5 Scenario model

Our scenario model is very simple in its basic design. It determines in each year the total embodied CO2 impact of each building type based on the amount of new construction and renovation. This requires the building volume and the CO2 footprint of construction in that particular year. The CO2 footprint in the given year is determined by the industry performance in that year (which improves x% each year compared to the previous year) and the reference footprint (lowest, average or highest relative performance) in the base year 2021.

The scenario model can be used by being able to turn different 'dials'. For example, what would happen to the Carbon Budget if the trend of biobased material use continues and the proportion of biobased material use increases? Or of urban mining? But, also questions like what would happen if the industry improves faster or slower in a given year, or if we start building only with the best-in-class assumptions.

The further operation of the Excel model and assumptions used can be found in Annex 1.

6 Scenarios

In this chapter, we will describe and demonstrate a number of scenarios. The goal is ultimately to model the building performance at which we could complete the total construction task within budget. This is the final scenario that led us to our proposal for the target values.

6.1 Business as usual

The first scenario to consider is one in which industry improves at 2% per year (by our best estimate, this has been the maximum rate of improvement over the past 10 years) and not much else changes.

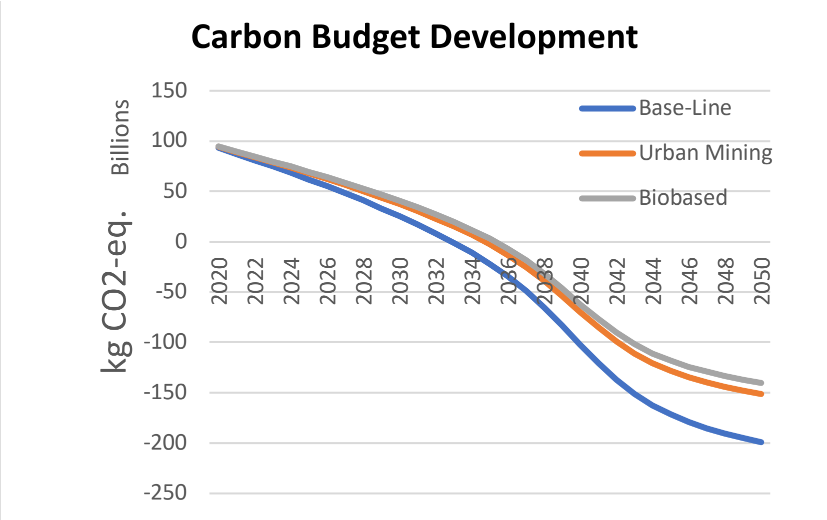

Figure 1. Business as Usual scenario elaboration. Baseline is based on 2% annual improvement in the industry. Renovation is included according to the Baseline renovation pace, see Annex 1.

The elaboration shows that in a Business-as-Usual scenario, the budget for the Base-line scenario is used up around 2032. Successful introduction of urban mining and/or biobased building on a large scale may delay this point until 2036.

Ultimately, we exceed the budget by approx. 150-200% percent.

We can separate new construction and renovation impacts from this scenario for additional insight. This teaches us that there is more renovation than new construction, but it will start later.

