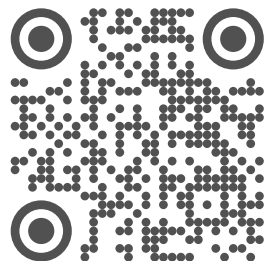


URBAN LCA

A DESIGN TOOL FOR CARBON & BIODIVERSITY ASSESSMENT
ON THE URBAN SCALE





The Urban LCA tool, the appendix,
and this report are an open resource
(copyleft) and available for download
and use here: www.effekt.dk/urbanlca

01 Introduction	05	Preface
	06	Key Learnings & Conclusions
02 The Urban LCA Tool	09	Vision & Purpose
	10	Climate Stability & Functioning Ecosystems
	11	Decision-Making in Urban Development
	12	Design Iteration
	13	Urban Indicators
	14	Urban Categories
03 Case Analysis	43	Project Overview
	46	Scenarios
04 Next Steps	63	From Urban LCA to Building LCA
	64	Areas for Future Research
	66	Project Team

01 Introduction

Preface

About

This report serves as a summary of our work on the Urban LCA beta tool for carbon and biodiversity assessment (beta version: usable and feature-complete, but may still have bugs or missing data before final release). The report does not include all content of the tool – instead, it gives an overview of the most important features and learnings. Additionally, an appendix explains background information on method, implemented data, and references.

Structure

The report is structured into four parts:

Part 1 outlines the overall structure of the report and presents the main learnings and conclusions of the project.

Part 2 as the main section explains the vision and purpose for different stakeholders, the tool itself, which indicators are used, and which parts of urban development are measured. For each urban category, it summarises the most important findings regarding carbon emissions, material footprint and biofactors.

In Part 3, the general tool gets tested on a concrete urban area – the development of Frederiksberg Hospital. It showcases the intended use of the tool: comparing different development scenarios in terms of their impact. It then summarizes the key findings.

The fourth and final part of the report outlines reflections, data gaps and limitations of the tool. It identifies areas for future improvements and relevancy of possible further tool versions.



Visualisation showing an overview of the Frederiksberg Hospital development, highlighting key aspects of urban planning—from mobility and green spaces to utilities and more.

Key Learnings & Conclusions

Following the tool development, we have tested Urban LCA on a real-world case: the Frederiksberg Hospital area. We have compared four different urban scenarios—ranging from full demolition and new construction to complete preservation and transformation. This analysis yielded valuable insights on their CO₂ emissions as well as biodiversity impact. In this section, we present the six key learnings from the study. Further details are provided later in the report.

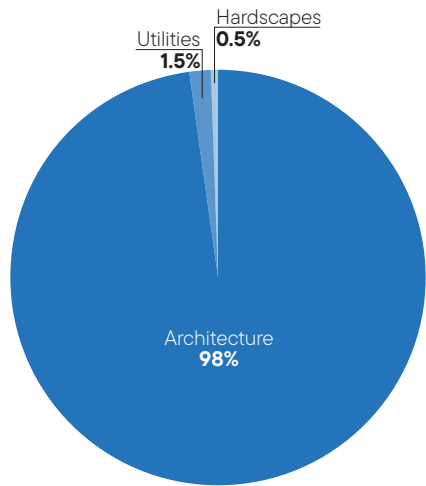
Learning 1

Buildings have the largest impact in urban development

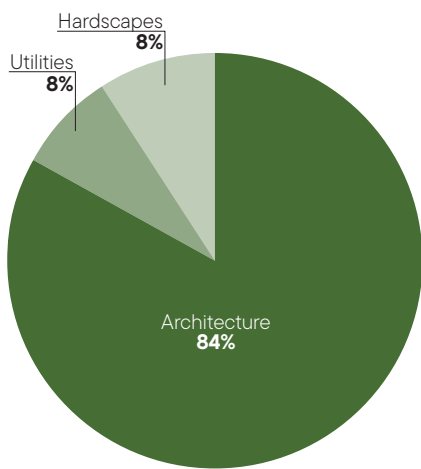
The architecture category (buildings) accounts for over 95% of carbon emissions and 80% of the material footprint.

The case analysis of Frederiksberg Hospital’s current planning reveals this as a clear priority.

While low-emission choices in Hardscapes, Softscapes, and Utilities are still relevant, early planning should focus primarily on architecture’s environmental impact.



Carbon emission split for Scenario 1A.



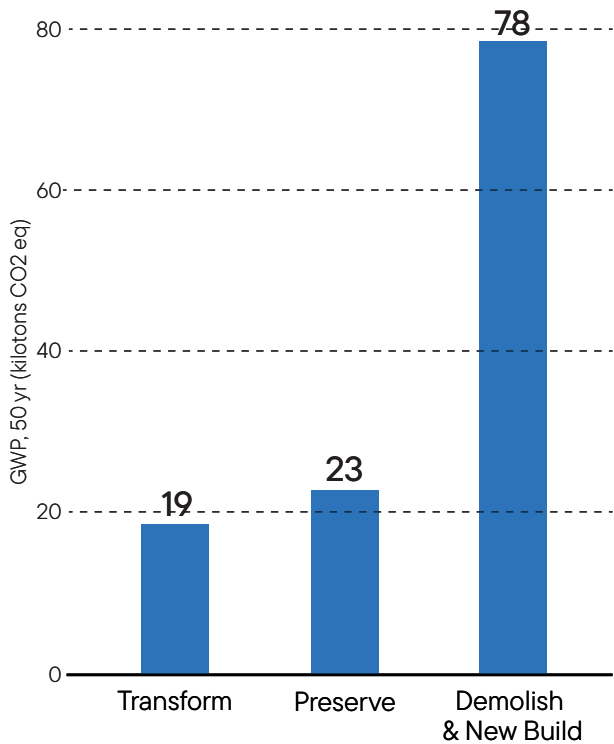
Material footprint split for Scenario 1A.

Learning 2

Transformation is better than preservation & new construction

Transformation significantly reduces carbon emissions and biodiversity impacts compared to new construction. Additionally, all transformation types—light, moderate, or deep—outperform preservation in overall results. **While preservation avoids embodied carbon emissions and additional material footprints from building activity, its poor operational energy performance places a substantial strain on the planet. In contrast, transformation involves material inputs during construction, but the emissions savings achieved through energy retrofitting outweigh these material impacts.**

This aligns with findings at the European level, where the European Commission emphasizes the need to renovate 146 million buildings by 2050 to reach Net-Zero (European Commission, 2020, ‘Renovation Wave: The European Green Deal’).



Comparison of carbon emissions for different activities.

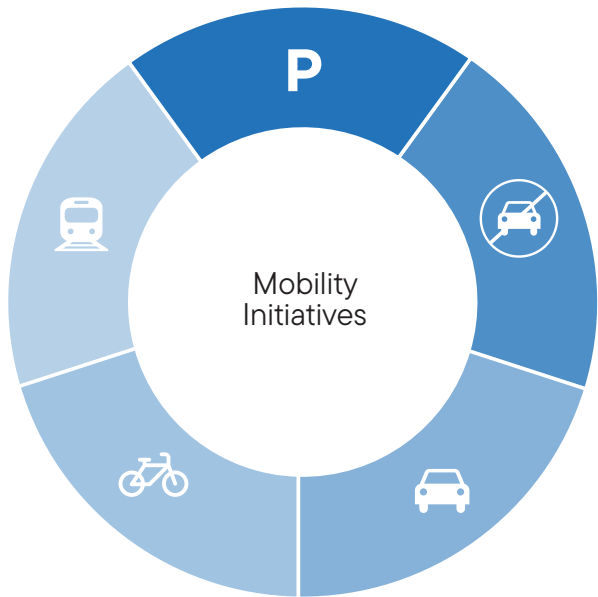
Learning 3

Municipal mobility initiatives save crucial emissions

The mobility section of the tool enables planners to adjust mobility initiatives and review the resulting emission reductions.

The results demonstrate significant savings, with municipalities playing a key role in this process.

Through their municipal plans and local plans, municipalities can implement measures such as parking restrictions, incentives for increased bicycle use, planning of additional public transport, and revisions to parking norms, amongst others.

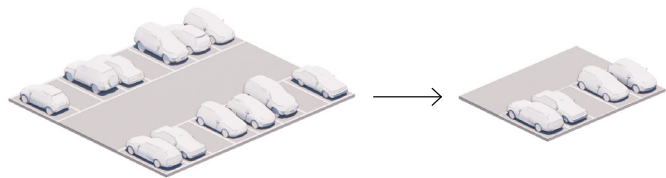


Five mobility initiatives can be chosen in Urban LCA.

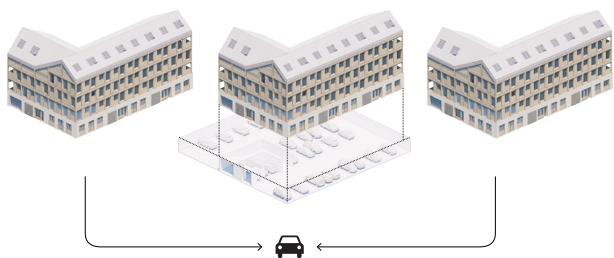
Learning 4

Parking conclusions

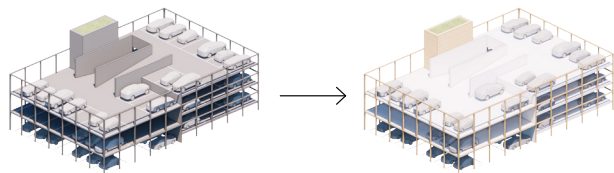
Number of parking spots: The most effective way to reduce impact is by decreasing the number of parking spaces. Stricter parking regulations result in smaller parking facilities, which lead to a lower impact.



Centralised parking basements: Centralized parking basements create lower emissions and material footprint compared to individual parking basements located beneath each building. Urban planners should try to combine multiple parking basements into larger, centralised ones.



Parking houses: Parking houses create lower impacts than parking basements. As an additional study in the Frederiksberg Hospital project, we found minimal differences between concrete and hybrid parking construction. Timber is used for e.g. columns but requires larger dimensions, offsetting savings. Ramps, decks, and elevators are usually still in concrete.



On-ground parking: Out of the three parking options in Urban LCA, on-ground parking is the most environmentally friendly, due to its minimal material use. However, this does not weigh in other possible space uses and only focuses on comparing the parking options between each other.



Learning 5

Choose a sustainability class as early as possible

Scenarios 1A and 1B differ only in their sustainability classes: BR25 and Reduction Roadmap 2025. Consequently, Scenario 1B achieves lower emissions and material footprints.

Setting clear, science-based targets from the beginning is crucial toward regeneration. This should not be solely left to later stages of building projects or tools such as LCAbyg. **Establishing early targets minimizes risks related to compliance with financial regulations, such as the EU Taxonomy, appeals to responsible investors, and ensures a future-proof development without costly redesigns due to evolving environmental regulations. Additionally, it enables the preparation of early tender documents, partnership agreements, codes of conduct, and due diligence processes, ensuring the right stakeholders and planners are engaged from the beginning.**

Business-as-usual	9.9
BR25	9.0
Low emissions class	7.2
Reduction Roadmap 2025	7.6
Reduction Roadmap 2027	4.7
Reduction Roadmap 2029	1.8

Limit values of the sustainability classes in Urban LCA (A1-A5, B4, B6, C3-C4, new construction, apartments, [kg CO₂/m²/year])

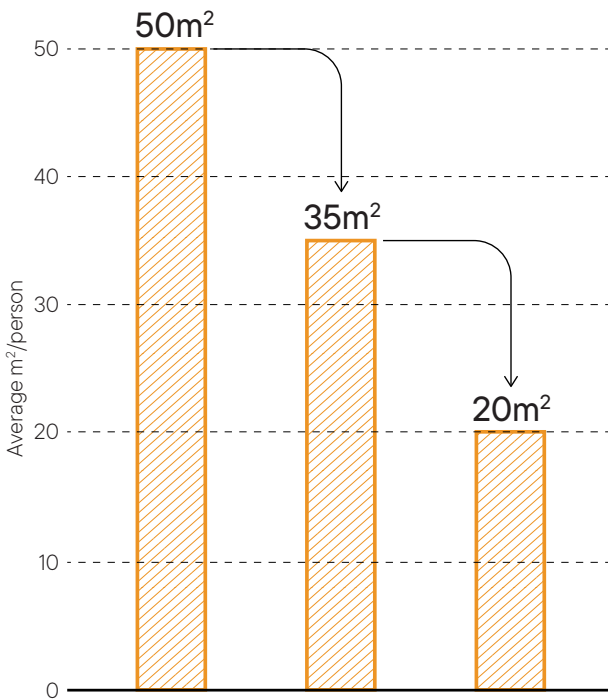
Learning 6

m²/person is an effective strategy for reducing impact

Part of the reason why scenario 3 has the lowest carbon emissions and material footprint is due to its low overall square meters.

Since the scenario is planned for the same amount of residents as the other scenarios, this leads to significantly lower living space per resident.

This raises the question of how much space we need to live. The Danes' land use per person has been increasing for a number of years and is now at 54 m² per person. Lower land use per person is an effective measure to reduce emissions.



Carbon and biodiversity impact reduction through less m² per person.

02

The Urban LCA tool

Vision & Purpose

It has become clear that in recent years extensive research has been carried out into the climate impact of buildings, just as tools and data have been developed to calculate and evaluate emissions of building construction through Building LCAs. However, there is far less data and fewer examples of quantification of the climate impact from the urban areas of which the buildings are a part, as well as their impact on biodiversity. This despite the fact that the urban context greatly influences carbon emissions through, for example, infrastructure, mobility, landscape, buildings and resident composition.

This creates a need for an industry tool, which identifies the data needed to create a common method for evaluating urban areas, and which at the same time shows approaches to CO₂ reductions and increased biodiversity on an urban scale. This will help to lift the sustainable agenda early into the planning phase, just as for city planners and builders across private and public projects it will be able to contribute to designing and developing districts with lower climate impacts, which today is a difficult task due to a lack of tools, data, and best practice cases.

The Urban LCA tool is designed for use in the early design phases, as the integrated data is based on statistical values that involve some uncertainty. Therefore the tool should primarily be used to identify trends rather than provide exact values and it does not act as a replacement for detailed tool of later stages. For more information on the data, methods and definitions of terms, please refer to the appendix. For the later design phases, Building LCA tools, such as LCAbyg, should be used instead.

Beyond practical benefits, the tool contributes to a cultural shift in the building industry, encouraging a proactive approach to sustainability. By integrating environmental data into the design dialogue, the tool acts as a bridge between creativity and sustainability. **The tool helps to focus on CO₂ and biodiversity impacts in the early phases of urban development so that they become an integral part of the decision-making process.**

For Municipalities

Through the tool, municipalities can include carbon and biodiversity impact thinking into their early planning and decision making for future development of urban areas. **Once programs and square meters are added to a project, the tool allows you to measure and compare their impact – without the need for the design of later stages.**

By providing a practical and science-based tool, it supports city planners to adhere to municipal climate targets regarding carbon emissions, biofactors, and biodiversity goals and integrate them into tenders, briefs and planning documents. Since the tool is open source, municipalities can collaborate to develop and improve their own tools for sustainable urban development.

Construction					CO ₂ emissions								Biodiversity		
					Existing	New					Total		On-site	Off-site	
Activity	Amount	Unit	Construction	Sustainability class	C3-C4	A1-A3	A4-A5	B1	B4	B6	C3-C4	Total	Total, 50 yr	Biofactor [-]	Material footprint [ton]
					[kg GWP]	[kg GWP]	[kg GWP]	[kg GWP]	[kg GWP]	[kg GWP]	[kg GWP]	[kg GWP]	[kg GWP]		
Building site A					GWP	GWP	GWP	GWP	GWP	GWP	GWP	GWP	GWP		
													60,000		98,000
Transformation - deep	4,412	m²	Residential - Apartments	BR25 regulation	0.1	0.5	0.2	0.0	0.8	0.9	1.7	4.2	920	0	288
Transformation - deep	3,235	m²	Office	BR25 regulation	0.3	1.0	0.3	0.0	0.9	1.3	1.6	5.5	884	0	214
Transformation - moderate	836	m²	Residential - Apartments	BR25 regulation	0.1	0.4	0.1	0.0	0.8	1.1	1.7	4.2	175	0	26
Transformation - moderate	244	m²	Residential - Row housing	BR25 regulation	0.6	0.8	0.3	0.0	0.8	1.4	1.5	5.3	64	0	9
Transformation - moderate	1,833	m²	Office	BR25 regulation	0.3	0.7	0.2	0.0	0.9	1.7	1.6	5.5	501	0	59
Transformation - moderate	12,693	m²	Health	BR25 regulation	0.3	0.7	0.2	0.0	1.0	1.8	1.8	5.8	3,681	0	685
Transformation - moderate	1,133	m²	Other	BR25 regulation	0.3	0.7	0.2	0.0	0.9	1.8	1.8	5.8	329	0	59
Transformation - light	22,032	m²	Residential - Apartments	BR25 regulation	0.1	0.1	0.0	0.0	0.6	1.7	1.7	4.2	4,673	0	131
Transformation - light	3,180	m²	Residential - Row housing	BR25 regulation	0.0	0.1	0.1	0.0	0.9	2.0	1.5	4.5	722	0	23
Transformation - light	4,670	m²	Office	BR25 regulation	0.0	0.1	0.0	0.0	0.8	2.7	1.6	5.3	1,243	0	28
Transformation - light	332	m²	Health	BR25 regulation	0.0	0.1	0.0	0.0	0.8	2.8	1.8	5.6	94	0	3
Transformation - light	495	m²	Other	BR25 regulation	0.0	0.1	0.0	0.0	0.8	2.9	1.8	5.7	140	0	5
New building	53,552	m²	Residential - Apartments	BR25 regulation	0.0	4.4	1.5	0.0	0.8	0.6	1.7	9.0	24,117	0	37,213
New building	6,877	m²	Residential - Row housing	BR25 regulation	0.0	3.9	1.5	0.0	0.7	0.6	1.5	8.2	2,822	0	5,800
New building	6,677	m²	Office	BR25 regulation	0.0	4.2	1.5	0.0	0.7	0.9	1.6	9.0	3,007	0	4,718
New building	461	m²	Health	BR25 regulation	0.0	4.5	1.5	0.0	0.8	1.0	1.8	9.5	219	0	546
New building	665	m²	Daycare institution	BR25 regulation	0.0	4.5	1.5	0.0	0.8	0.9	1.8	9.5	316	0	668
New building	8,733	m²	Other	BR25 regulation	0.0	4.5	1.5	0.0	0.8	1.0	1.8	9.5	4,151	0	9,957
New building	12,901	m²	Parking basement	BR25 regulation	0.0	8.9	1.2	0.0	0.0	0.0	0.5	10.5	6,771	0	37,232
Preserve	738	m²	Residential - Apartments	BR25 regulation	0.0	0.0	0.0	0.0	0.8	2.0	1.7	4.5	167	0	0
Preserve	187	m²	Office	BR25 regulation	0.0	0.0	0.0	0.0	1.0	3.2	1.6	5.9	55	0	0
Preserve	1,491	m²	Daycare institution	BR25 regulation	0.0	0.0	0.0	0.0	1.1	3.3	1.8	6.2	453	0	0
Preserve	11,333	m²	Other	BR25 regulation	0.0	0.0	0.0	0.0	1.1	3.4	1.8	6.3	3,575	0	0
Demolish	165	m²	Residential - Apartments	BR25 regulation	1.7	0.0	0.0	0.0	0.0	0.0	0.0	1.7	14		0
Demolish	342	m²	Office	BR25 regulation	1.6	0.0	0.0	0.0	0.0	0.0	0.0	1.6	28		0
Demolish	11,141	m²	Health	BR25 regulation	1.8	0.0	0.0	0.0	0.0	0.0	0.0	1.8	977		0
Demolish	2,496	m²	Daycare institution	BR25 regulation	1.8	0.0	0.0	0.0	0.0	0.0	0.0	1.8	220		0

The Urban LCA excel tool

For Businesses & Developers

For a company that wants their projects to follow planetary boundaries, it may currently be difficult to ensure this due to a lack of tools and data. Similarly to municipal use, developers can apply Urban LCA in their program and business model thinking and create scenarios based on preliminary square meter calculations.

With the increase of financial regulations like EU Taxonomy and CSDR (regulatory company frameworks for impact and risk reporting), compliance is becoming an increasingly pressing focus. Urban LCA supports the creation of carbon and biodiversity targets and their monitoring throughout a development project. **Furthermore, the results of this tool can be included in early tendering processes.**

For Planners

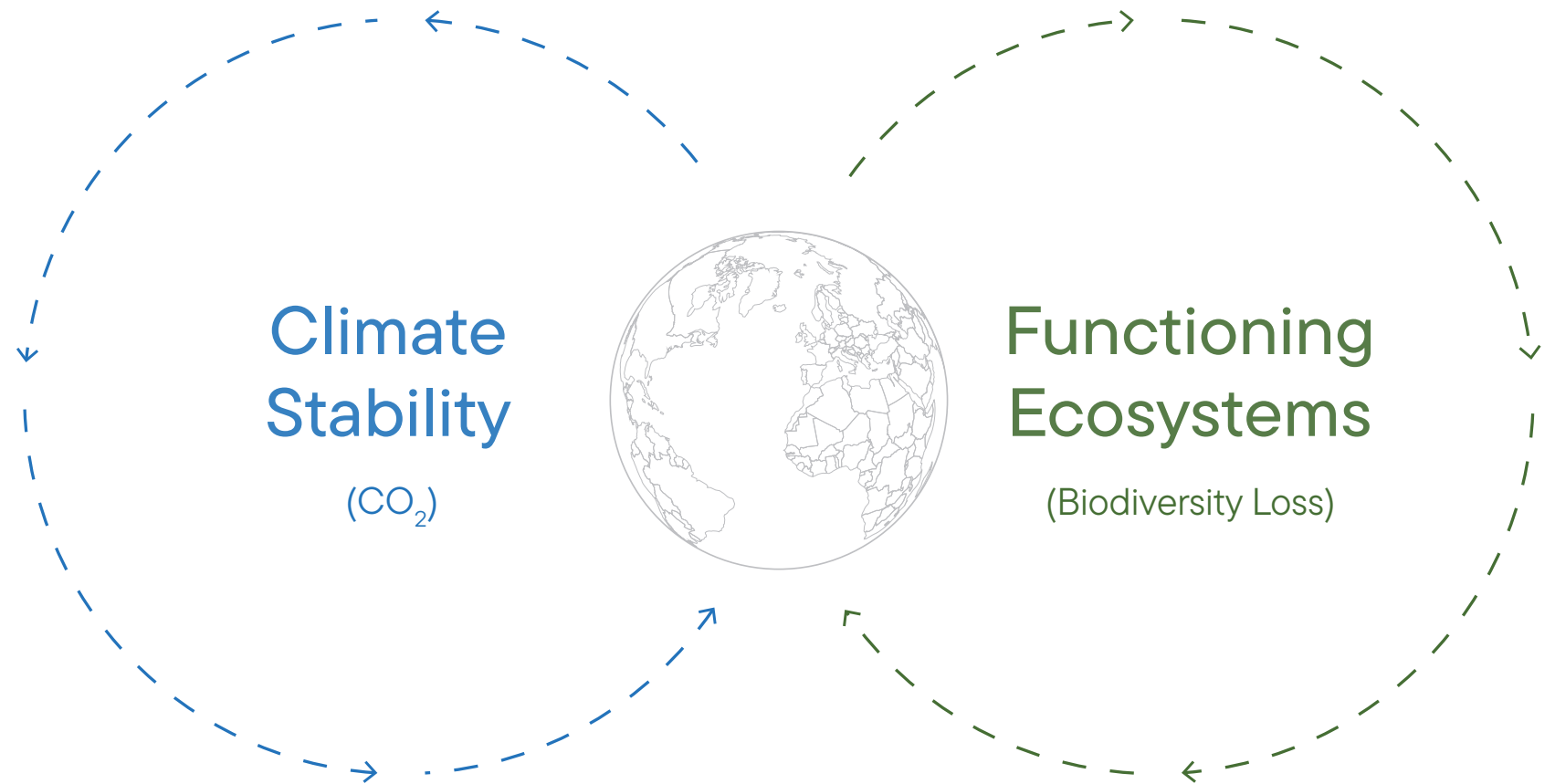
Planners can use Urban LCA in the early design phases to compare carbon and biodiversity impacts of their design studies, despite the low amount of detail and known parameters at these stages. This leads to the generation of accessible knowledge and data about climate impact and biodiversity in urban areas, which can contribute to more fact and evidence-based planning and development of sustainable city planning.