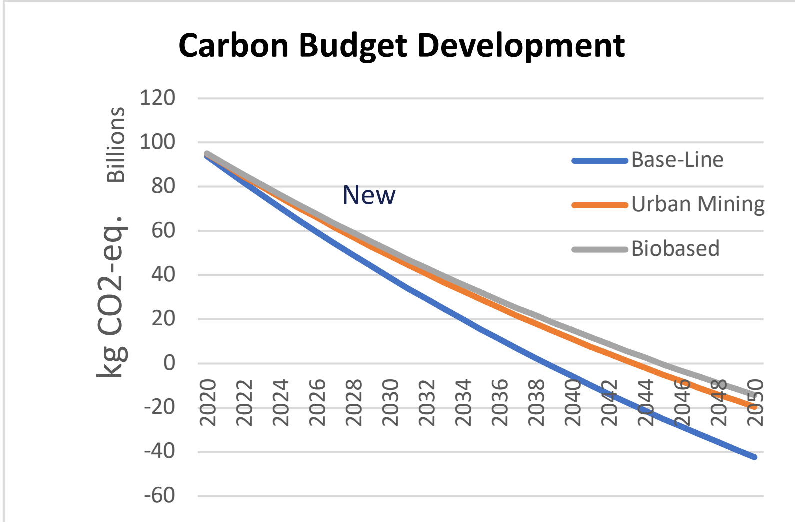

Figure 2. The new construction portion of the Business-as-Usual scenario

For renovation, we have distributed it over time using an S-curve. This is a difficult assessment to make, after all, we don't know how quickly we will ultimately complete this task together. The distribution that we have adopted as a basis is shown and explained in Annex 1. This one is important though, because with the annual improvement of industry, delaying implementation in our embodied scenarios leads to lower final emissions. On the other hand, of course, renovating the current stock at a later date means that operational energy use emissions would remain high for longer. Ultimately, an integral analysis (both embodied and operational) must be carried out. This integral analysis is not part of our study now, but the model is suitable for the inclusion of the operational part as well.

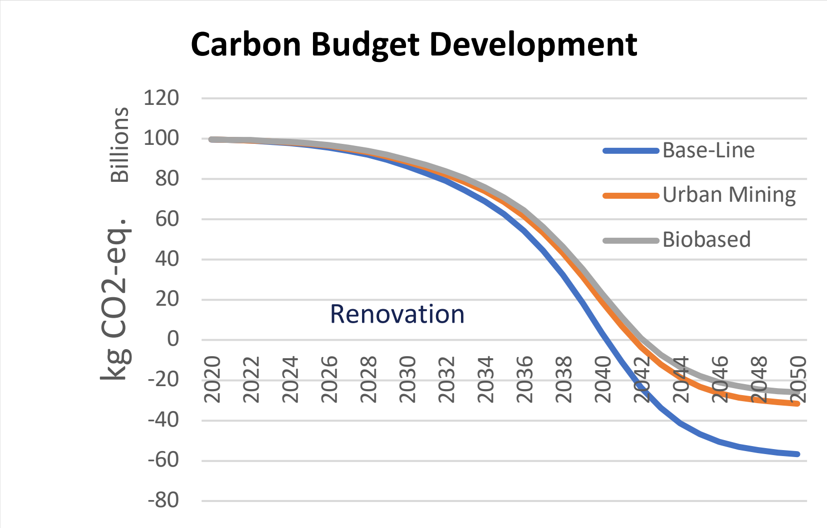

Figure 3. The renovation portion of the Business-as-Usual scenario.

6.2 A more ambitious industry scenario

The next scenario of interest is one in which the building materials industry transforms itself more rapidly. This transformation is aimed at phasing out fossil fuels and in practice will include energy conservation as well as innovations in materials and production. This is all summed up in an annual rate by which the industry lowers its embodied CO2 impact. To date, there have been no industry commitments beyond 2-3% improvement per year. As the Business-as-Usual scenario already demonstrates, this is insufficient to remain within the budget. So, we created scenarios that are more ambitious, to explore what this would then entail.

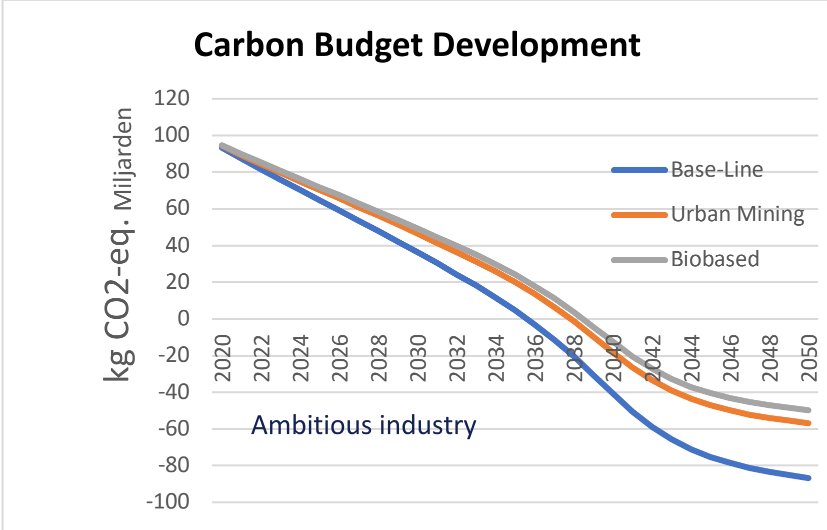

Figure 4. Scenario with 5% annual improvement in the industry. This is much faster than we have seen so far and more ambitious than any plan that is now in place from the industry.

6.3 Scenario target values

Finally, we did an exercise with the industry on ambitious (5%) and implementation in the best-in-class performance group and added to that a % reduction overall. We have increased this % reduction everywhere until the baseline scenario (without urban mining and biobased) could be executed within the budget. This appears to be the case with a 15% reduction. As a result, the settings for this scenario are:

1. Industry 5% annual improvement
2. Best in class performance
3. 15% better overall

From this scenario we can then read the CO_2 target values per m^2 for each building type. This does not mean that we expect urban mining or biobased to be unsuccessful, on the contrary.
These two approaches to action, we believe, will be a very important part of meeting the targets.

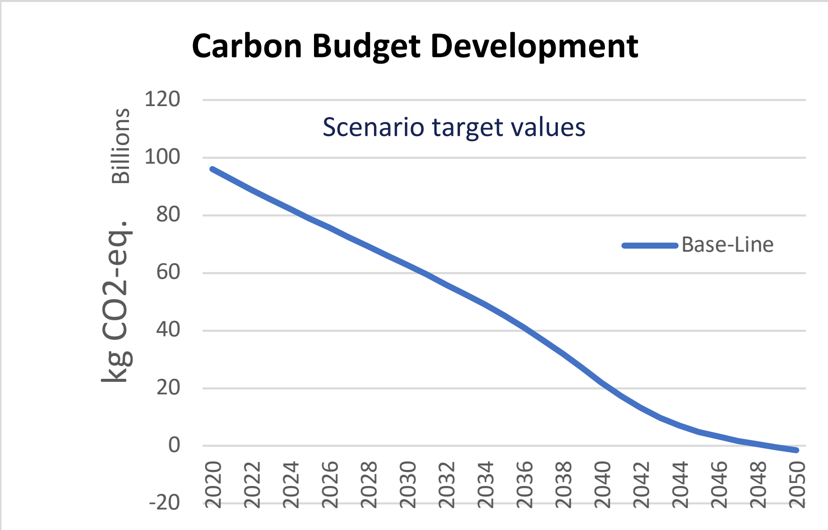

Figure 5. Optimal scenario to set target value. 15% better performance than the best-in-class group from our dataset.

7 Paris Proof target values

From the target values scenario, as presented in Section 6.3, we are proposing target values for embodied carbon per m^2 by structure type. With these target values, we come close or stay just within our CO_2 budget. The reduction of the target values towards 2050 is being presented indicatively. We would like to set the targets for 2021 now and they should be applicable for a certain number of years. It would be our suggestion that the target values be periodically reinforced. The Dutch Concrete Agreement can be taken as a reference. In it, ECI ceiling values are used for the purchase of concrete. These are tightened every 3 years according to the current proposal. Such a period could also be useful for Paris Proof embodied carbon target values.

Table 4. Proposal for target values for Paris Proof structures. Target value is indicated in embodied carbon per m2 of building. Embodied Carbon can be calculated according to the Paris Proof embodied carbon calculation protocol

Paris Proof target values	embodied carbon			
NEW CONSTRUCTION	kg CO_2-eq. per m^2			
	2021	2030	2040	2050
Residence (single-family home)	200	126	75	45
Residence (multi-family home)	220	139	83	50
Office	250	158	94	56
Retail real estate	260	164	98	59
Industry	240	151	91	54

The target values do not yet go to zero by 2050 because of the construction of our model; the industry values improve 5% each year from the previous year. That means they move asymptotically toward zero. We will leave that aspect open for now, but of course the target values should go to zero towards 2050. The discussion of whether zero is really possible and whether zero is really necessary is, we expect, going to be had, but not at this time.