Climate Stability & Functioning Ecosystems

The planetary boundaries are scientifically defined limits for key Earth systems that, if crossed, risk triggering large-scale, irreversible environmental change.

Among the nine boundaries, Climate Stability and Functioning Ecosystems are the two most directly influenced by urban development. These systems are deeply interconnected—functioning ecosystems support climate stability, and a stable climate is essential for ecosystems to thrive.

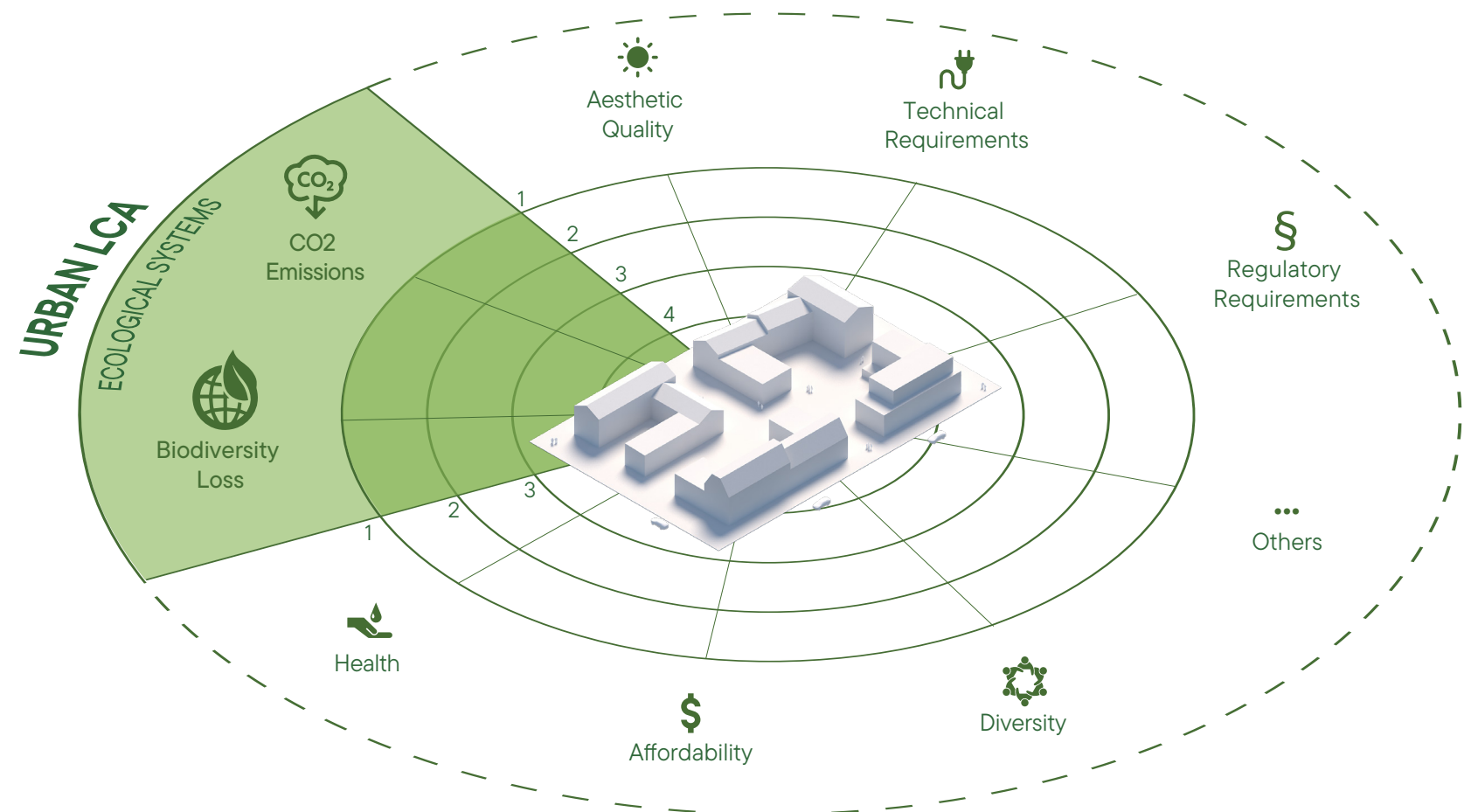
To avoid exceeding the planet's ecological limits, urban developments must minimise their pressure on these systems. Urban LCA therefore uses carbon emissions and biodiversity impact as its two main indicators.



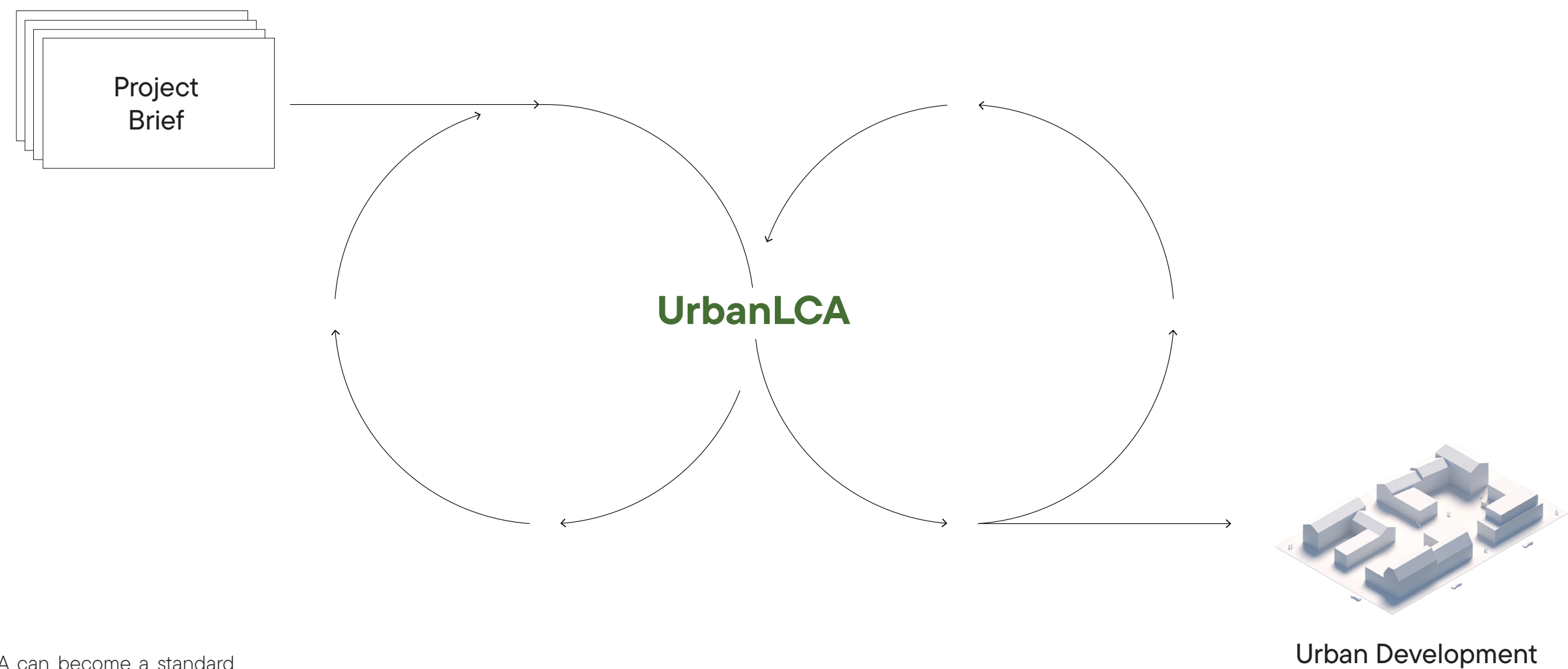
Decision-Making in Urban Development

Urban LCA focuses on carbon emissions and biodiversity impact. It is important to understand that these are two essential parameters for a thriving planet - but there are more factors to consider in your urban decision-making. The tool does not consider other decision-making factors such as regulatory, financial, social, aesthetic, technical or health and consequently can not be used as the only measurement for high-quality development.

Urban LCA therefore serves as an additional layer and quantitative support in decision-making and cannot be seen as a replacement of other, already established design processes.



Design Iteration through Urban LCA



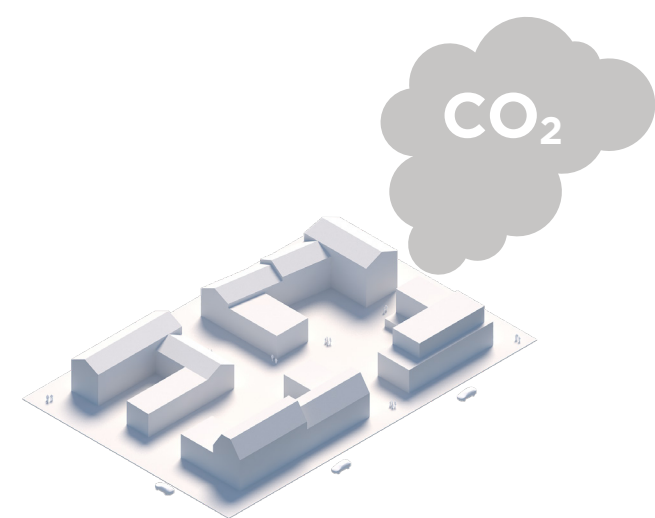
As an early-phase design tool, Urban LCA can become a standard tool in the initial stages of urban planning. Unlike traditional processes, where environmental impacts are assessed in later stages, this tool enables planners to make informed decisions early, when designs are still fluid and adaptable. Instead of using this tool to deliver impact results once all decisions have been made, the purpose is to influence the decisions with quantitative information. It delivers instant feedback on carbon emissions and biodiversity impacts, supporting iterative and evolving design workflows. **By allowing comparisons of multiple scenarios, the tool helps refine initial designs based on its results.**

Together with the general principles for optimisation presented later in this report, this significantly reduces the risk of redesigns in later phases.

This is particularly important in meeting sustainability targets, and aligning with regulatory requirements. The tool allows stakeholders to monitor their impact from the very beginning towards later stages, **where Urban LCA can then be replaced by more accurate Building LCA tools.**

Urban Indicators

Carbon Emissions



CO₂ eq / m²

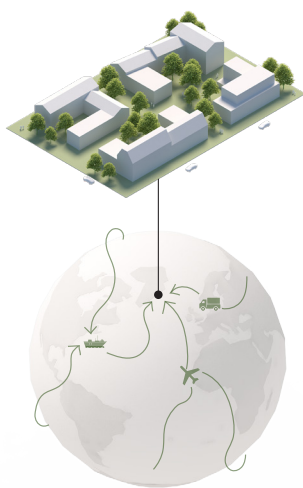
The tool measures CO₂eq per square meter to quantify carbon emissions from urban development activity. In this report, the term “carbon” and “CO₂eq” are used interchangeably, both meaning carbon equivalents. Both “total tons CO₂” as well as “kg CO₂/m²/year” are used in this project.

Biodiversity Impact



Biofactor (on-site)

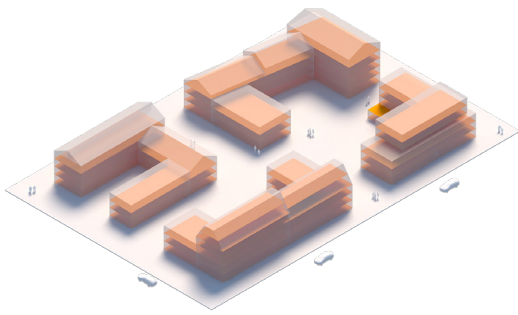
The biofactor is used to measure urban greenery and to compare before and after site conditions. However, its relevance to broader environmental impacts is minimal when considering the full supply chain and an improvement in biofactor does not necessarily lead to an improvement in biodiversity. Urban LCA uses the DGNB method, but can be changed to a biofactor method that has been chosen for a specific project, e.g. a biofactor method of a municipal plan.



Material footprint (off-site)

To understand how construction impacts nature beyond the building site, the Urban LCA tool uses “material footprint”—which represents the weight of the used materials. While there are other ways to measure impacts on biodiversity, they usually need a lot of detailed data and complex analysis. Material footprint is a simpler and more accessible option, and still gives a good idea of environmental impact—it matches closely (73%) with more advanced methods. Off-site biodiversity is calculated for Architecture, Hardscapes, and Utilities, but not for Softscapes and Mobility.

Building Area



Total m² and m² / person

To compare scenarios with varying built square meters, the tool includes an indicator for total building area. This only refers to the Architecture category and does not include m² from the other categories of Softscapes, Hardscapes or Utilities. The report also highlights differences in m² per resident for the different scenarios to account for resident density.

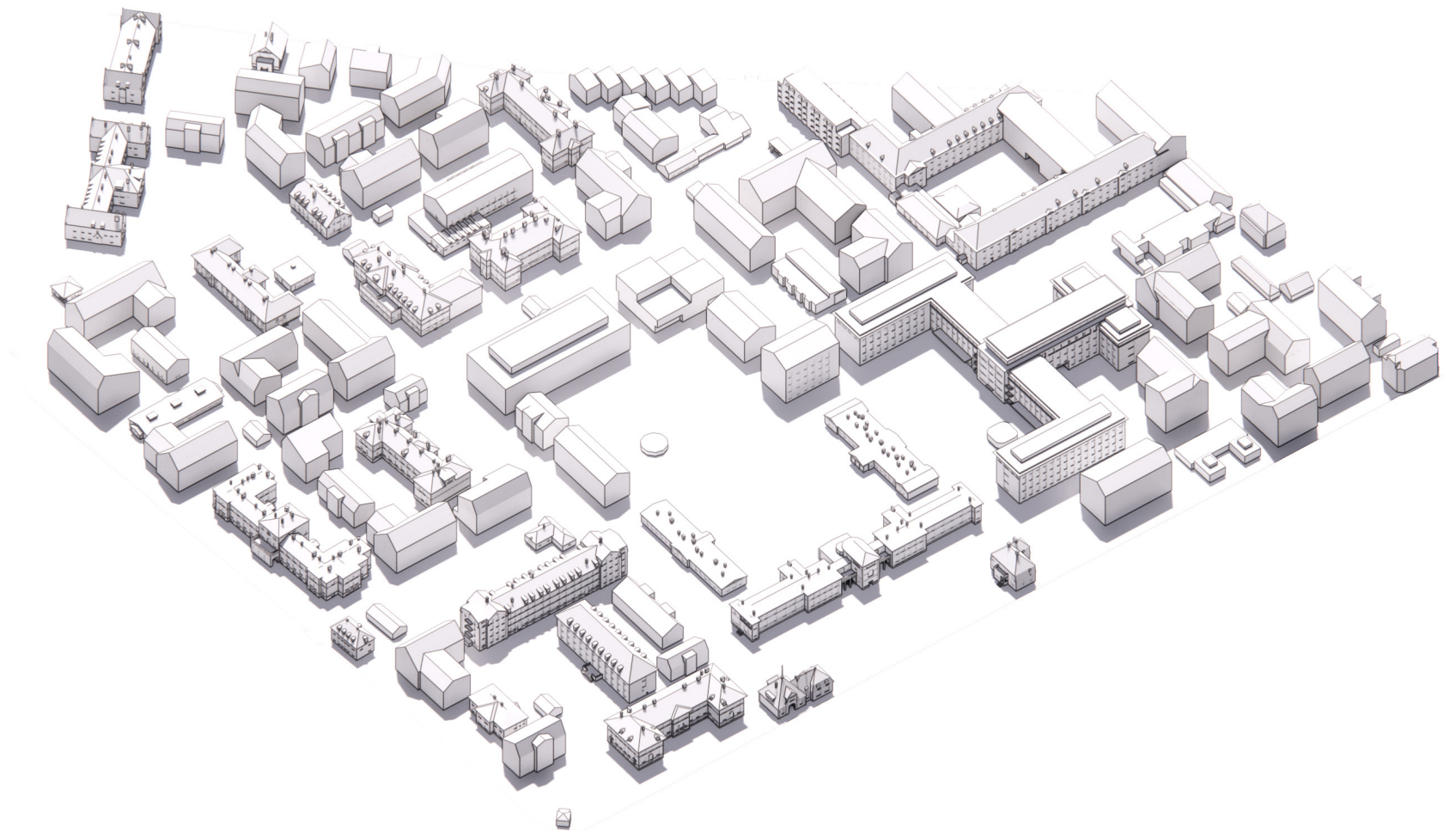
Urban Categories

OVERVIEW

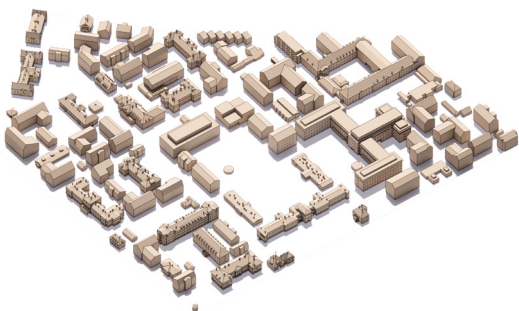
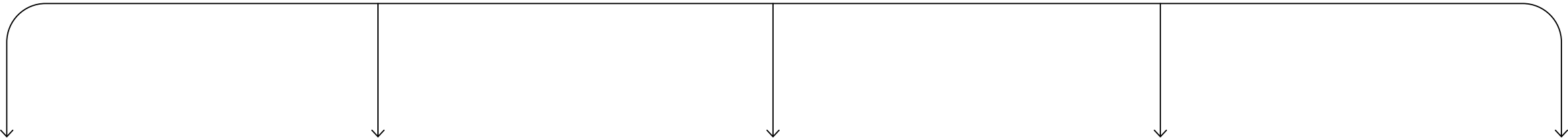
The tool considers five key aspects of an urban area: Architecture, Softscapes, Hardscapes, Utilities, and Mobility.

The first three categories—Architecture, Hardscapes, and Softscapes—function as **design tools**, allowing users to assess and refine their designs based on the tool results. The Utilities category serves as an **inventory tool** (providing a complete picture of urban development impacts) rather than a design tool, since choosing between different utility types isn't possible. The Mobility category offers suggestions for emission reduction and acts as a **behavioural tool**.

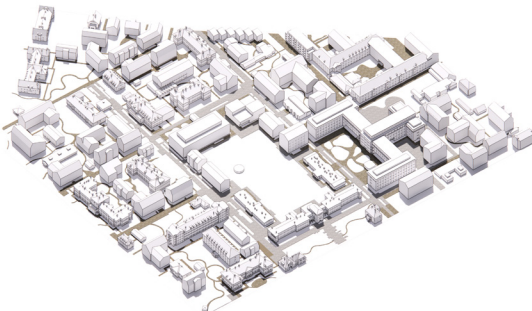
The following pages provide detailed descriptions of each category, including available options that tool users can choose and some of the key emission impacts. Detailed data information can be found in the appendix.