Table 5. Proposal for target values for Paris Proof structures. Target value is indicated in embodied carbon per m^2 of building. Embodied Carbon can be calculated according to the Paris Proof embodied carbon calculation protocol.

Paris Proof target values	embodied carbon			
RENOVATION	kg CO_2-eq. per m^2			
	2021	2030	2040	2050
Residence (single-family home)	100	63	38	23
Residence (multi-family home)	100	63	38	23
Office	125	79	47	28
Retail real estate	125	79	47	28
Industry	100	63	38	23

8 References

1. **IPCC**: Climate Change 2021: The Physical Science Basis. sl : IPCC, 2021.
2. **CBS.** population register. [Online] https://www.cbs.nl/nl-nl/visualisaties/dashboard-bevolking/bevolkingsteller.
3. **National Environmental Database (NMD) Foundation.** Determination Method for the Environmental Performance of Construction Works 1.0, including amendment sheets Oct 2020 and Feb 2021. [Online] www.milieudatabase.nl.
4. **Industry.** Whole life carbon; a proposed amendment to The Building Regulations 2010. sl : UK Industry, July 20, 2021. AD-Z+proposal.

ANNEX 1. Explanation of the Excel model

Carbon Budget (Visual)
The main tab with the input tab, where selections can be made for the desired scenario, or 'turning the dials' and the graph showing the carbon budget until 2050.

'Carbon Budget Development' graph
Explanation: The result of the entire Excel. It visually shows the embodied Carbon Budget up to and including 2050.

'Default value' table
Explanation: These are the default values of the model.

- Introduction of the Carbon Budget in 2020 for the construction sector in the Netherlands (in MT and kg). The default input is 100MT.
- The default value for annual industry improvement. The assumption is that it will improve annually by 5%.

'For Projection' table
Explanation: Input for results 'Carbon Budget Development' graph. Here the carbon budget can be calculated for 3 different categories:

- Include only the results for renovation, new construction, or the entire task to calculate the remaining budget
- For certain types of buildings or the entire target
- Choice of the bandwidth of the results in relation to the benchmark
  - Low: best scoring out of the selection
  - Average: average value of the selection
  - High: worst scoring out of the selection

'Target value scenario' table
Explanation: If it is set to 0%, the results are displayed for the actual results without any additional improvement.
If we still do not stay within the carbon budget, we can enter here a percentage of how much better than the average we want to score.

This value can be modified just as often with trial and error until the graph indicates that we are staying within budget.

Occurring in the background

Embodied CO_2 impact

Explanation: Combines data from the 'CO2 impact database' and 'S- curve'. The total embodied CO2 per year for all possible options is displayed here.
Input for: Carbon Budget (Data)

Carbon Budget (Data)

Explanation: Tables with the sum of different building types from 'Embodied CO_2 impact'. The total embodied CO_2 budget is aggregated and displayed here per year.
Representation in tables: Total embodied CO2 budget per year combined

CO_2 impact databases

Explanation: Here are the CO_2 emissions for new construction and renovation per m^2 for all building categories in different scenarios. Each scenario is again split into three categories of environmental impact.
Scenarios

- Baseline
- Urban mining: Variation on the baseline, based on market share and CO_2 reduction in relation to the baseline
- Biobased: Variation on the baseline, based on market share and CO_2 reduction in relation to the baseline

Environmental categories

- Low
- Average
- High

Table 6 Basic settings for urban mining and biobased scenarios in our model

•	Market share		Reduction rates	
	Urban Mining	Biobased	Urban Mining	Biobased
Residence (single-family home)	20.00%	50.00%	80.00%	40.00%
Residence (multi-family home)	20.00%	50.00%	80.00%	29.00%
Office	20.00%	50.00%	80.00%	50.00%
Retail real estate	20.00%	50.00%	80.00%	42.00%
Industry	20.00%	50.00%	80.00%	42.00%

S-Curve

Explanation: Here, the new construction and renovation rate per building category is determined through 2050.