Urban Development



Architecture
(design tool)



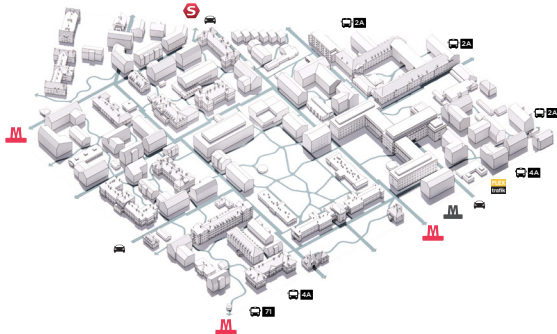
Hardscapes
(design tool)



Softscapes
(design tool)



Utilities
(inventory tool)



Mobility
(behavioural tool)

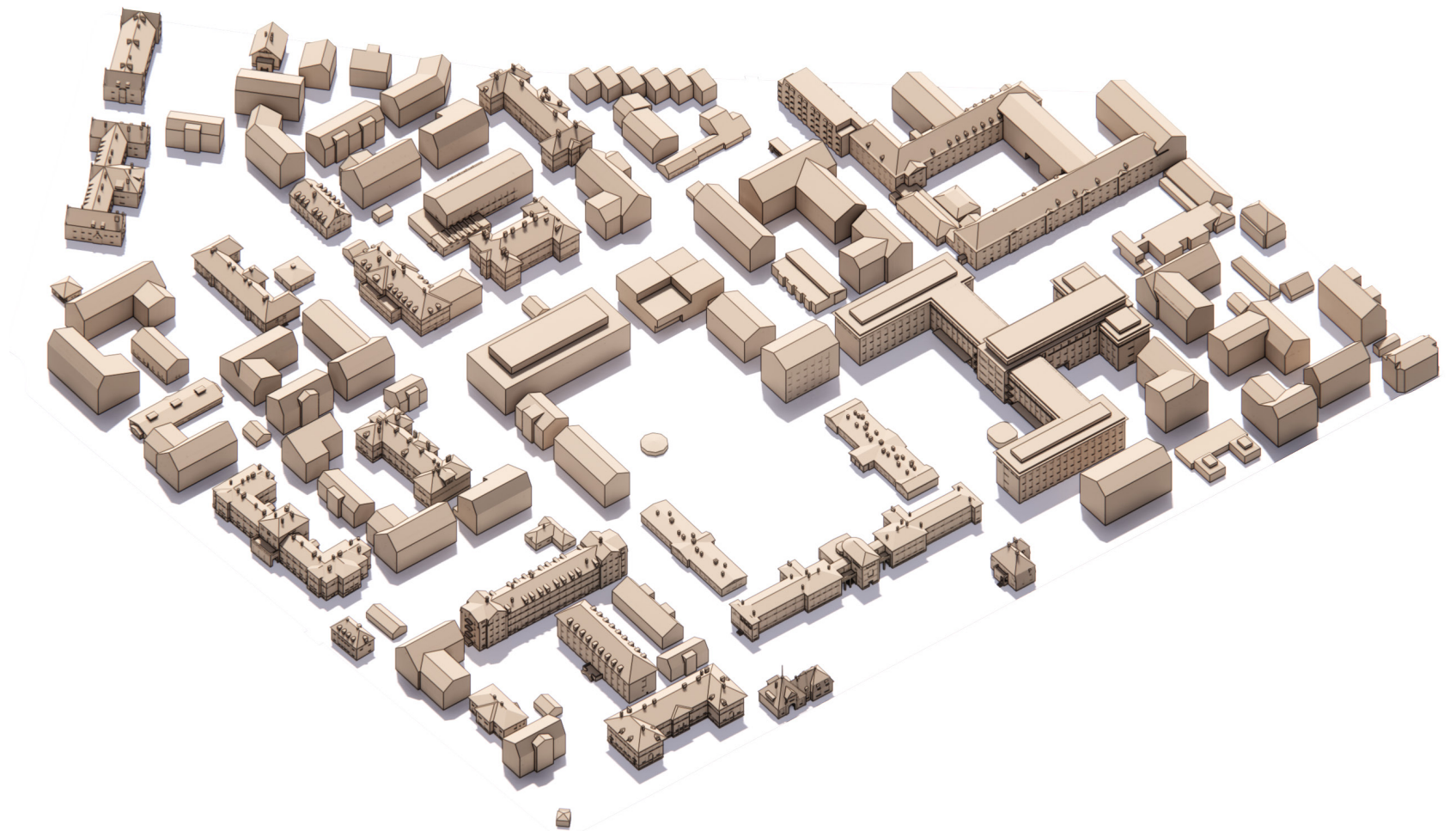
ARCHITECTURE

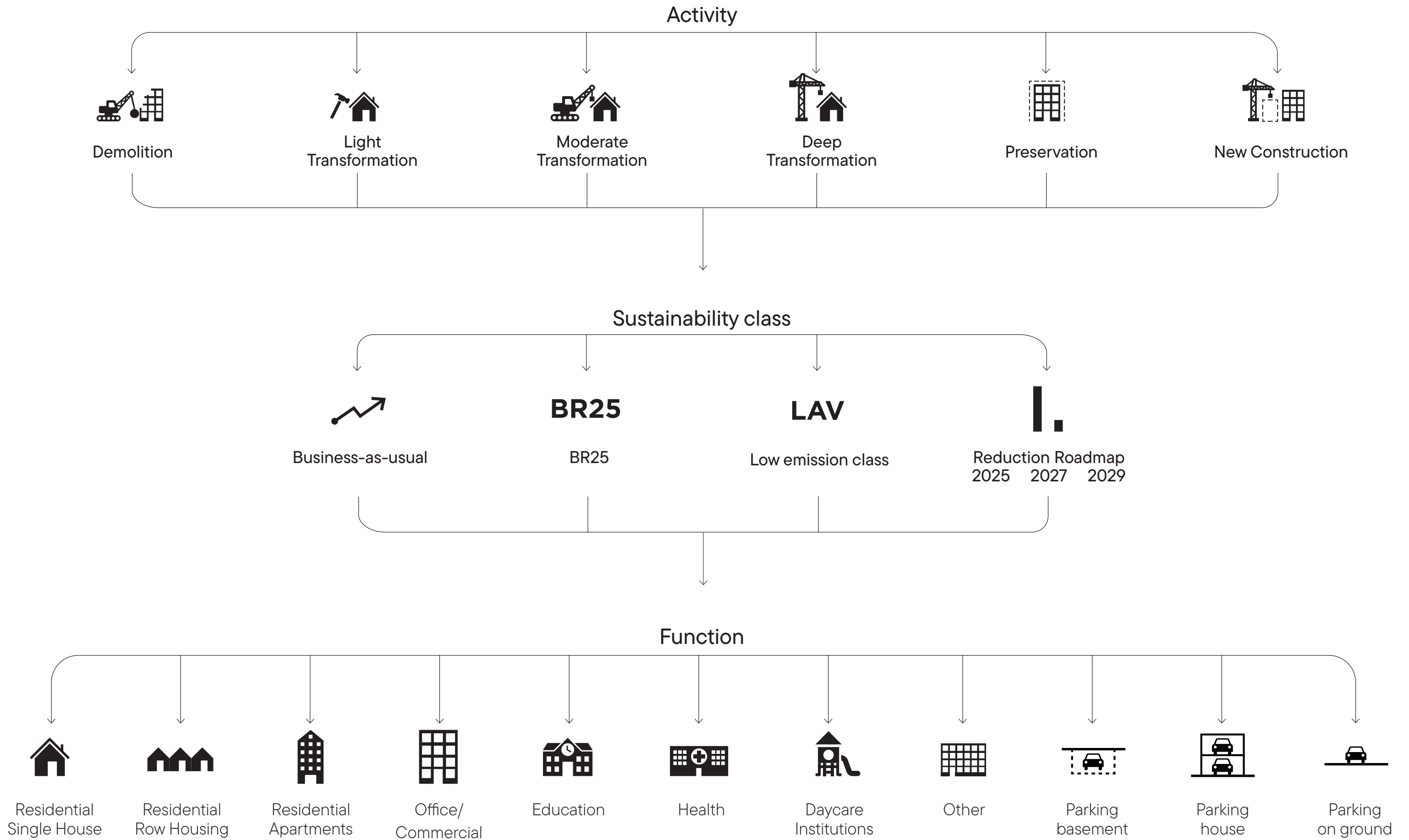
In the architecture category, users can select options for Activity, Sustainability Class, and Function.

Activity lets you choose between six different options of what you are constructing. Demolition involves the complete removal of a building, Light transformation focuses on extending the building's lifespan with minor improvements, deep transformation additionally targets significant upgrades, such as roof and façade replacements, to enhance energy efficiency and preservation leaves the building unchanged without any construction. New construction covers all activities required to build a new structure.

The Sustainability Class offers six levels of carbon emission limits, from business-as-usual (current averages) to Reduction Roadmap 2029 (science-based limit values for the Danish construction sector, based on a yearly reduction of emissions: www.reductionroadmap.dk).

Finally, Function allows users to choose from 11 building types. These functions influence emissions and biodiversity impacts due to differences in program, layout, and structure.





Architecture

Comparison of CO₂ emissions for 1000 m² for all functions, according to BR25
(Emissions for on-ground parking are assumed as 0):



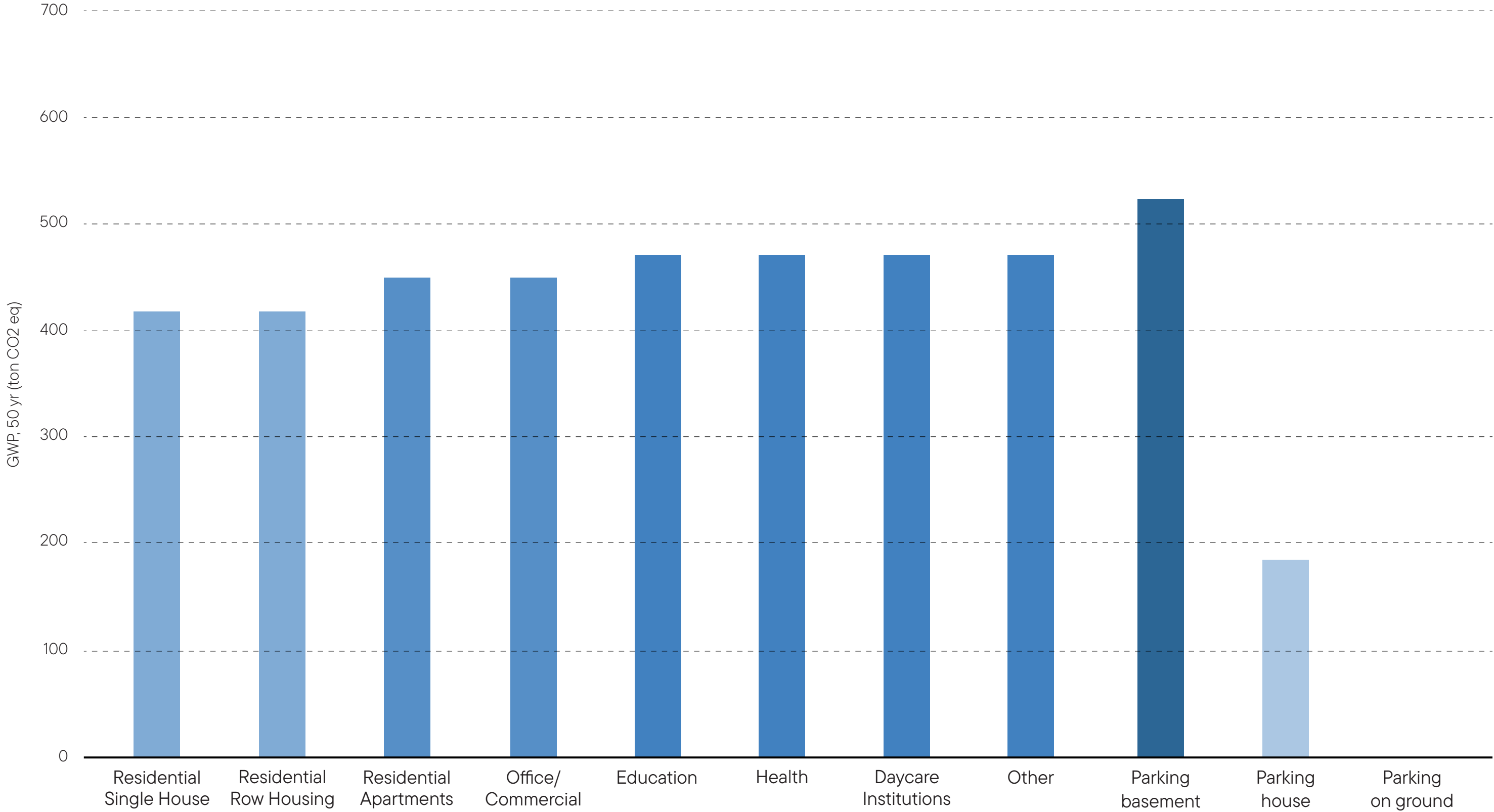
CO₂
emissions



All functions
1000 m²



BR25



Architecture

Comparison of material footprints for 1000 m² for all functions, according to BR25
(Material footprints for on-ground parking are assumed as 0):



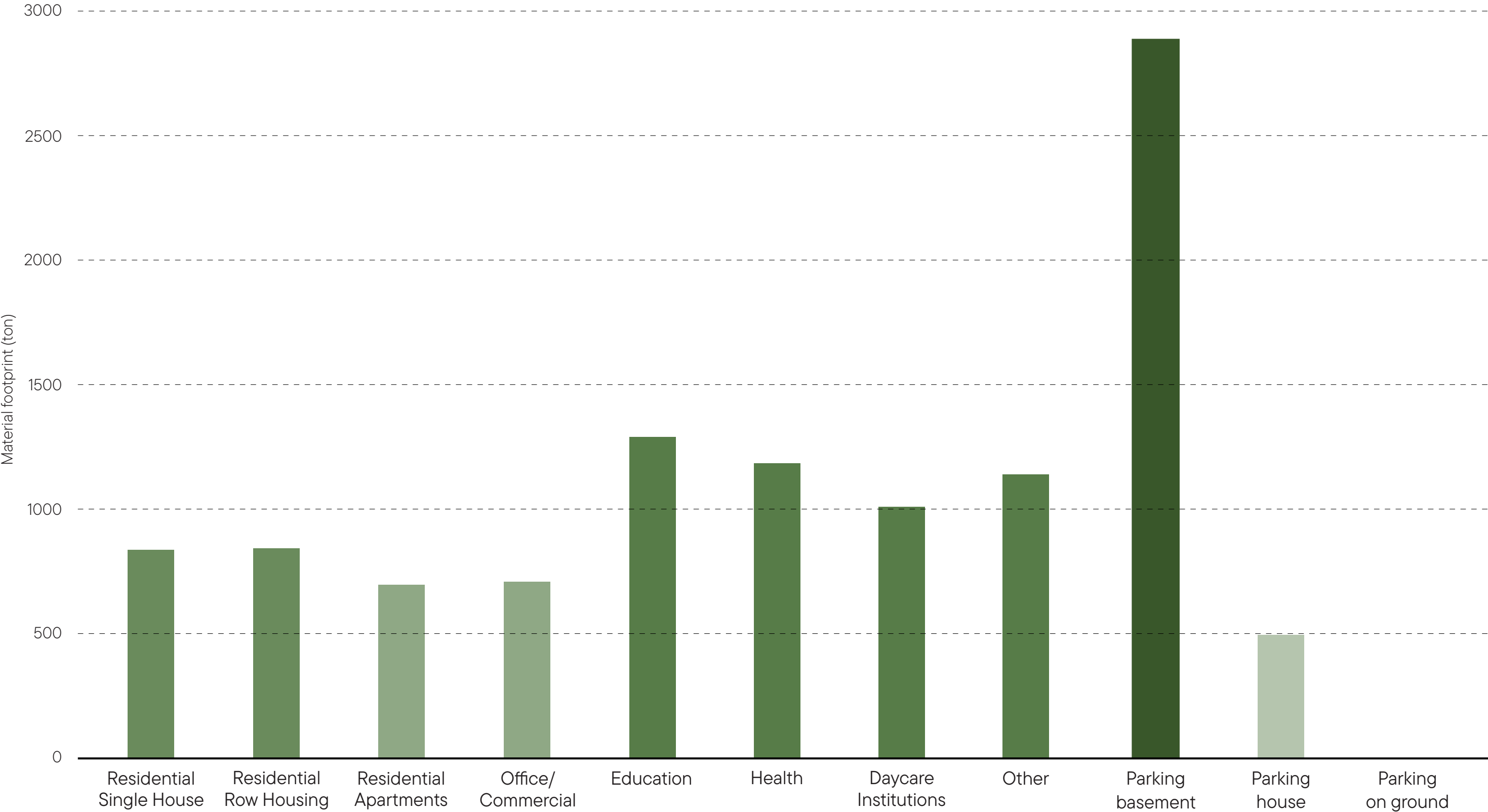
Material footprint



All functions 1000 m²



BR25



Architecture

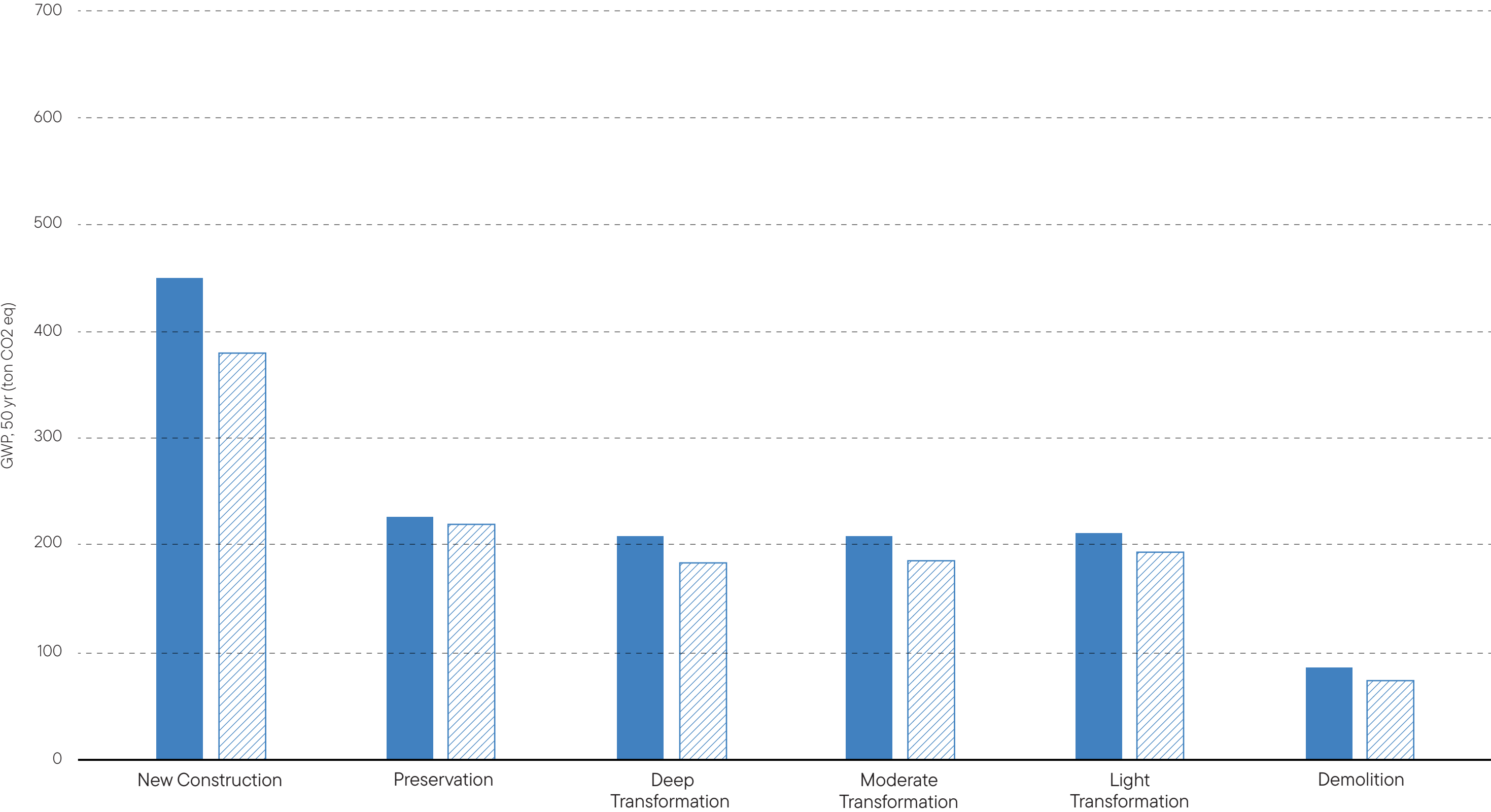
Comparison of CO₂ emissions for 1000 m² of apartments and the different construction activities, according to BR25 and Reduction Roadmap 2025:



CO₂ emissions



Apartments 1000 m²



BR25 Reduction Roadmap 2025

Architecture

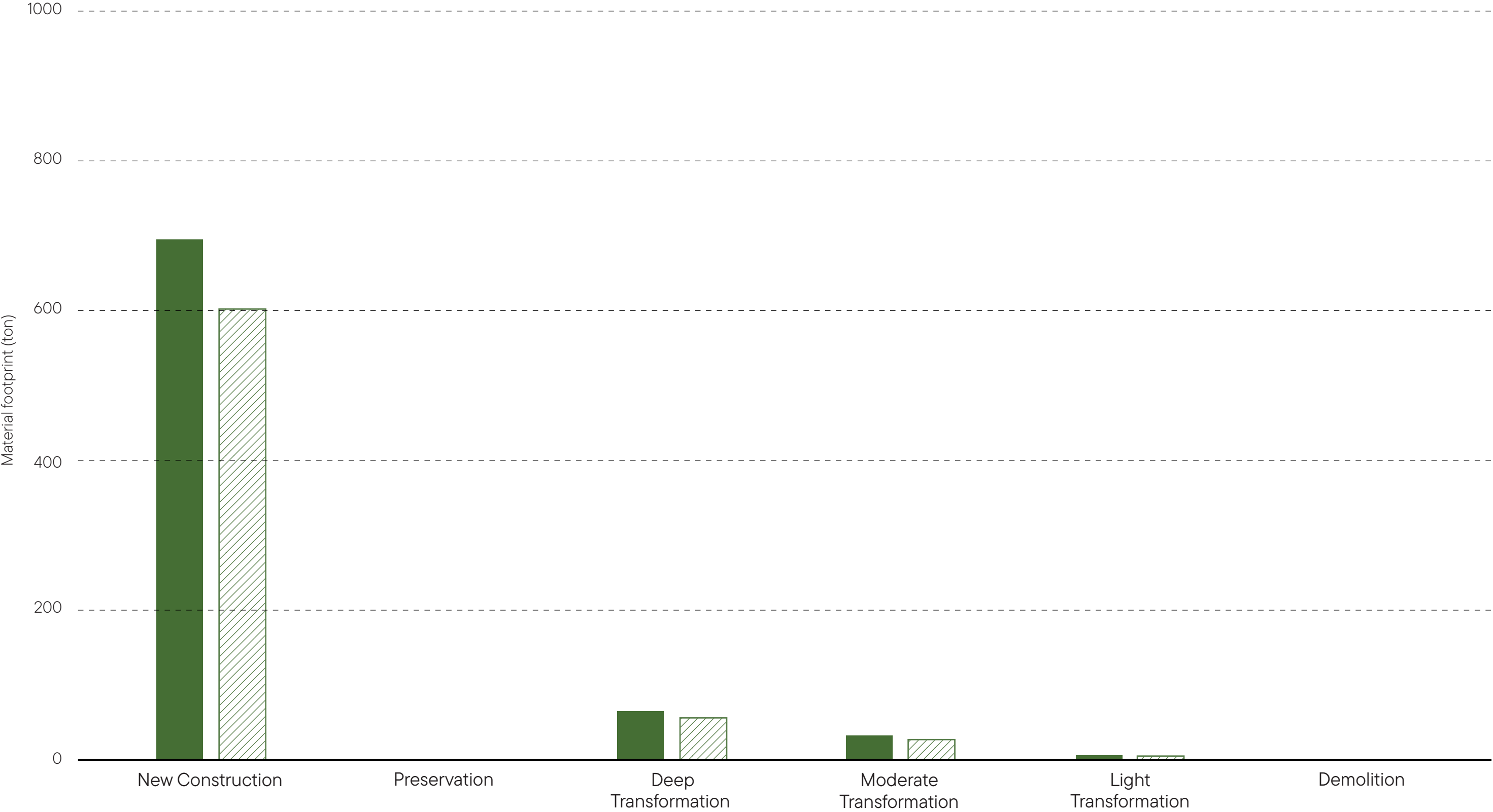
Comparison of material footprints for 1000 m² of apartments and the different construction activities, according to BR25 and Reduction Roadmap 2025:



Material footprint



Apartments 1000 m²



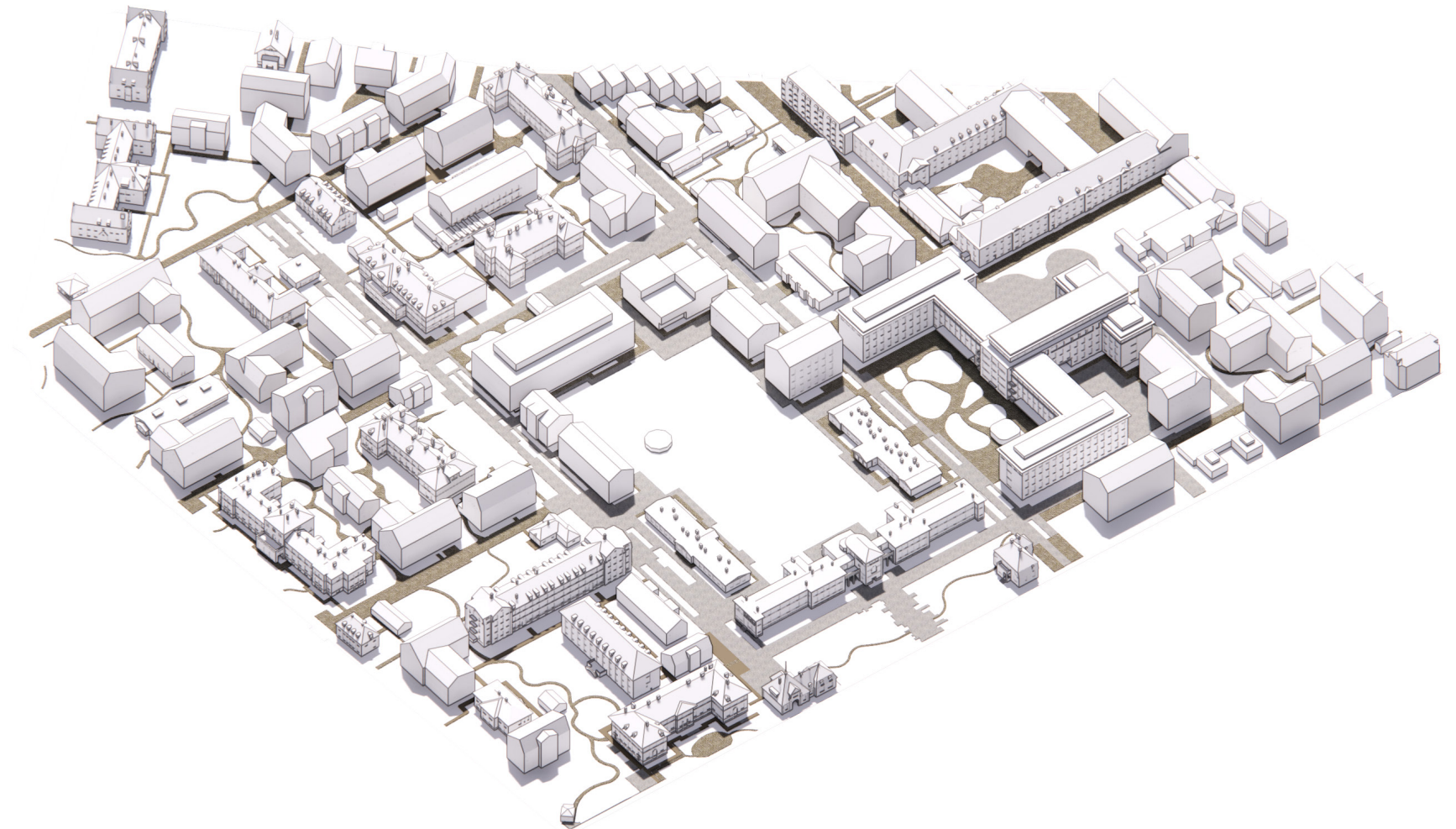
BR25 Reduction Roadmap 2025

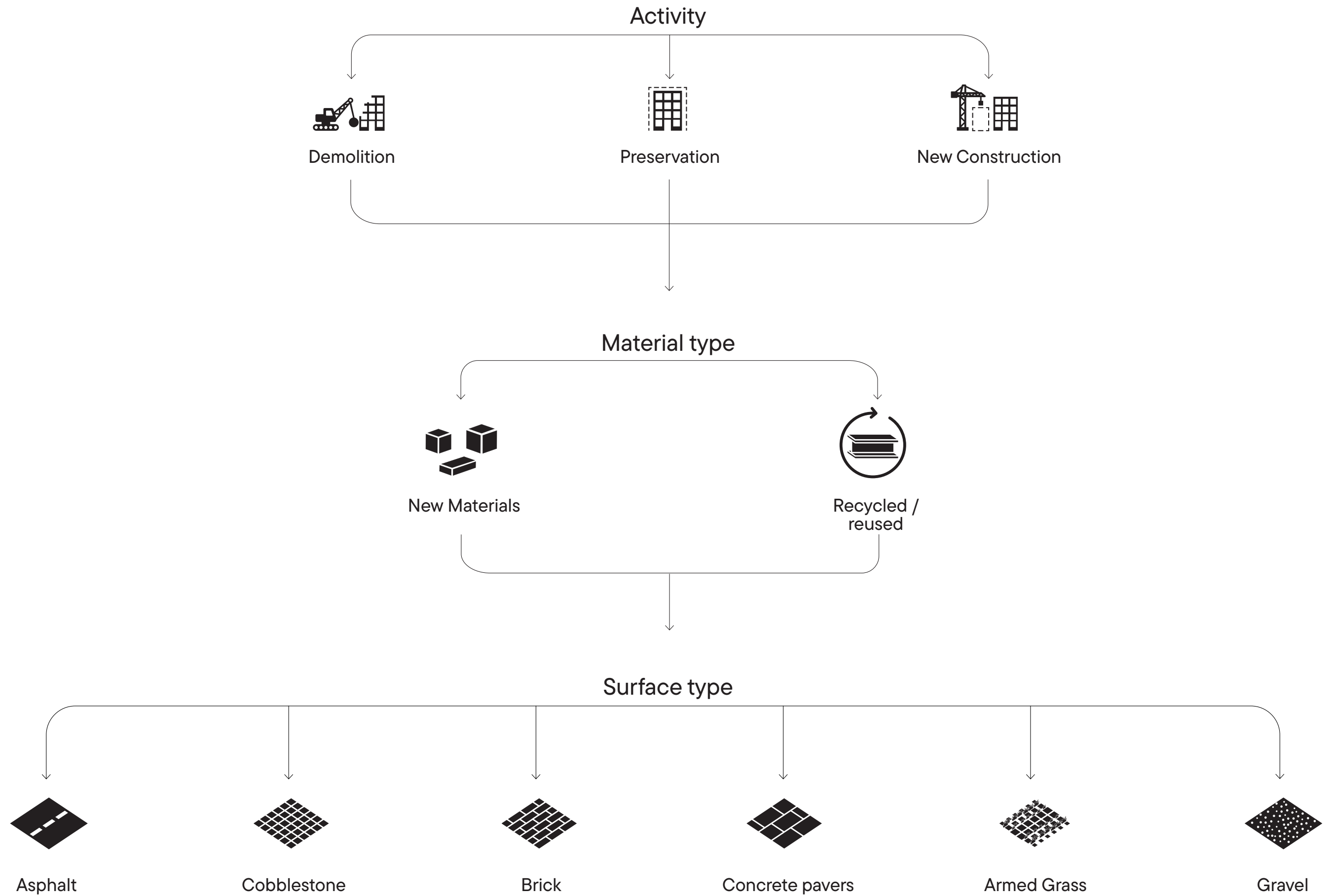
LANDSCAPE - HARDSCAPES

The Hardscape category is divided into Activity, Material type and Surface type.

Activity lets you choose between Demolition, Preservation and New Construction, while either new or reused/recycled materials can be chosen under Material type. The Reused/recycled category is included with the assumption of direct reuse, where emissions in the LCA phases are set to zero.

Surface type provides six different surfaces, with “Asphalt” further divided in different transport frequencies: Asphalt T0 (only light vehicles), Asphalt T1 (<1 truck per day), Asphalt T2 (up to 65 trucks per day), Asphalt T3 (65–120 trucks per day), Asphalt T4 (120–560 trucks per day), Asphalt T5 (560–1200) trucks per day). Two surface types (Gravel and Armed Grass), contribute to the site’s biofactor.





Hardscapes

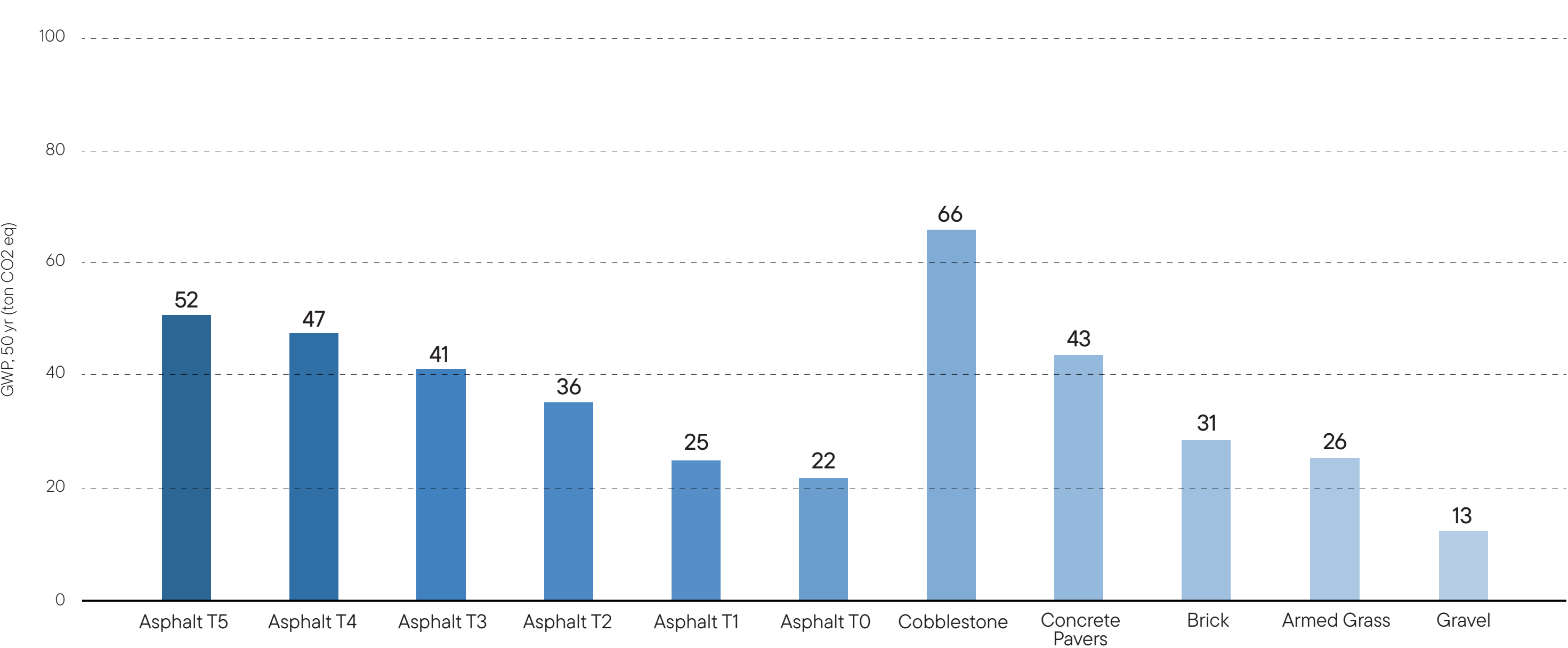
Comparison of CO₂ emissions for 1000 m² of new materials for all surface types:



CO₂
emissions



1000 m²
New materials



Hardscapes

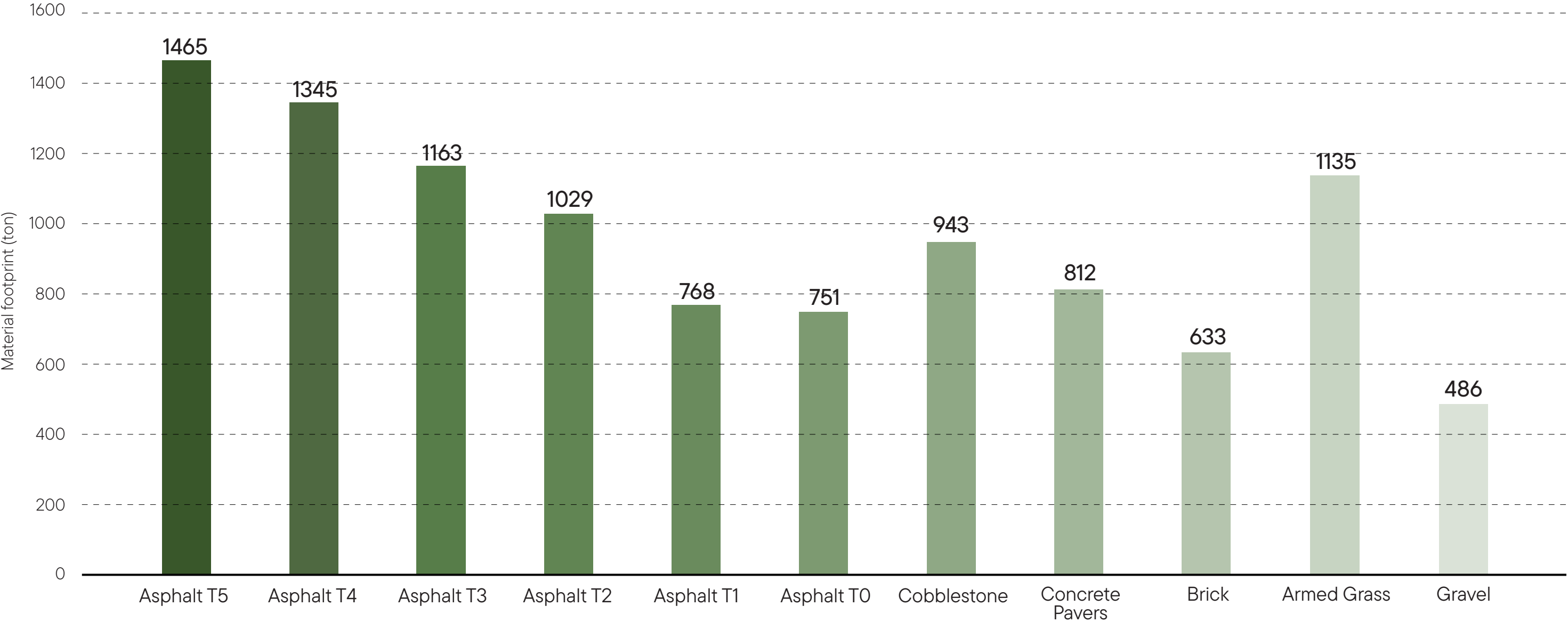
Comparison of material footprints for 1000 m² of new materials for all surface types:



Material footprint



1000 m²
New materials



LANDSCAPE - SOFTSCAPES

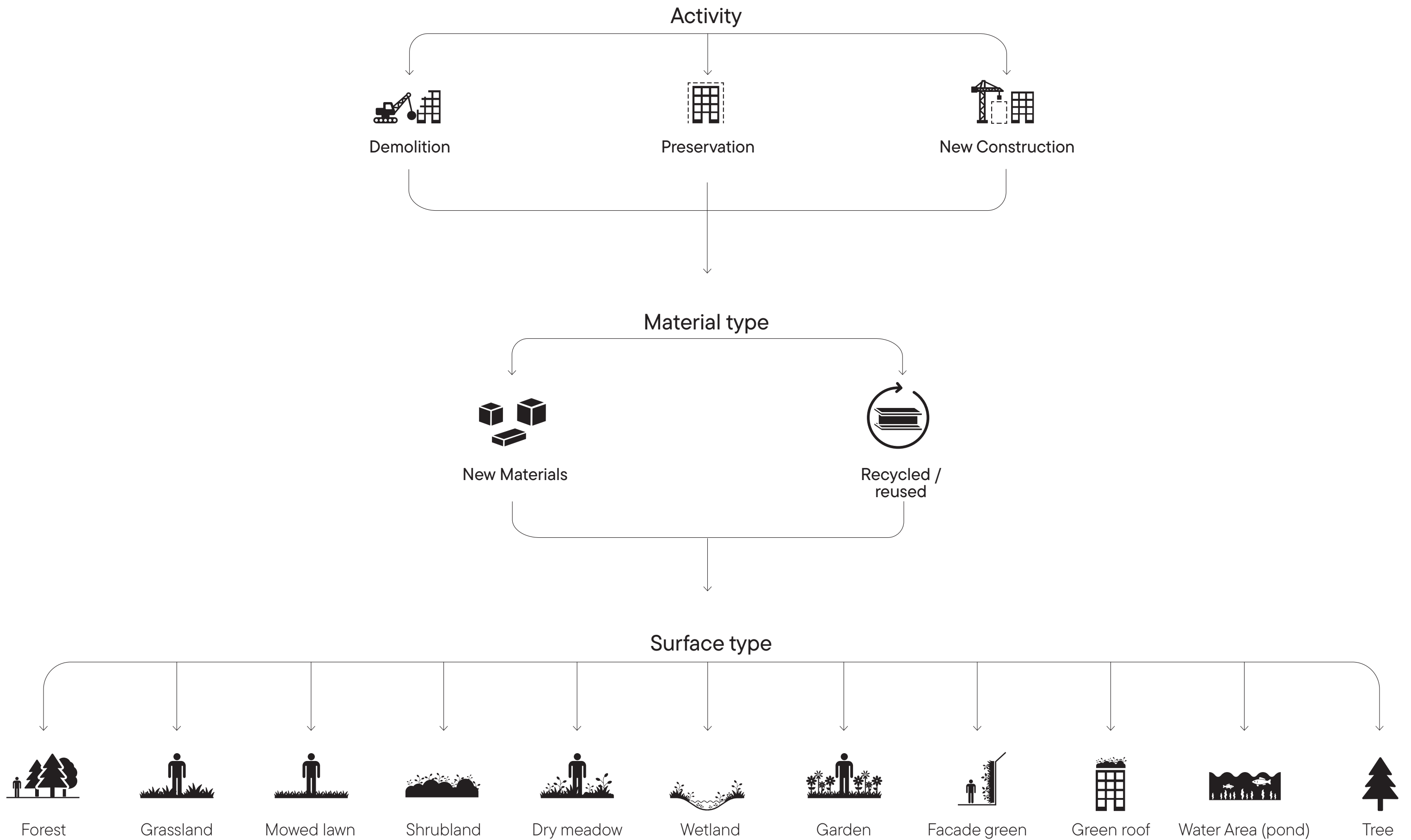
The Softscape category is divided into Activity, Material type and Surface type.

Activity lets you choose between Demolition, Preservation and New Construction, while either new or reused/recycled materials can be chosen under Material type. The Reused/recycled category is included with the assumption of direct reuse, where emissions in the LCA phases are set to zero.

Surface type includes eleven different surfaces. Additionally to carbon emissions, the Softscapes category includes a biofactor calculation.

As seen on the following page, most softcape types sequester more emissions than they create, therefore they are shown as negative.