New construction

This assumes that 70,000 homes will be built each year until 2050 and 6,200,000m² per year for non-residential construction. They are then assigned to building categories:

- 'residence (single-family home)': 2/3 of 70,000 homes
- 'residence (multi-family home)': 1/3 of 70,000 homes
- 'office': 2/4 of 6,200,000m² per year
- 'retail real estate': 1/4 of 6,200,000m² per year
- 'industry': 1/4 of 6,200,000m² per year

Renovation

For all these building categories, the renovation rate has been determined. It follows an S-Curve that is equal to the parameters specified in the 'Carbon Budget (Visual)' tab. How many m² of building per building category need to be renovated is determined according to the current inventory, based on CBS statistics.

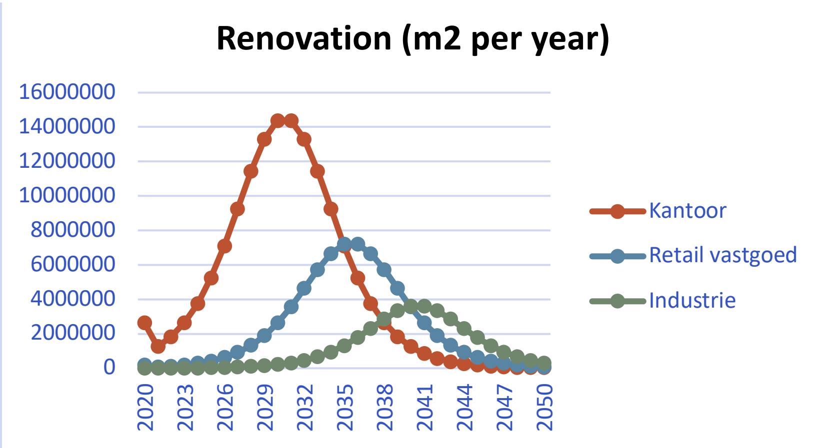

Figure 4 Example of how an S-curve distribution of the renovation volume over the years occurs in the model. The shape of the distribution can be controlled with parameters.

ANNEX 2. Dataset of embodied CO2-eq. per m2

GROUP	ADMINISTRATION	Results – Building total [kgCO2e/m2/a]								
Name	Project Name / Code	A1-3 Production	A4-5 Transport, Construction	B1-4 Use, Maintenance, Repair, Replacement	B5 Refurbishment	B6-7 Operational energy use, water use	C1-2 Deconstruction, Transport	C3-4 Waste processing, Disposal	(D) Reuse, recovery, recycling	total
Parameter code	admin_project_code	GHG_A123_m2a	GHG_A45_m2a	GHG_B1234_m2a	GHG_B5_m2a	GHG_B67_m2a	GHG_C12_m2a	GHG_C34_m2a	GHG_D_m2a	
Unit remarks	Please specify	[kgCO2e/m2	[kgCO2e/m2	[kgCO2e/m2	[kgCO2e/m2	[kgCO2e/m2	[kgCO2e/m2	[kgCO2e/m2	[kgCO2e/m2	[kgCO2e/m2
13	Woning S Tussen	4,146	0,207	0,044	MND	MND	0,288	0,000	-0,367	4,32
14	Woongebouw M	5,569	0,242	0,081	MND	MND	0,360	0,000	-0,454	5,799
15	Woning M Tussen	6,705	0,281	0,145	MND	MND	0,551	0,000	-0,461	7,220
16	Woning M Hoek	4,563	0,228	0,049	MND	MND	0,159	0,000	-0,390	4,610
17	Woning L vrij	4,753	0,209	0,082	MND	MND	0,240	0,000	-0,545	4,738
18	woonwagen	5,957	0,088	0,251	MND	MND	0,209	0,000	-0,883	5,622
19	Woongebouw XL	5,383	0,210	0,042	MND	MND	0,417	0,000	-0,538	5,514
20	Kantoor M	7,313	0,525	0,221	MND	MND	0,365	0,000	-0,646	7,778
21	Kantoor XL	6,818	0,426	0,184	MND	MND	0,273	0,000	-0,838	6,862
22	Onderwijsgebouw 1000m2	5,439	0,609	0,135	MND	MND	0,631	0,000	-0,721	6,092
23	Onderwijsgebouw 6000m2	4,331	0,500	0,081	MND	MND	0,471	0,000	-0,666	4,718
24	Bedrijfsgebouw 398 m2	5,623	0,513	0,200	MND	MND	0,606	0,000	-1,247	5,696
25	Bedrijfsgebouw 3276 m2	4,893	0,472	0,184	MND	MND	0,637	0,000	-0,956	5,231
26	Logiesgebouw collectief 1500 m2	4,628	0,467	0,082	MND	MND	0,570	0,000	-0,456	5,290
27	Logiesgegebouw individueel 1500 m2	5,418	0,432	0,111	MND	MND	0,595	0,000	-0,498	6,057
28	Woongebouw groepszorg	5,056	0,228	0,060	MND	MND	0,416	0,000	-0,408	5,352
29	Woongebouw groepszorg	4,586	0,165	0,048	MND	MND	0,393	0,000	-0,432	4,759
30	Woongebouw zorgcluster	4,140	0,171	0,011	MND	MND	0,205	0,000	-0,283	4,244
31	Woongebouw zorgcluster	6,700	0,269	0,041	MND	MND	0,410	0,000	-0,651	6,768
32	Overdekt winkelcentrum	6,277	0,611	0,154	MND	MND	0,772	0,000	-1,084	6,730
33	Woongebouw groepszorg	4,100	0,210	0,014	MND	MND	0,173	0,000	-0,297	4,200
34	woongebouw zorgcluster	4,731	0,244	0,041	MND	MND	0,296	0,000	-0,246	5,067
35	Overdekt winkelcentrum	6,350	0,623	0,166	MND	MND	0,824	0,000	-1,101	6,862
36	solitaire winkelunit	6,265	0,613	0,198	MND	MND	0,876	0,000	-1,066	6,886
37	zalencomplex	5,126	0,614	0,168	MND	MND	0,720	0,000	-0,740	5,888
38	grote zaal	6,419	0,737	0,205	MND	MND	0,827	0,000	-1,008	7,181
39	theaterzaal	6,049	0,608	0,088	MND	MND	0,633	0,000	-1,026	6,353
40	sporthal	9,939	0,579	0,194	MND	MND	0,424	0,000	-2,682	8,454
41	zwembad	18,118	0,900	0,169	MND	MND	0,988	0,000	-5,512	14,663
42	tussenwoning basis	3,490	0,256	-0,020	MND	MND	0,270	0,000	-0,328	3,669
43	tussenwoning meer glas	3,533	0,251	-0,020	MND	MND	0,269	0,000	-0,330	3,703
44	tussenwoning erker	3,586	0,271	-0,019	MND	MND	0,277	0,000	-0,343	3,771
45	tussenwoning uitbouw	3,694	0,286	-0,018	MND	MND	0,304	0,000	-0,355	3,912
46	tussenwoning dakkapel	3,618	0,257	-0,020	MND	MND	0,261	0,000	-0,330	3,786
47	Tussenwoning, hout en baksteen	2,887	0,174	0,006	MND	MND	0,281	0,000	-0,382	2,966
48	tussenwoning, bijlage B, hout, baksteen	2,879	0,174	0,006	MND	MND	0,281	0,000	-0,382	2,958
49	tussenwoning, bijlage B, hout, houtbekleding	2,845	0,135	0,016	MND	MND	0,431	0,000	-0,404	3,022
50	tussenwoning isolatie	3,524	0,256	-0,020	MND	MND	0,277	0,000	-0,328	3,710