Softscapes

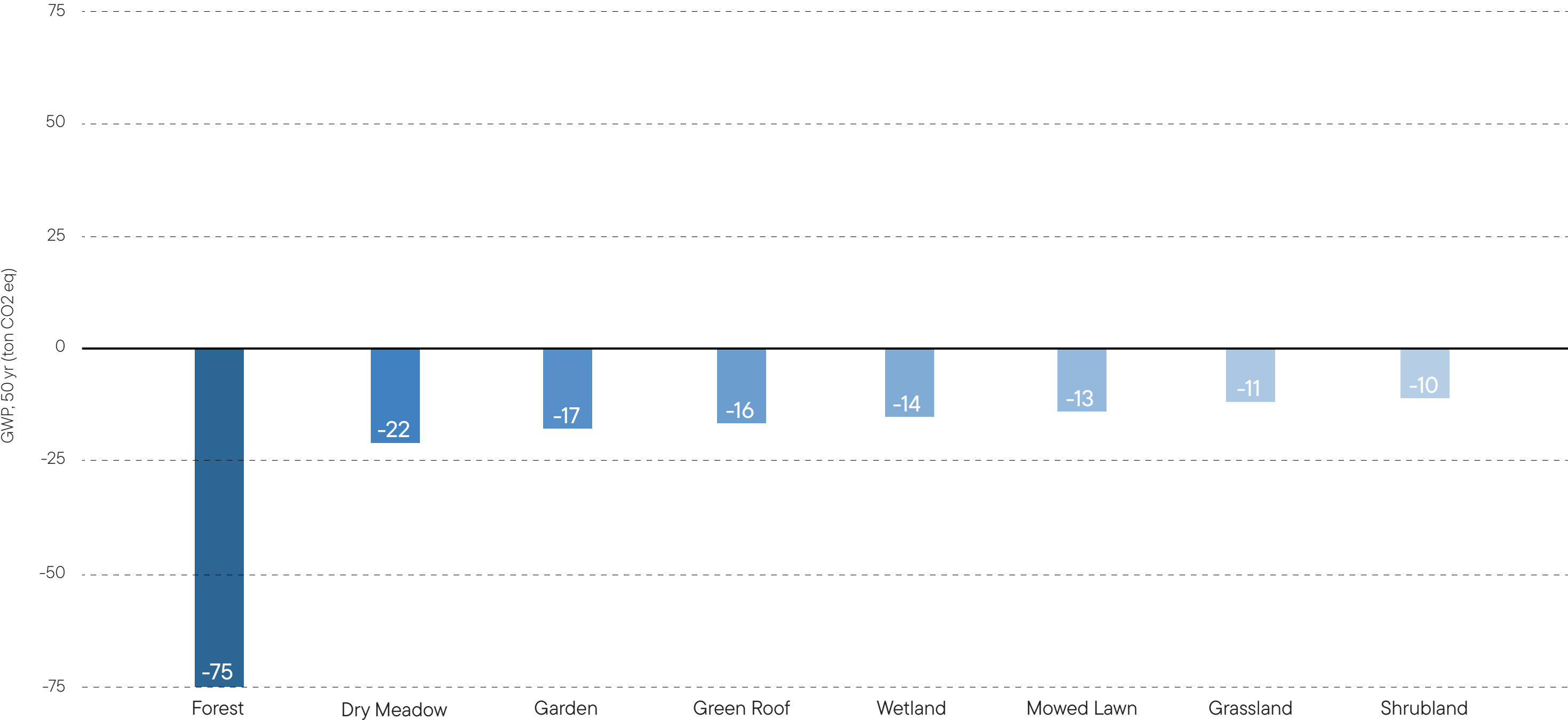
Comparison of CO₂ emissions for 1000 m² of new materials for all surface types*:



CO₂
emissions



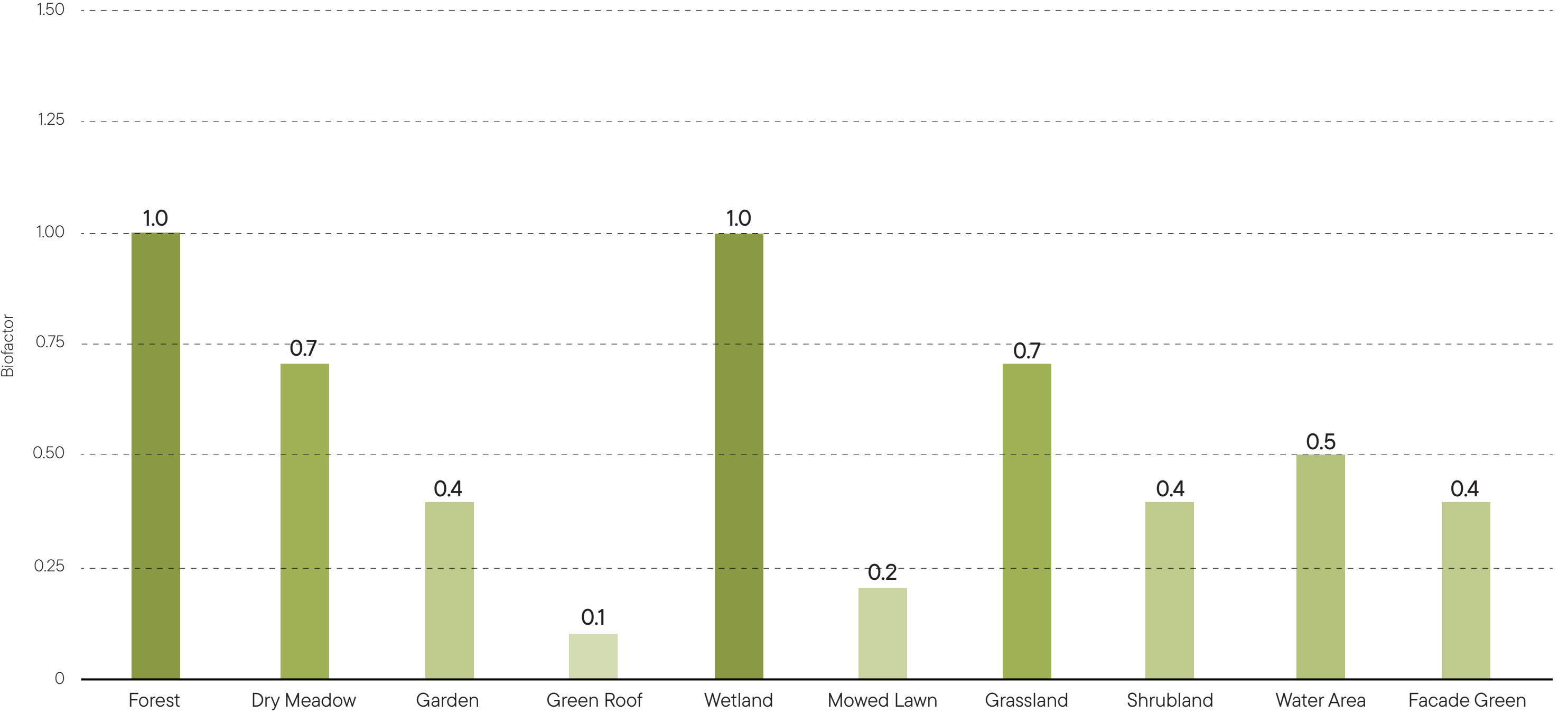
1000 m²
New materials



*The best available data has been used; new data will be incorporated after the completion of LCAlandskab.

Softscapes

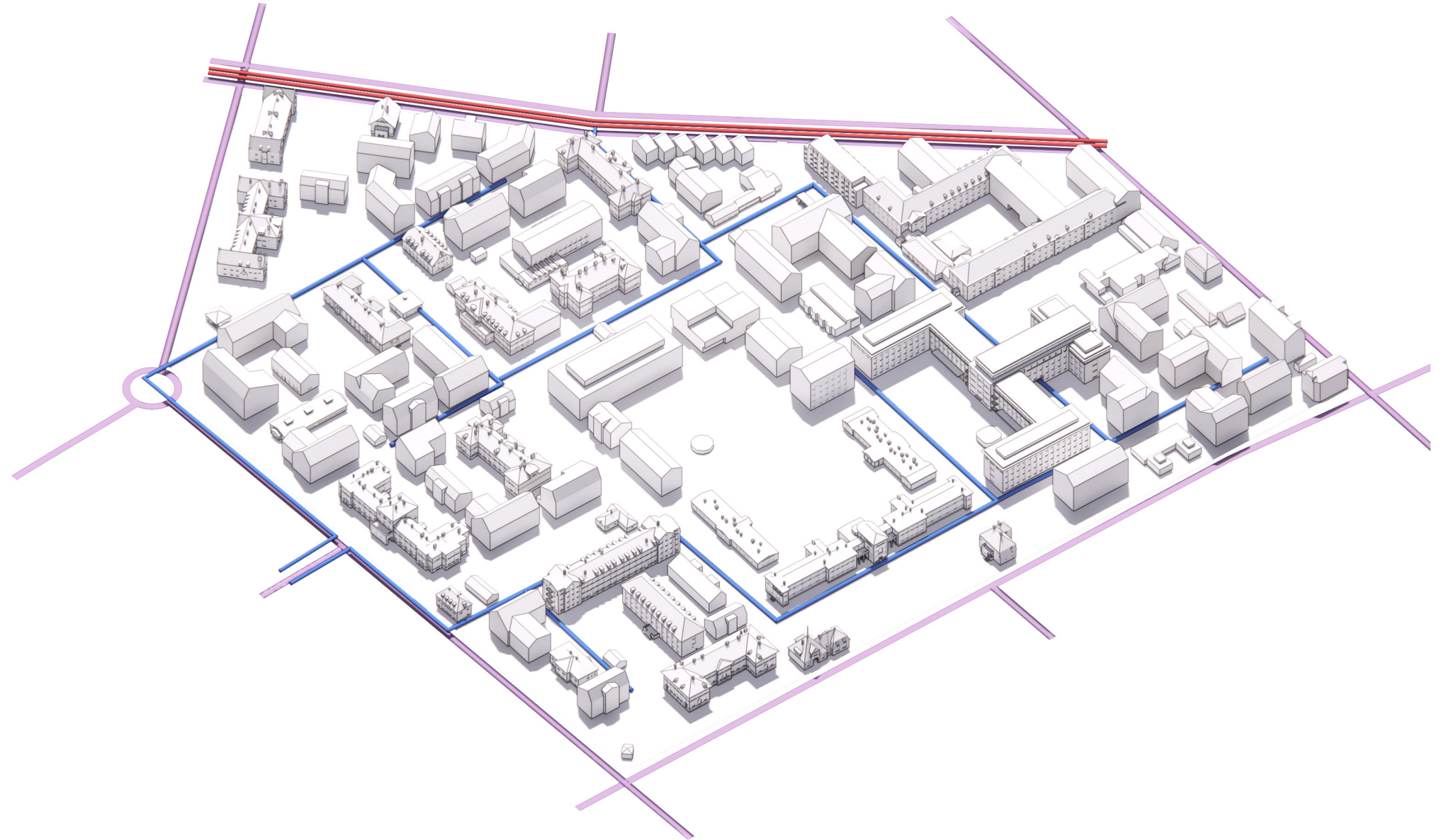
Comparison of biofactors for all surface types*:

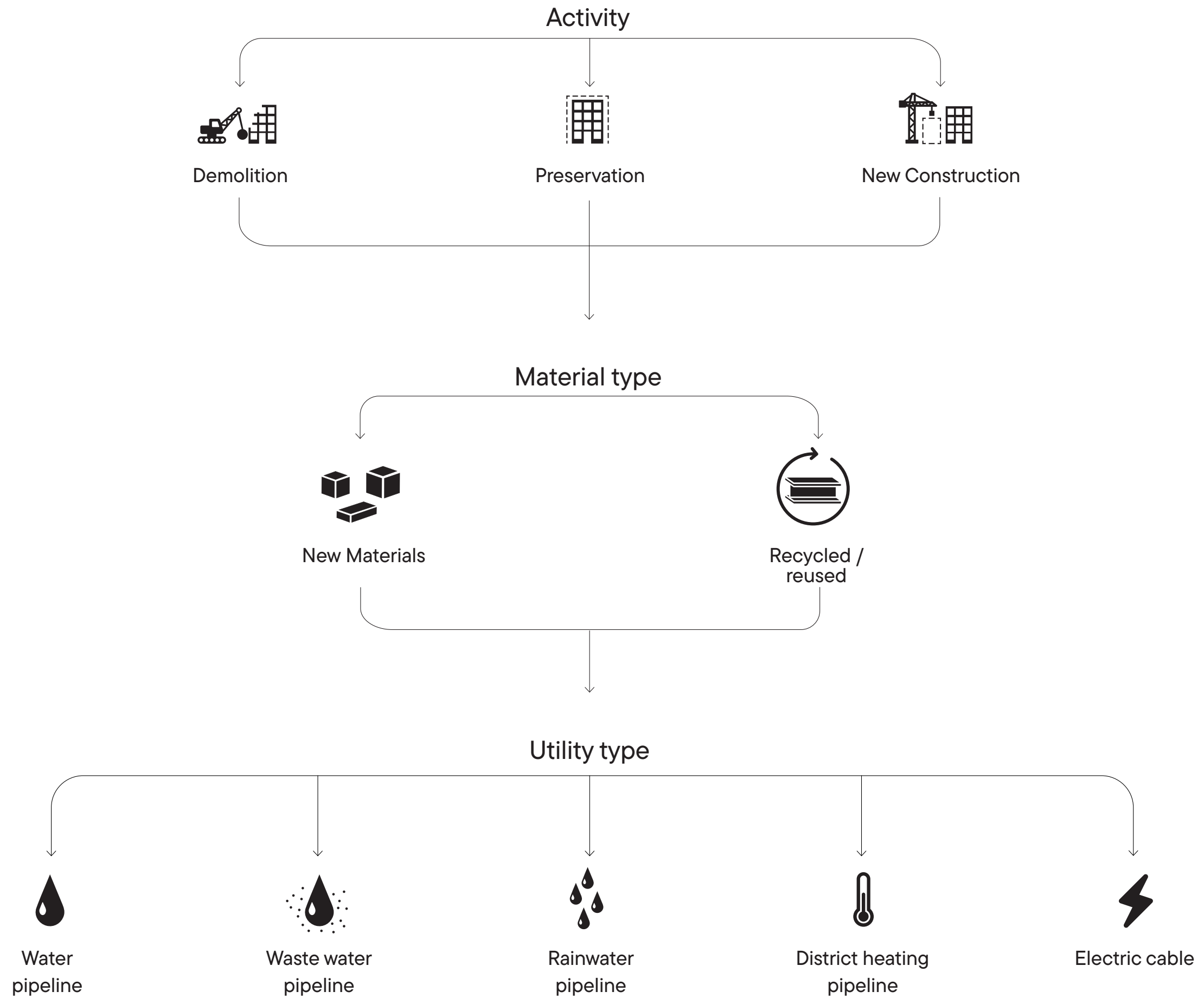


*data based on DGNB method.

UTILITIES

As visible on the right, the Utility category prioritises a full overview of urban development impact, rather than providing options for tool users to choose between. Activity lets you choose between Demolition, Preservation and New Construction, while either new or reused/recycled materials can be chosen under Material type. Urban LCA includes four different pipe types plus electricity channels.





Utilities

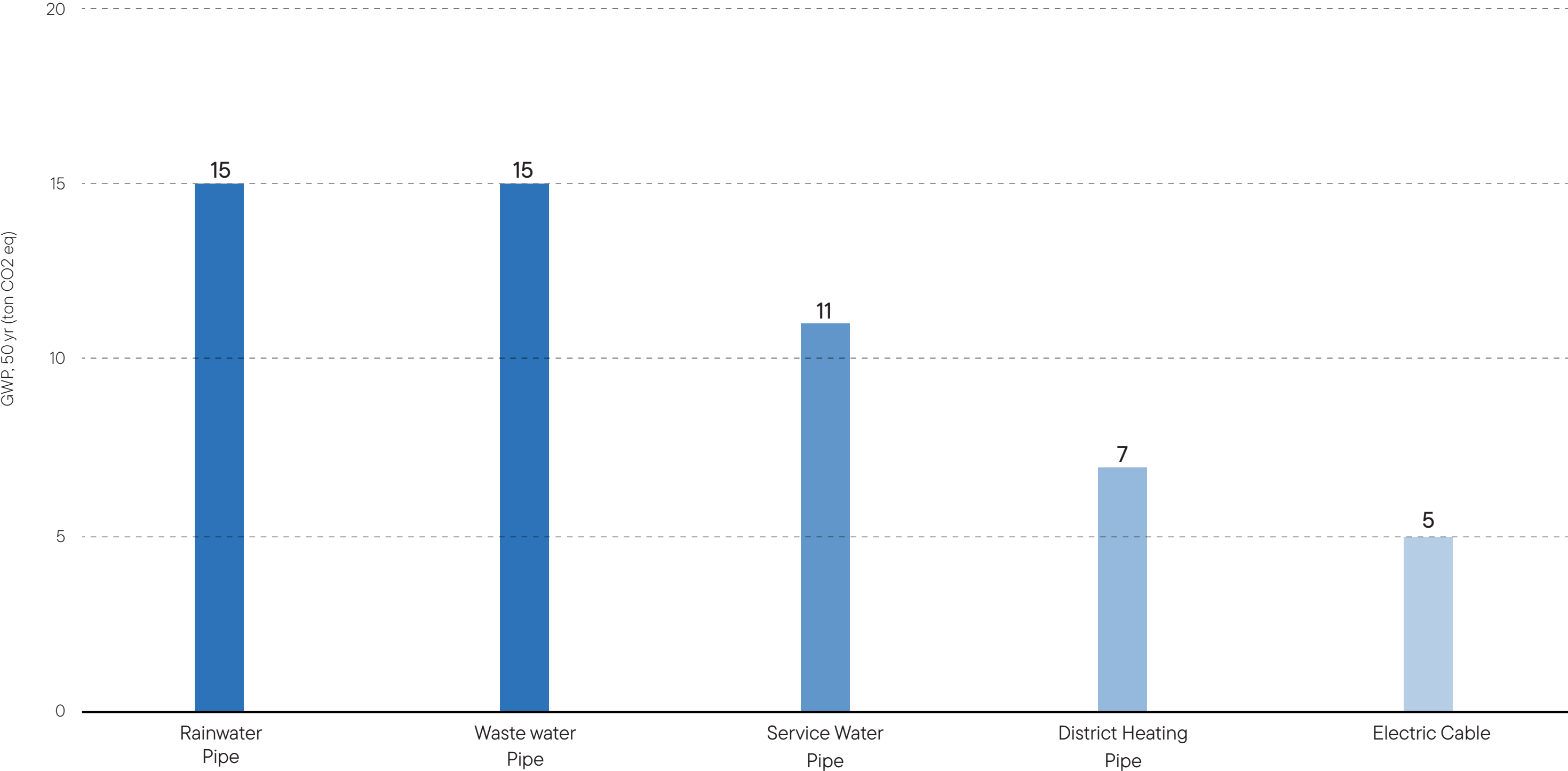
Comparison of CO₂ emissions for 100 m of new materials for all utility types:



CO₂
emissions



100 m
New materials



Utilities

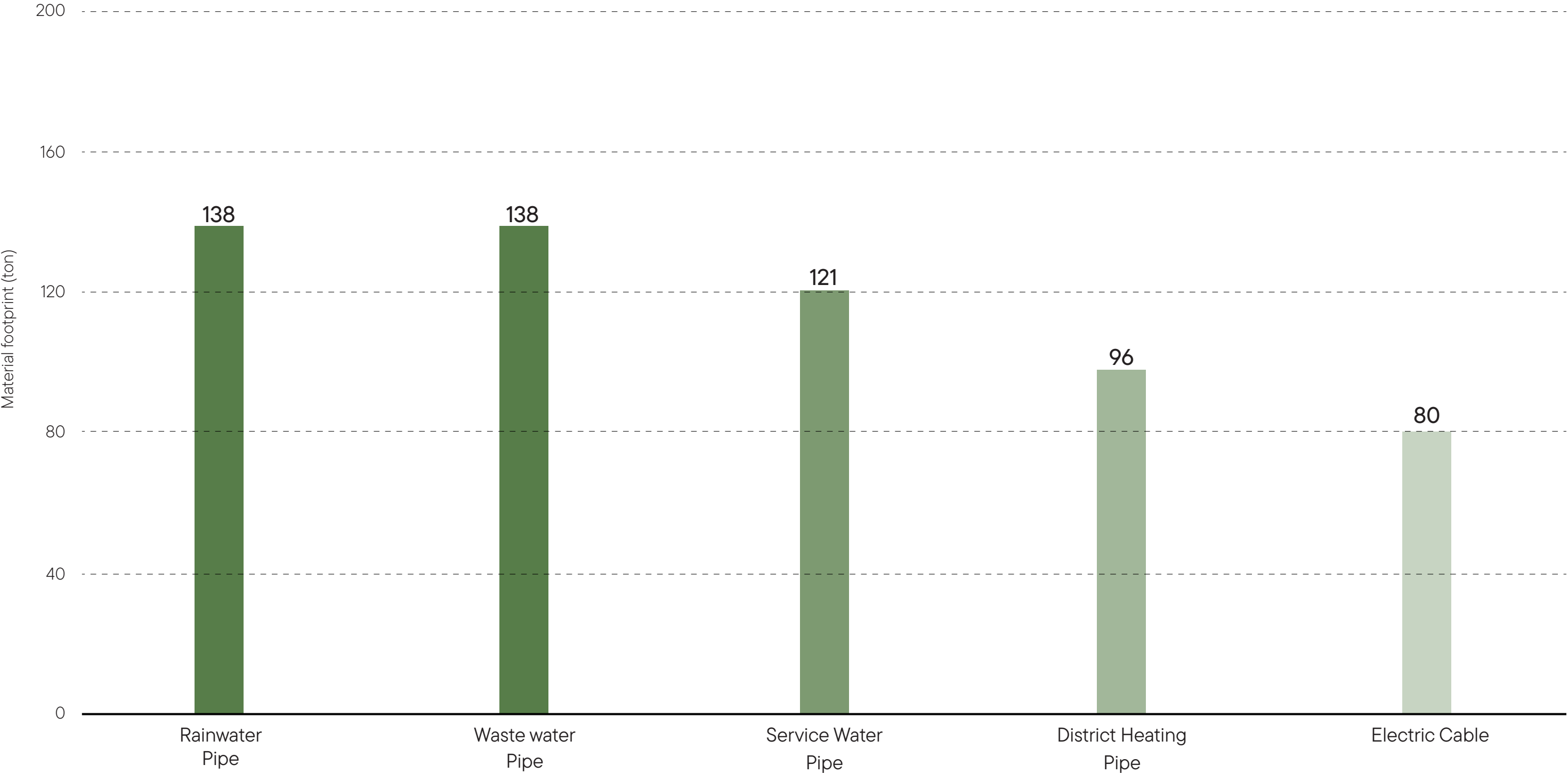
Comparison of CO₂ emissions for 100 m of new materials for all utility types:



Material footprint



100 m
New materials



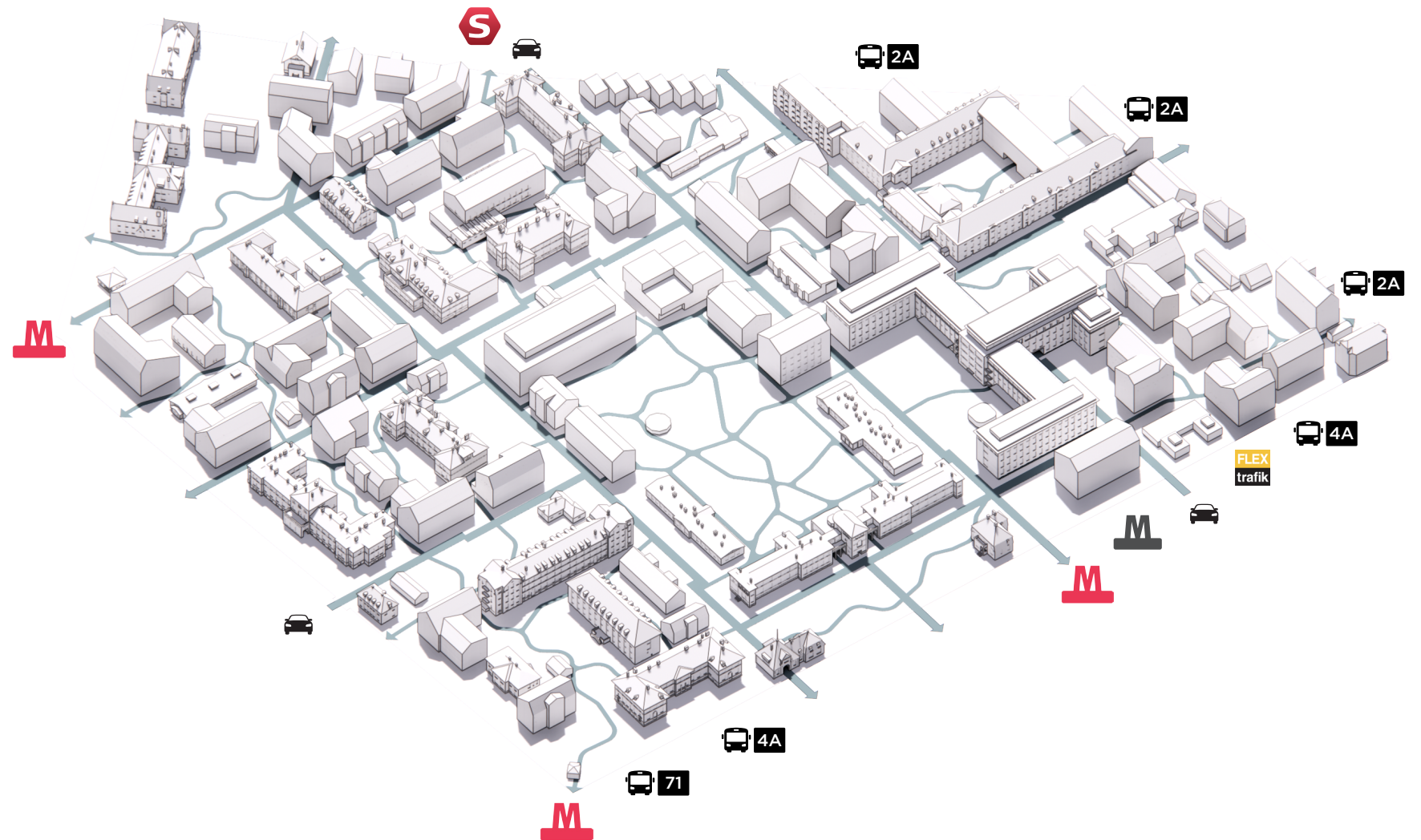
MOBILITY

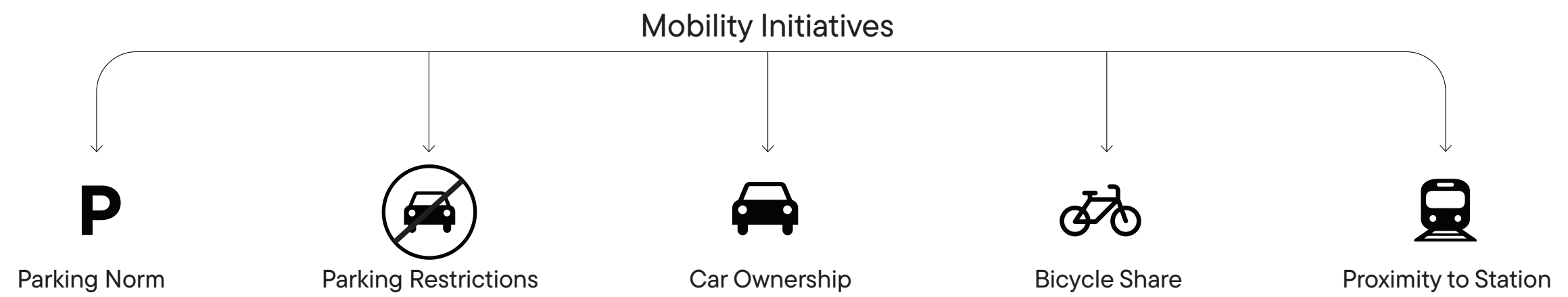
As described previously, the Mobility category is structured differently from the other categories of Architecture, Softscapes, Hardscapes, and Utilities. The Mobility category functions primarily as a behavioural analysis tool.

To illustrate an example, when people move to a new urban area, they 'move' their mobility behaviour and emissions with them, instead of creating new ones. To give an accurate description of the created emissions, they would have to be deducted from the area the new residents have moved from. Since the existing emissions from residents' mobility behavior are not known, the CO₂ impact from mobility is excluded from the overall comparison of the scenarios. This is because the CO₂ impact cannot be added to the construction/transformation of the new district, as the residents had a behavior in their previous homes.

Instead, the purpose of this category is to evaluate and compare various mobility initiatives based on their effectiveness in reducing carbon emissions. For instance, the tool enables users to assess different scenarios, such as varying levels of bicycle use among residents. By providing this data, the tool supports decision-makers, planners, and stakeholders in urban planning with actionable insight in mobility related decisions.

The analyses are based on mobility data from Frederiksberg from the Traffic Behaviour Survey (DTU) and corrected with general data from Turrater (Road Directorate) for the various mobility initiatives.

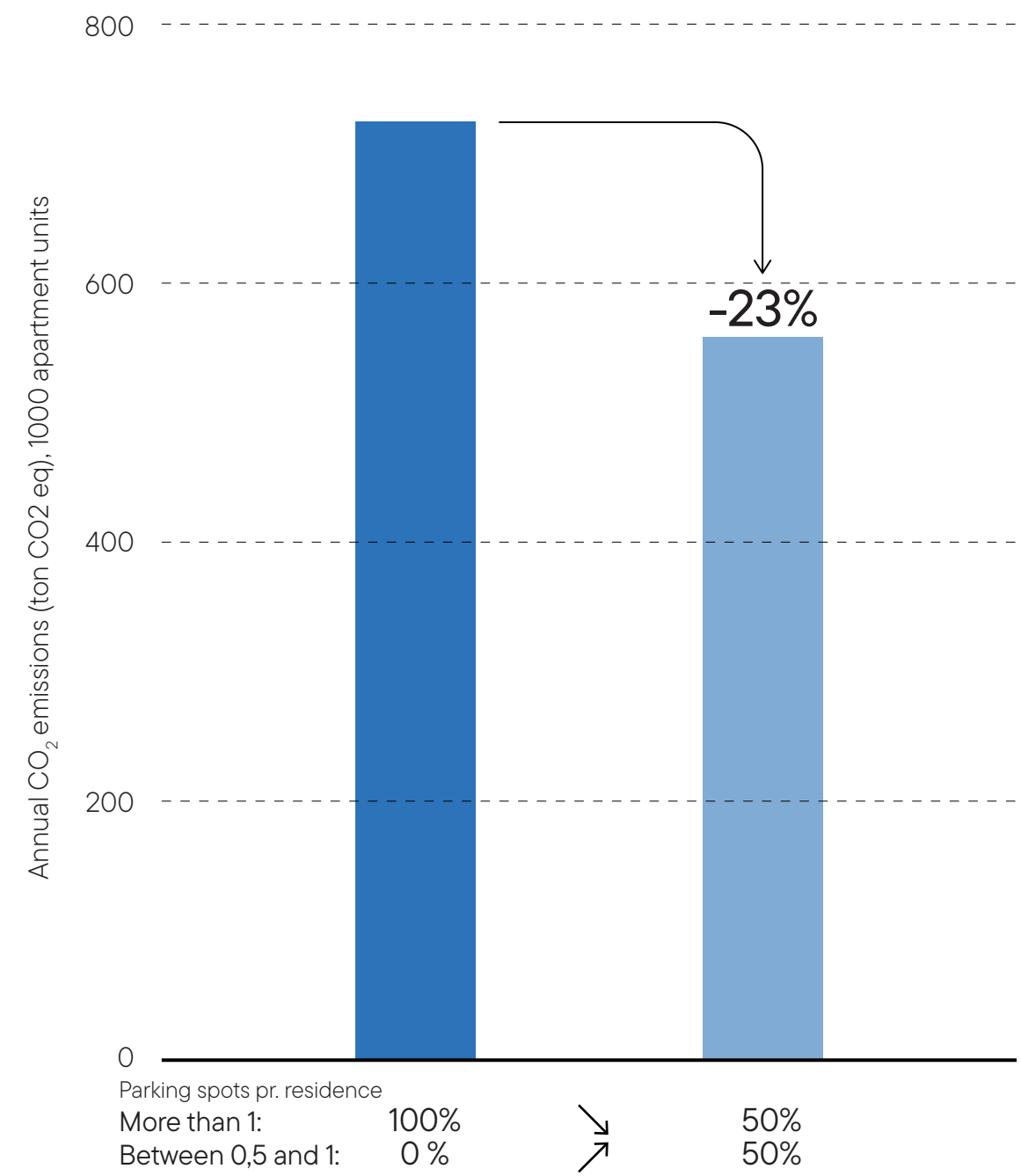






What if there are less parking spots per residence?

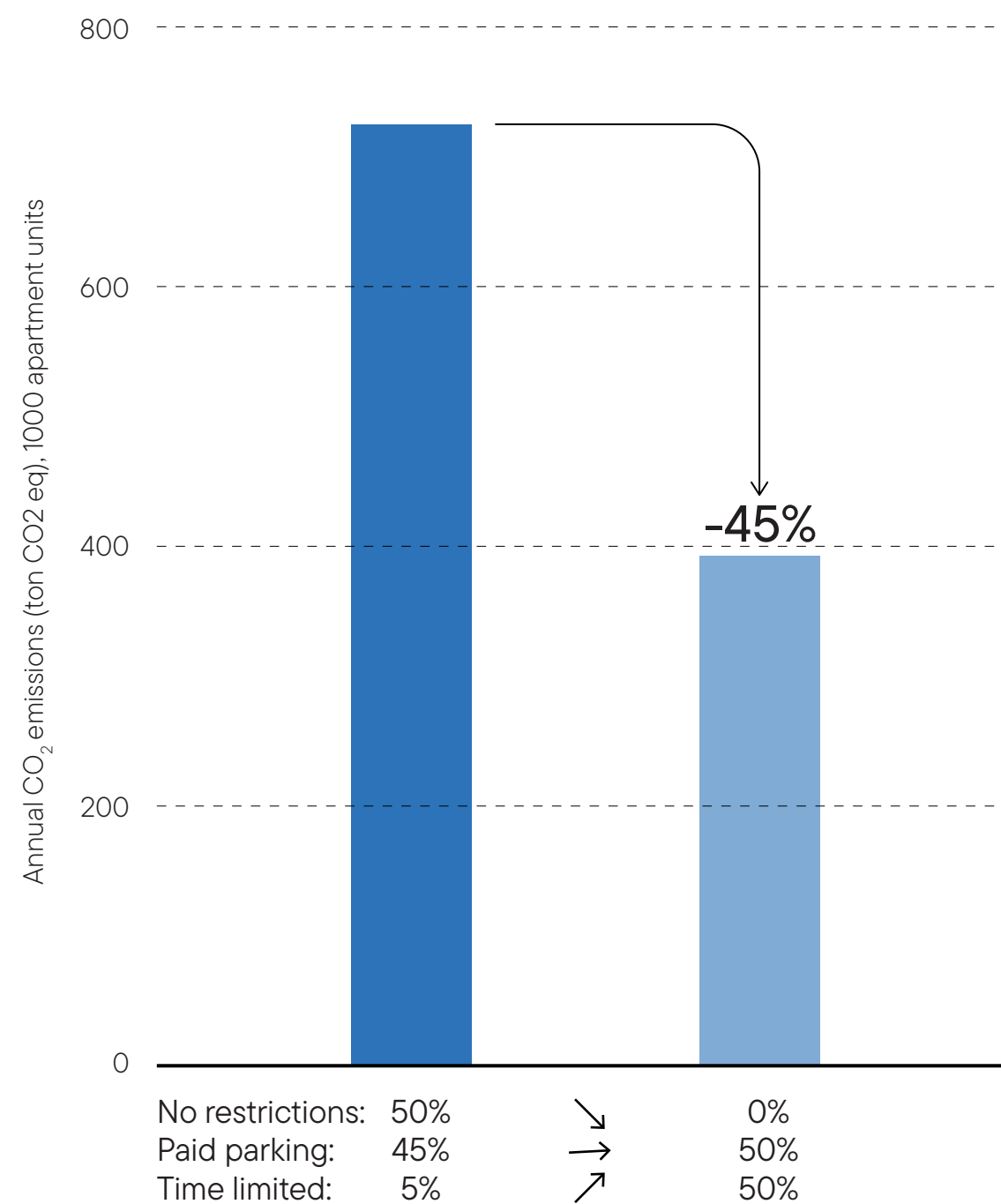
In this example, half of the residences move from having more than one parking spot, to having between 0,5 and 1 parking spots on average. This leads to a **23%** carbon emission reduction annually due to a decrease in the average number of car trips per household.





What if there are stricter parking rules?

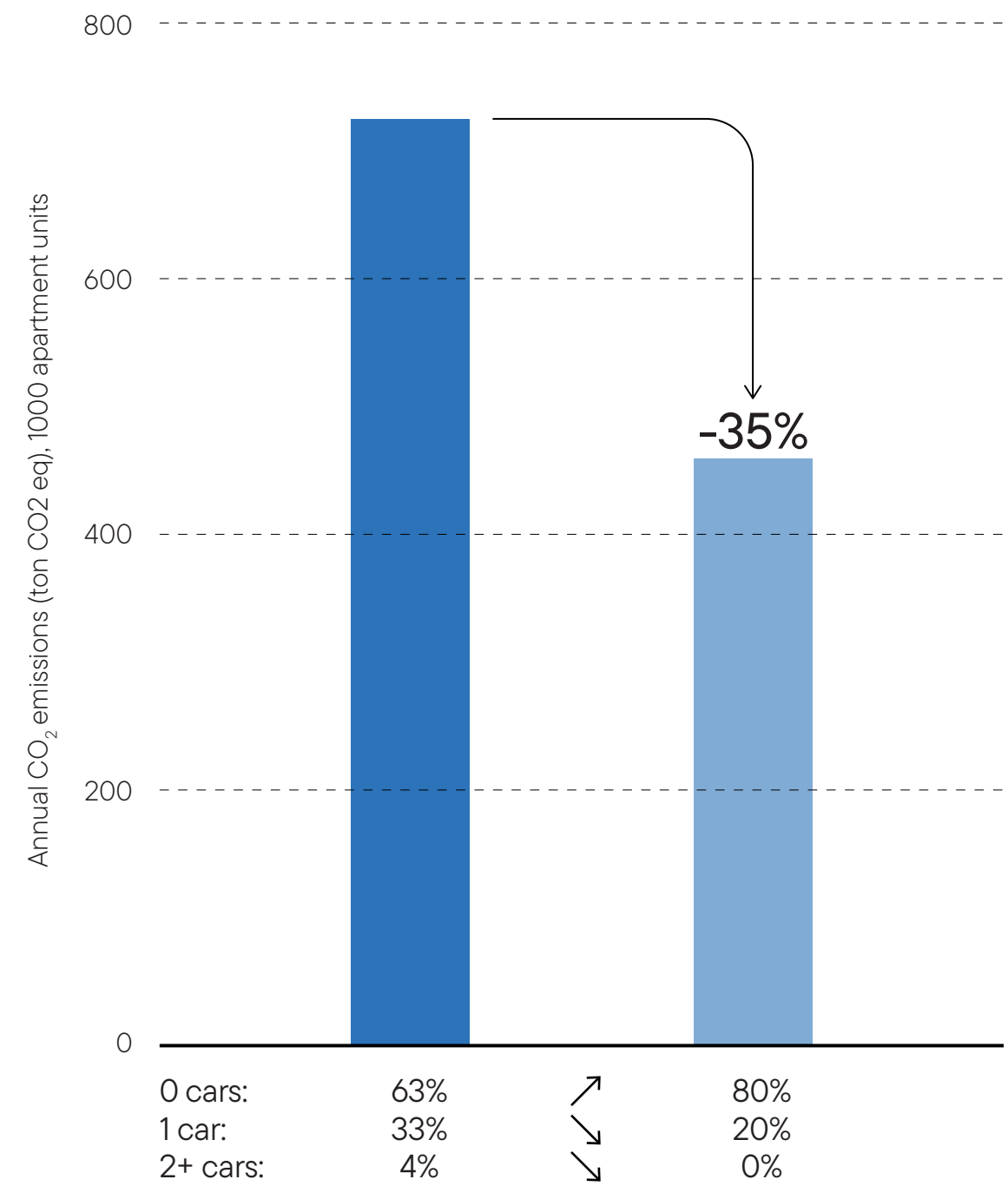
In this example, all parking spots are now either paid or time limited. This leads to a **45%** carbon emission reduction annually, since people opt for other low-emission transport options instead.





What if less residents own a car?

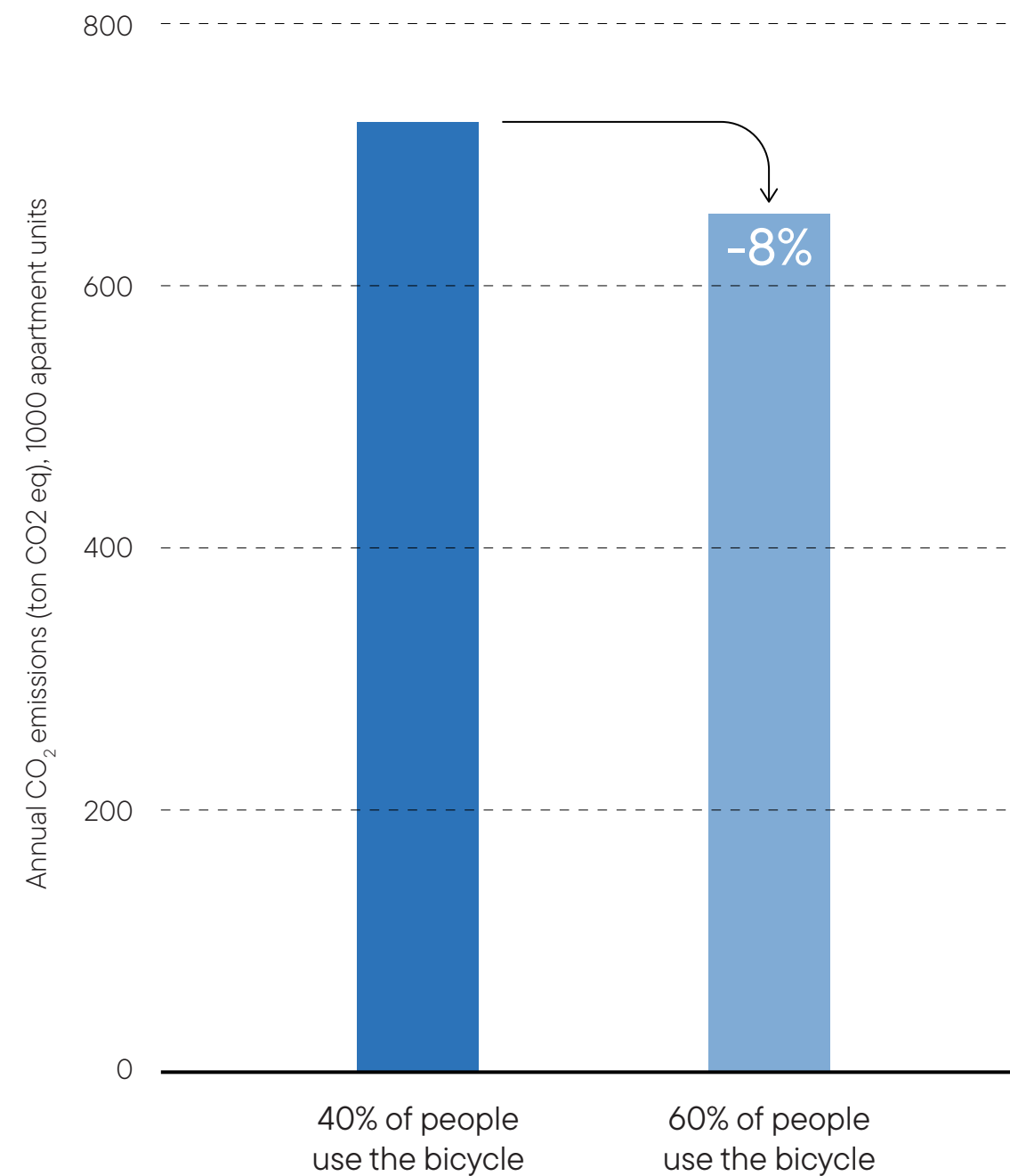
In this example, the share of residents who own one or two cars gets reduced – increasing the amount of residents who don't own a car and opt for other low-emission transport options instead. This leads to **35%** carbon emission reduction annually.





What if more residents use their bicycle?

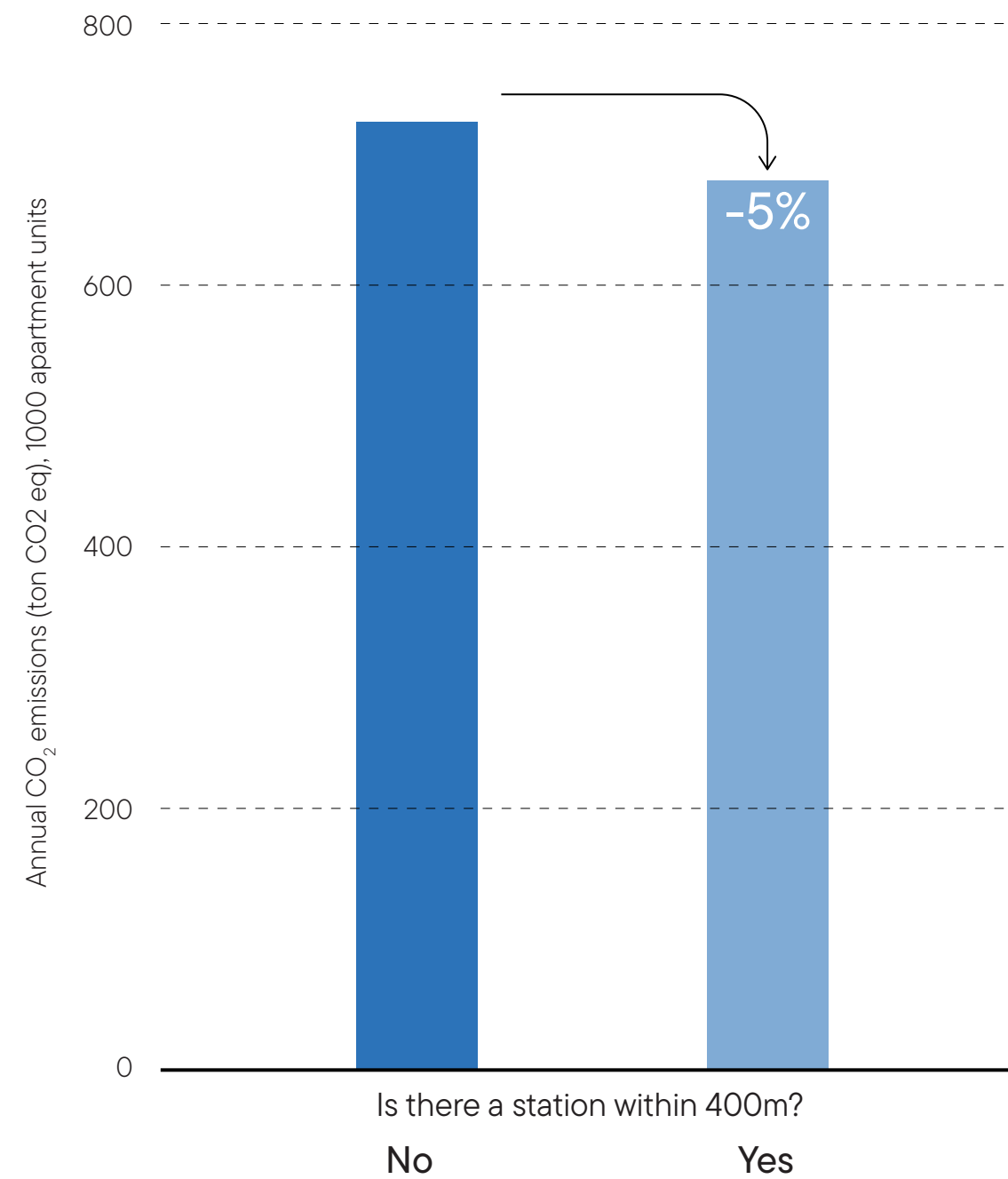
In this example, increasing the bicycle share for short trips (average 5 km) by 20 percentage points leads to a **8%** carbon emission reduction annually.





What if there is a public transport station nearby?

A station within 400m of the urban development, incentivises people to use public transport instead of individual car journeys and therefore reduces carbon emissions by **5%** annually.



03

Case Analysis

Project Overview

FREDERIKSBERG HOSPITAL

Frederiksberg Hospital is set to become the city's new neighbourhood. From 2027 onwards, the transformation of the area will build on the qualities already present—its many historic buildings and large, old trees. The new will grow from the old.

The vision states: “On the former hospital grounds, we are creating an open, welcoming, green and diverse neighbourhood where LIFE and CALM meet—offering sustainable solutions for the future and a distinct identity.”

This new neighbourhood for the whole city will become a “flowing city” with freestanding buildings and a green heart—a large new central park. The park will offer space for both LIFE and CALM, surrounded by culture, eateries, sports facilities, and small businesses.

Around the park, a series of mini-neighbourhoods will take shape, offering a mix of housing types with a focus on community and small-scale enterprises, along with a dedicated zone for local health services.

The Unique Frederiksberg Identity

Frederiksberg's green character stems in part from the “hygienic movement,” spearheaded by doctors and architects in response to the industrialization and urbanization of the capital in the 1850s. The movement aimed to ensure light and air through “the lungs of the city,” as it described the greenery, installations, and parks. Frederiksberg Municipality followed the movement's recommendations, planning areas such as Martensens Allé and N.J. Fjords Allé, characterized by light, air, and green spaces achieved through multiple openings in the apartment blocks leading to lush courtyards.



Today, Frederiksberg is perceived as a green city where buildings and nature are closely intertwined—a city with rich cultural heritage and vibrant urban life. These are qualities the hospital site has the potential to develop further, aligning with Frederiksberg’s identity and strong character.

The Hospital Area Today

The hospital was originally established in response to a health crisis. Today, we face a climate crisis, which will significantly influence future development. The combination of rich cultural heritage with future sustainability initiatives offers a fascinating mix. The development plan serves as a guide to creating synergy between the past and the future, thereby strengthening the area’s inherent identity and qualities.

Entering the hospital area today, one immediately senses its unique character—a distinctive location where many fine buildings and heritage trees already constitute more than half of the future neighborhood. Future development must build upon the original structure, preserving the story of the hospital era while also narrating the transformation from a single function to many new uses.



FREDERIKSBURG COMPASS: LCA & BIODIVERSITY IN THE DEVELOPMENT PROCESS

The idea of the Frederiksberg Hospital Compass is to combine quality goals for an attractive urban district with concrete sustainability targets that are upheld over time.

The Frederiksberg Compass will ensure that specific focus areas and sustainability quality goals are realized. The compass has three focus areas:

- The Green: Ensure the preservation of trees and plants and maximize the addition of green and blue solutions so that rainwater becomes a resource rather than a problem. This will enhance biodiversity and give the area a distinctive green character.

- Reducing Climate Impact: Green transport and energy solutions must ensure a low CO₂ footprint. **Early life cycle assessments** will help integrate ambitious climate targets into upcoming construction and development projects.

- Communities: Focus on establishing neighborhood and mini-neighborhood associations as well as shared solutions to make the district a good place to live, work, and thrive. A well-functioning social district where it is simple and easy to live more sustainably.

This compass will provide input for a quality program that, together with the development plan, will help Frederiksberg Municipality ensure that the new urban district achieves the desired quality, even when third

parties become involved in its realization and future use.

The compass is a strategic tool highlighting three themes and nine sub-themes, which are critically important for a holistic and interdisciplinary approach that benefits both people and the planet. It will be used to guide the construction and development process as a project-specific dialogue tool for use among citizens, stakeholders, investors, and the municipality.

Strong leadership is required from the landowner to maintain a broad, cross-cutting perspective on urban development. With an ambitious vision, a robust development plan, and the Frederiksberg Compass in hand, Frederiksberg Municipality, as both authority and landowner, has good conditions for realizing the hospital district as a leading example of urban development.

The selected themes represent areas that will receive focused attention throughout the entire process—from vision to realized plan and the life of the urban district.

At each stage leading to the final plan, there will be renewed focus and more detail. For example, the Urban LCA tool must be fully developed. The diagram shows three examples within each main theme.

As mentioned, initial steps have already been taken to work with LCA at the district level. As part of Plan22+, Frederiksberg Municipality has

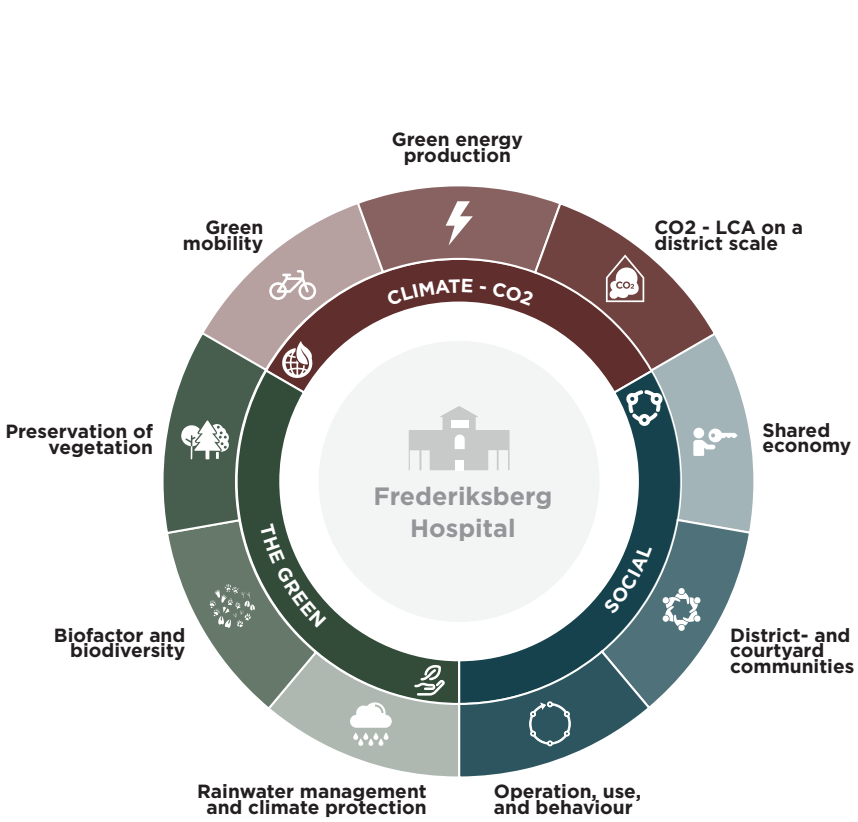
received funding for Urban LCA—a tool for the transformation of Frederiksberg Hospital.

The project’s goal is to map and communicate the climate impacts of the development of Frederiksberg Hospital while illustrating the potential of alternative strategies, solutions, and initiatives that can reduce climate impact and enhance biodiversity.

The sustainability tool will support the municipality’s overall goal of CO₂ neutrality. It will include relevant parameters to consider during urban development, such as the composition of buildings, infrastructure, and the design of natural spaces.

A Green Beacon

The vision is for the entire new district to become a green beacon. The development will aim to minimize climate impact, increase biodiversity, foster communities, and enhance urban nature—collectively promoting health for both people and the planet. DGNB certification, the Frederiksberg Compass, the municipality’s active ownership role, and planning tools will ensure that these green ambitions are fulfilled—even in the long term.



The green - from vision to realisation					
	1. DEVELOPMENT PLAN (Vision) Registration of trees and vegetation	2. DISTRICT PLAN (Quality) Nummerering & Udvælgelse	3. TENDER (Requirements) Valuation	4. IMPLEMENTATION (Control) Supervision / Replacement	5. FOLLOW-UP (Concluding) Operating plan of preservation

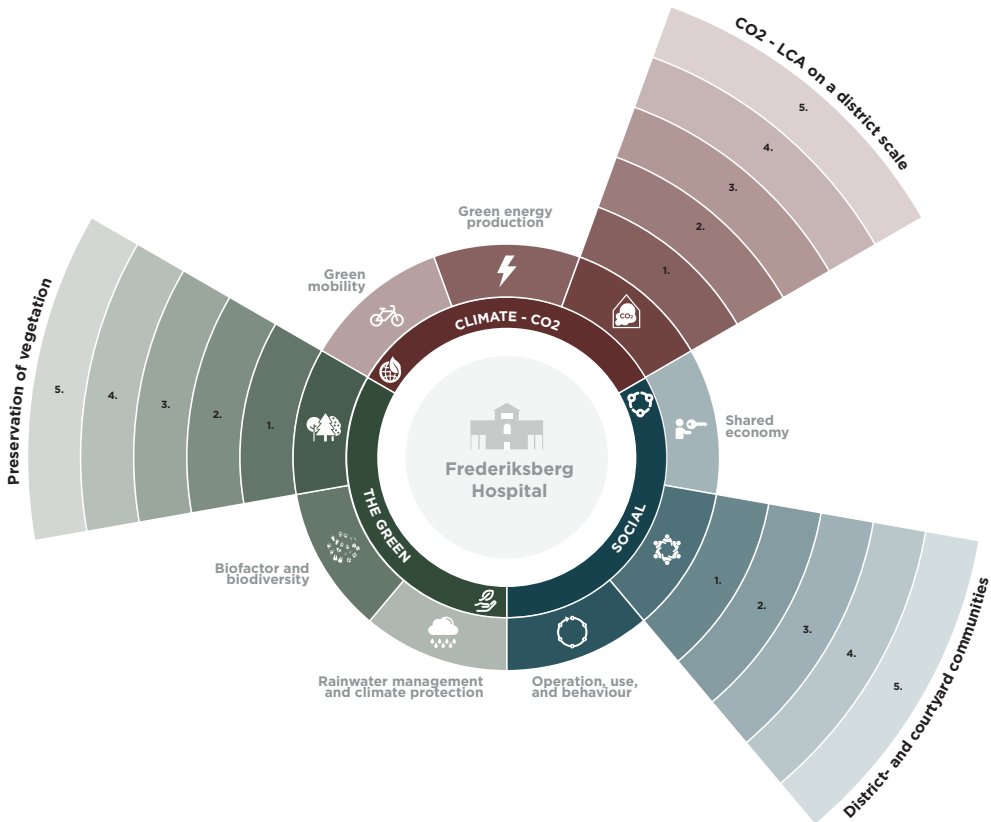
Example of how the compass is used to ensure the preservation of green over time

Climate - CO ₂ - from vision to realisation					
	1. DEVELOPMENT PLAN (Vision) Developing tools for LCA calculations on a district scale	2. DISTRICT PLAN (Quality) Employing tools to define material choices	3. TENDER (Requirements) LCA requirements upon land sale	4. IMPLEMENTATION (Control) Inspection and sampling	5. FOLLOW-UP (Concluding) Measuring behaviour and day-to-day operations Control of CO ₂ emissions during operations

Example of how the compass is used to work with LCA as a tool

Social - from vision to realisation					
	1. DEVELOPMENT PLAN (Vision) Physical framework for communities	2. DISTRICT PLAN (Quality) Defining housing typologies, types of ownership, and community houses	3. TENDER (Requirements) Framework for courtyard- and district associations Resident participation	4. IMPLEMENTATION (Control) Establishing organisational communities	5. FOLLOW-UP (Concluding) Courtyard- and district associations live and support communities

Example of how the compass is used to ensure communities over time



Scenarios

COMPARISON

For the development planning of Frederiksberg Hospital, four scenarios have been investigated for comparison.

Scenarios 1A and 1B are based on the same planning—the current development project—and differ only in the chosen sustainability class for architecture. Scenario 1A complies with BR25, while 1B complies with Reduction Roadmap 2025.

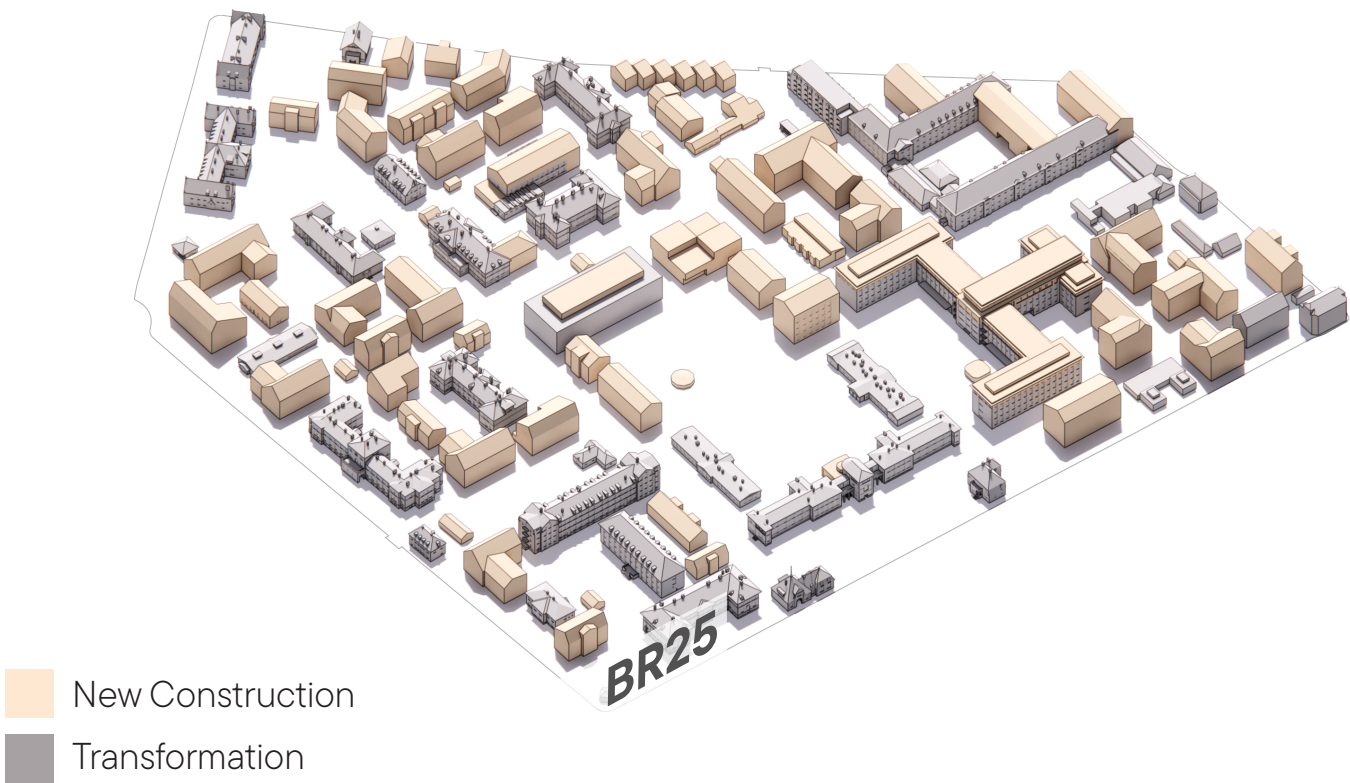
Scenarios 2 and 3 are fictional scenarios. They are supposed to show alternatives to the chosen development, in order to compare impacts across different design decisions. The visualisations do not represent a design development and are not indicative of the listed m².

In Scenario 2, all existing buildings are demolished and replaced with new construction matching the building square meters of the current development, representing standard industry practices.

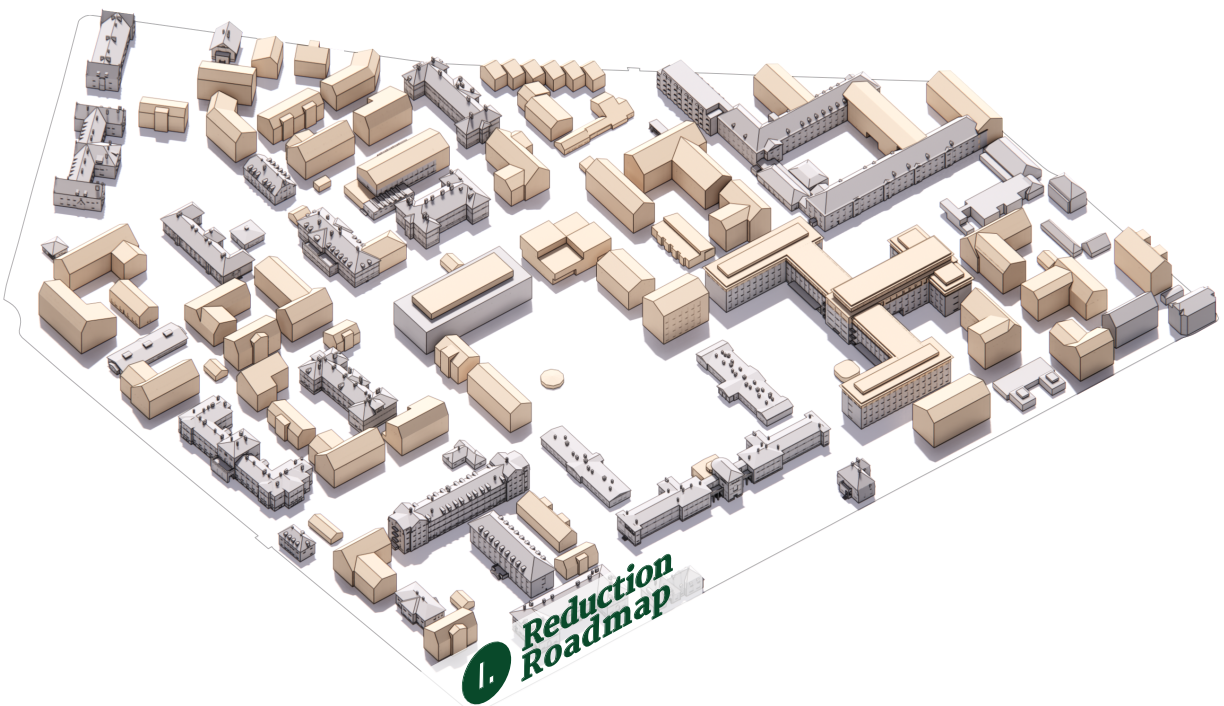
Scenario 3 represents the opposite approach, where no buildings are demolished, and all existing structures are either preserved or transformed. Scenarios 2 and 3 act as benchmarks for Scenario 1 and are both fictional; the visualizations are not design developments and do not reflect the square meters listed.

The same amount of people live in all scenarios.

Scenario 1a
Current planning
BR25

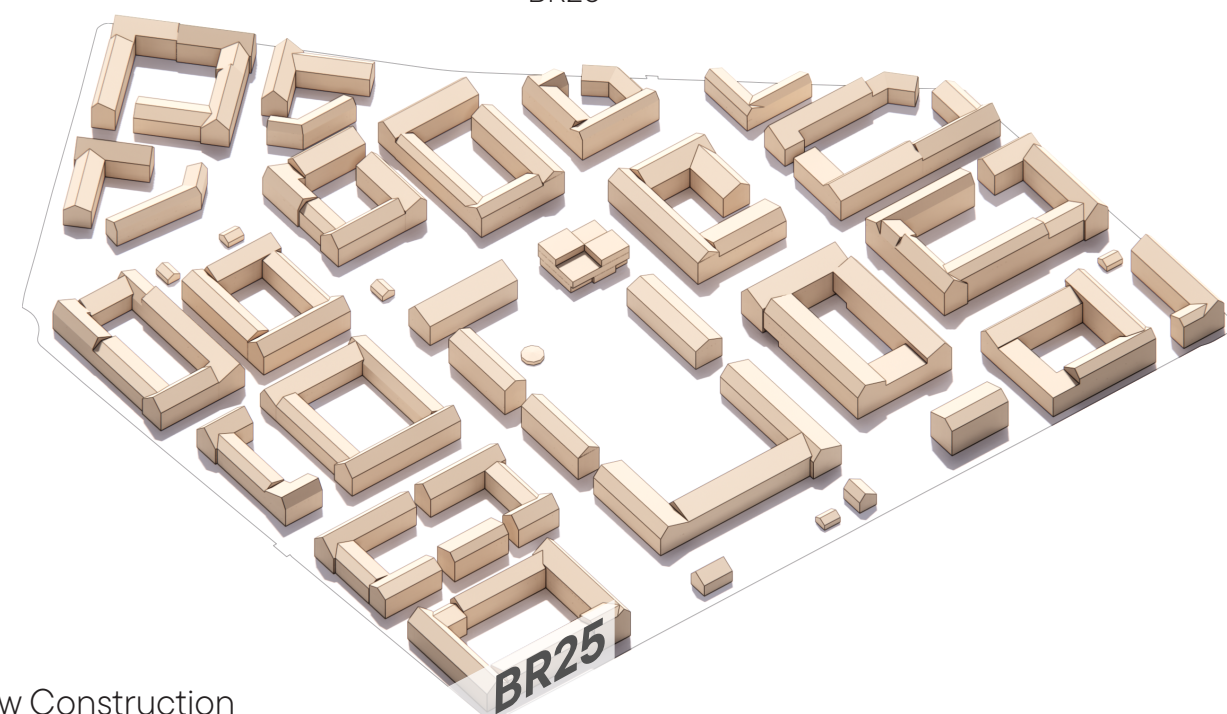


Scenario 1b
Current planning
Reduction Roadmap



Scenario 2

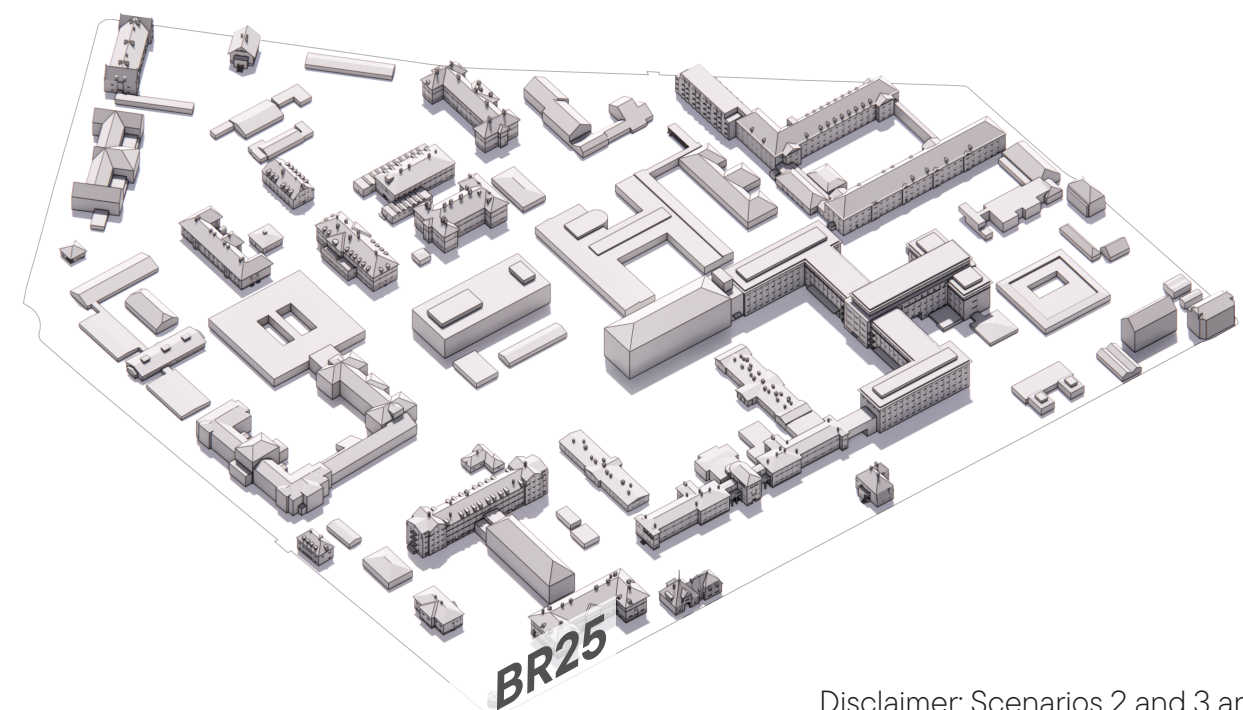
Demolition & New Build
BR25



- New Construction
- Transformation

Scenario 3

Transformation
BR25



Disclaimer: Scenarios 2 and 3 are fictional scenarios. The visualisations do not represent a design development and are not indicative of the listed m².

Scenario 1a

CURRENT PLANNING (BR25)

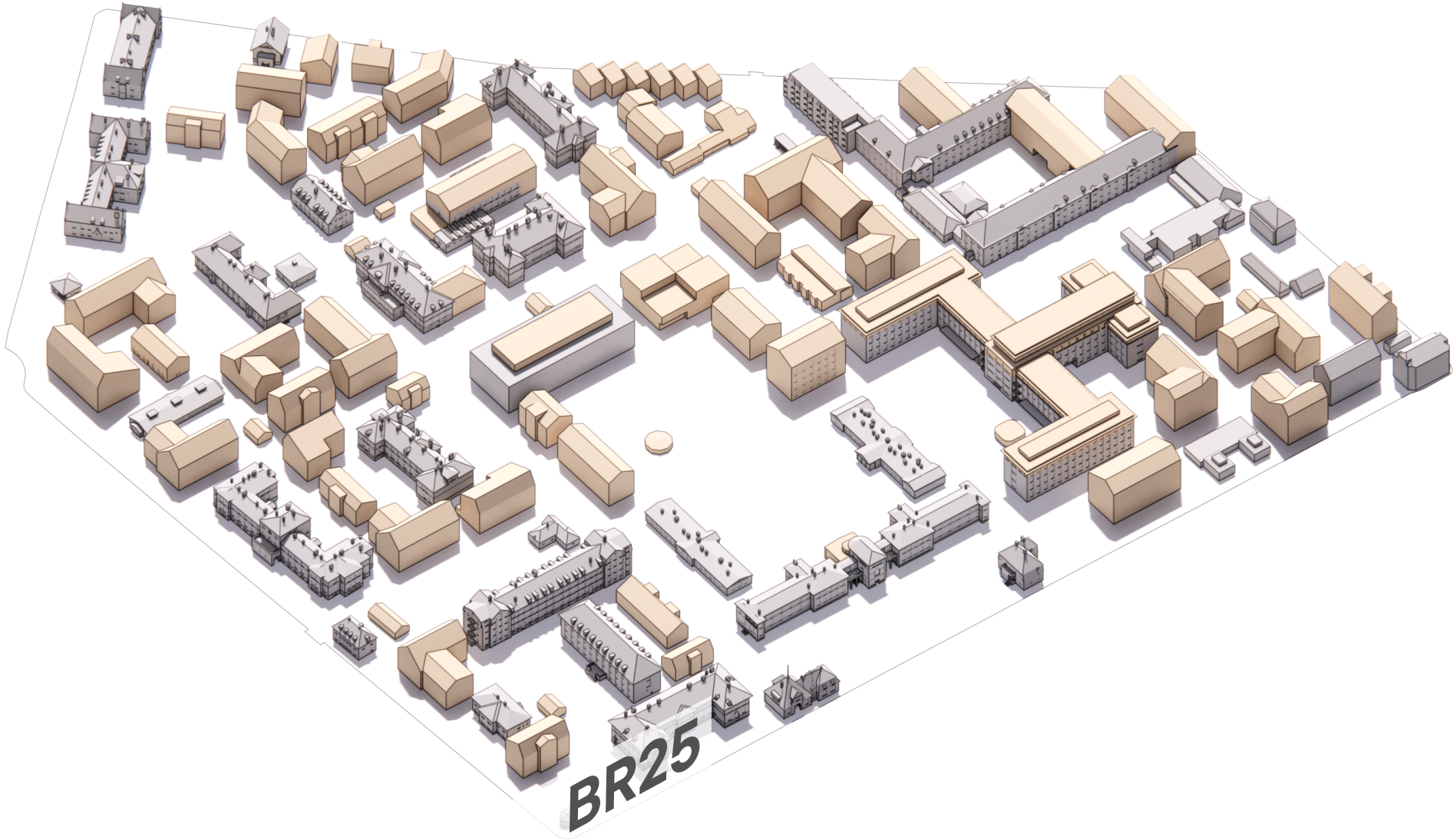
In scenario 1A, some existing buildings are being demolished, based on their assessed usability in the future development. Large parts of the existing building stock are preserved or transformed either as energy renovation or with a different use. 77.000 m² of new architecture is added to the site, as well as parking basements. It complies with BR25. Large parts of the landscape are preserved or upgraded, and a large effort has been made to keep the existing tree landscape.

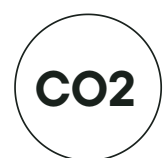
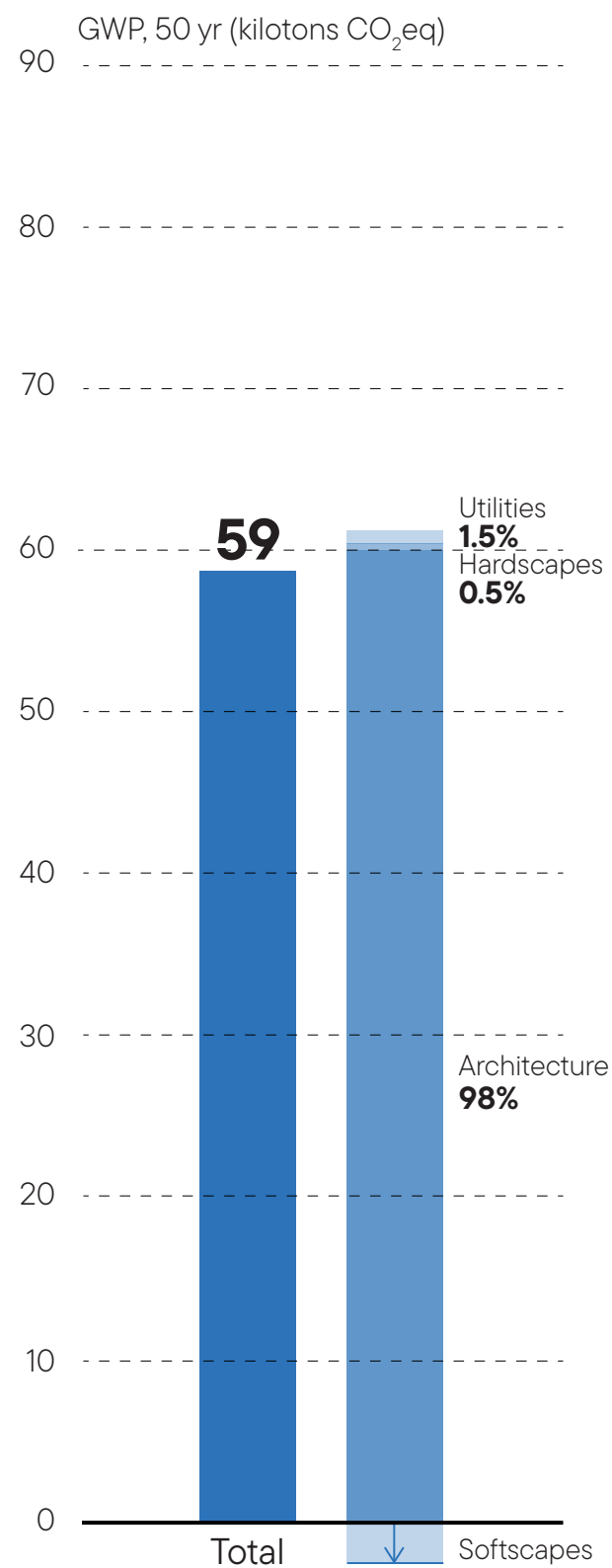
As a result, Scenario 1A results in 59 kilotons of CO₂ and 117 kilotons of material footprint. The development provides housing for 1950 residents and allocates 47 m² per person, which is the average for Frederiksberg Kommune.

The scenario has a biofactor of 0.65 (based on the DGNB method, which differs from the specific method of Frederiksberg). As for all other scenarios, since the Softscape category sequesters more emissions than it creates, they are deducted from the total CO₂ emissions.

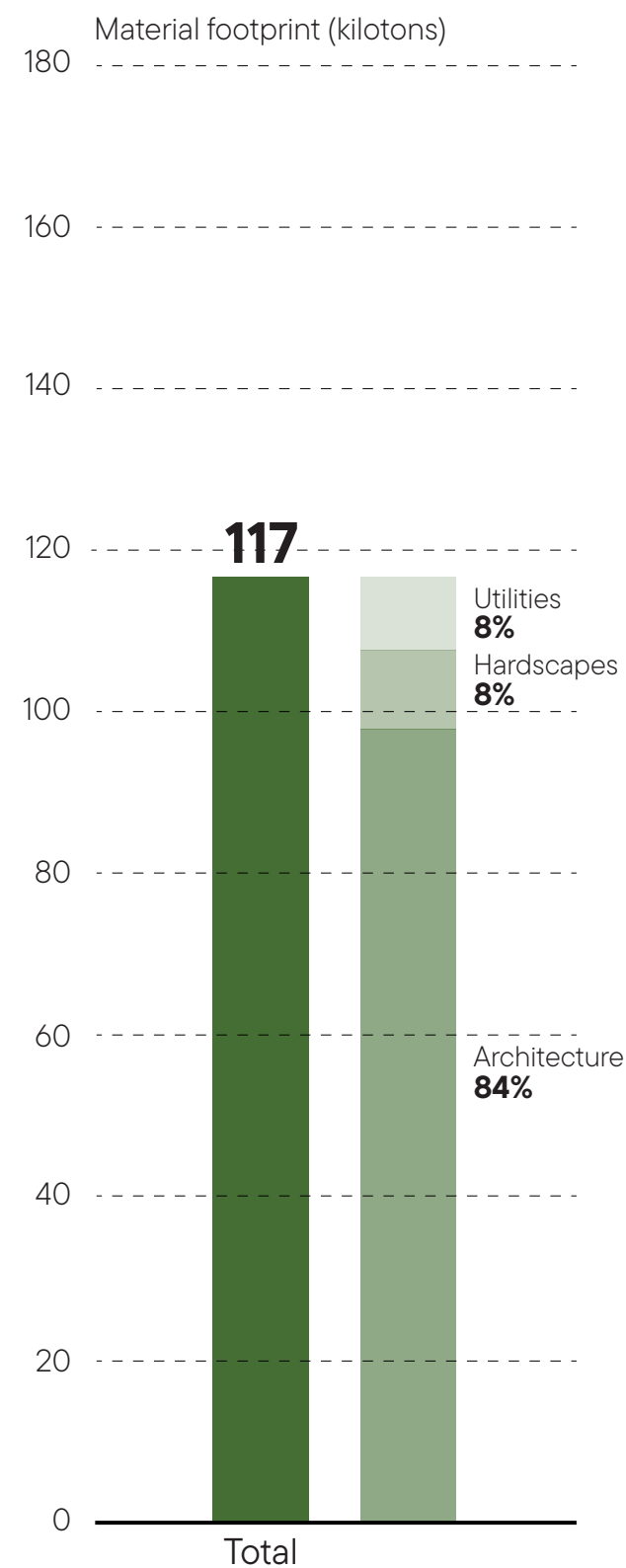
Scenario Info	
Total m ² :	145.800 m ²
New construction:	77.000 m ²
↳ whereof parking basements:	12.900 m ²
Transformed:	55.000 m ²
Demolished:	14.150 m ²
Preserved:	13.800 m ²
Residents:	1950 people

- New Construction
- Transformation

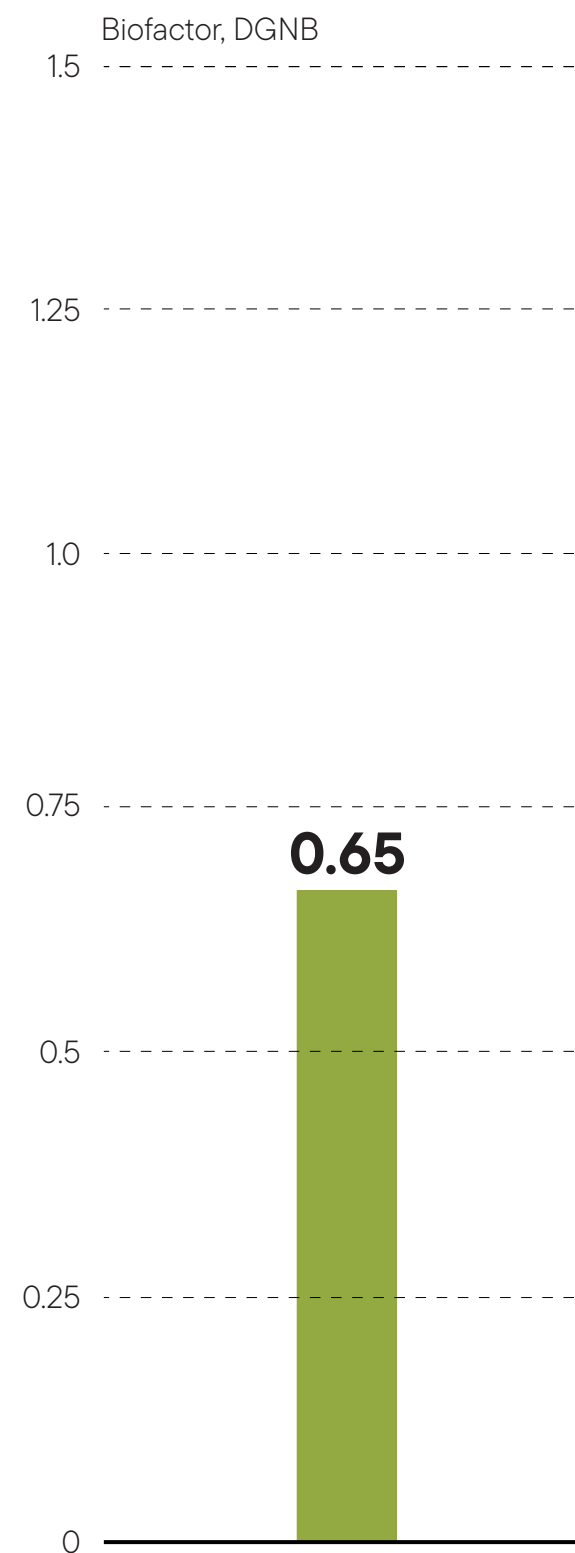




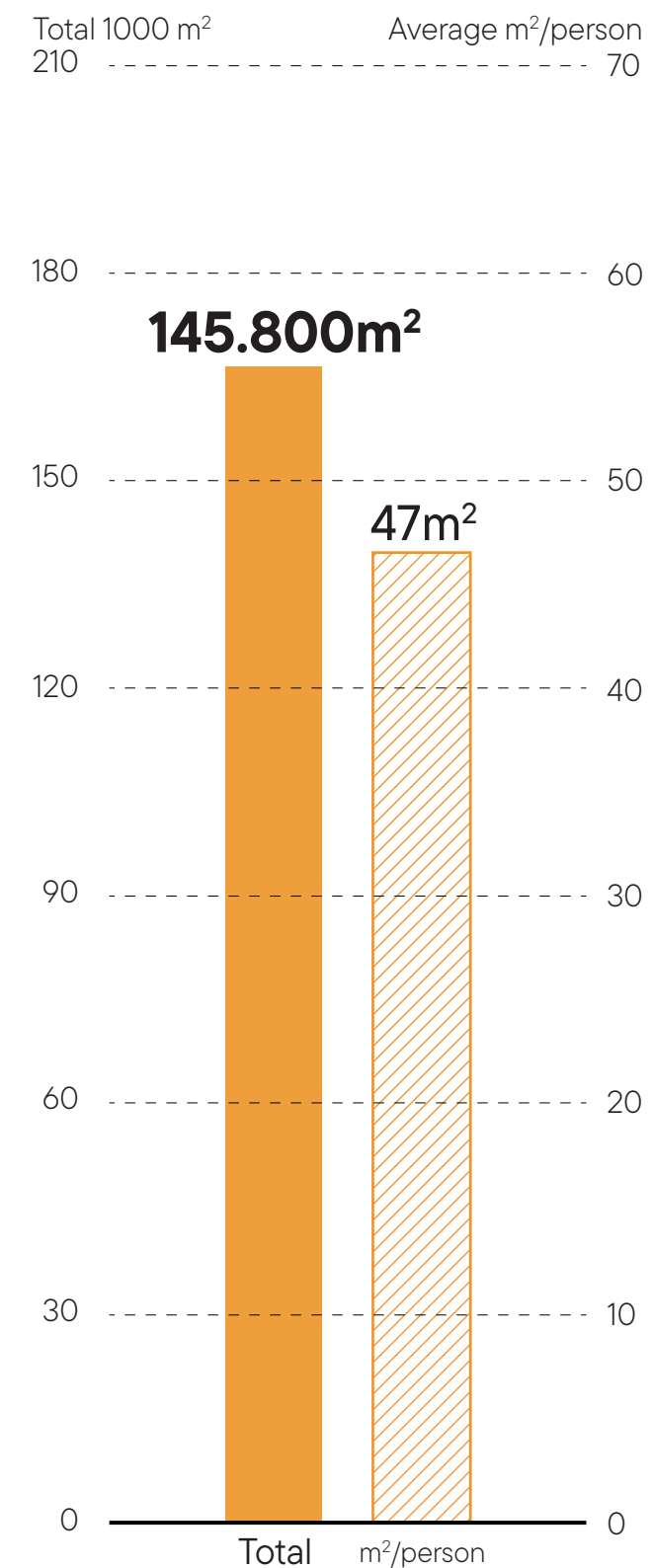
CO₂ emissions



Material footprint



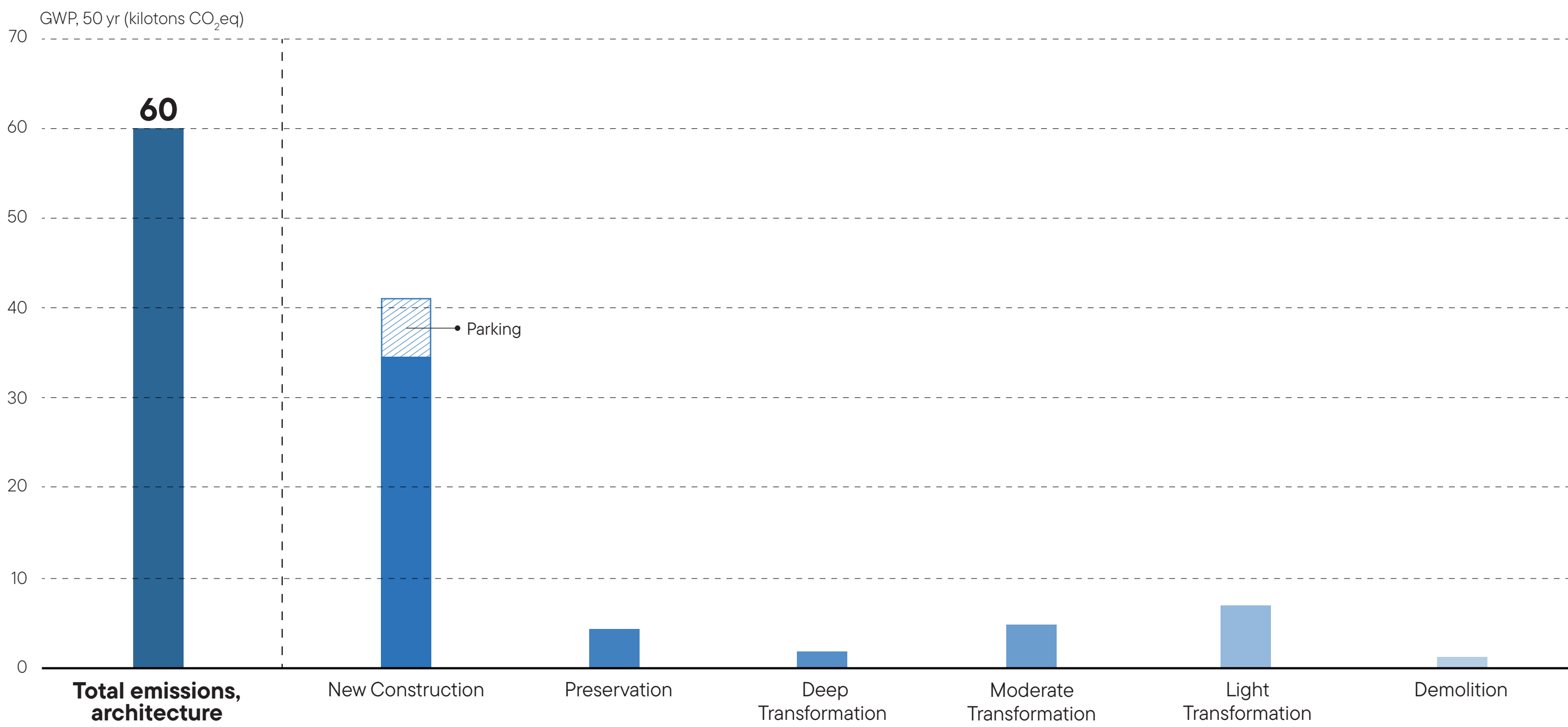
Biofactor



Building Area

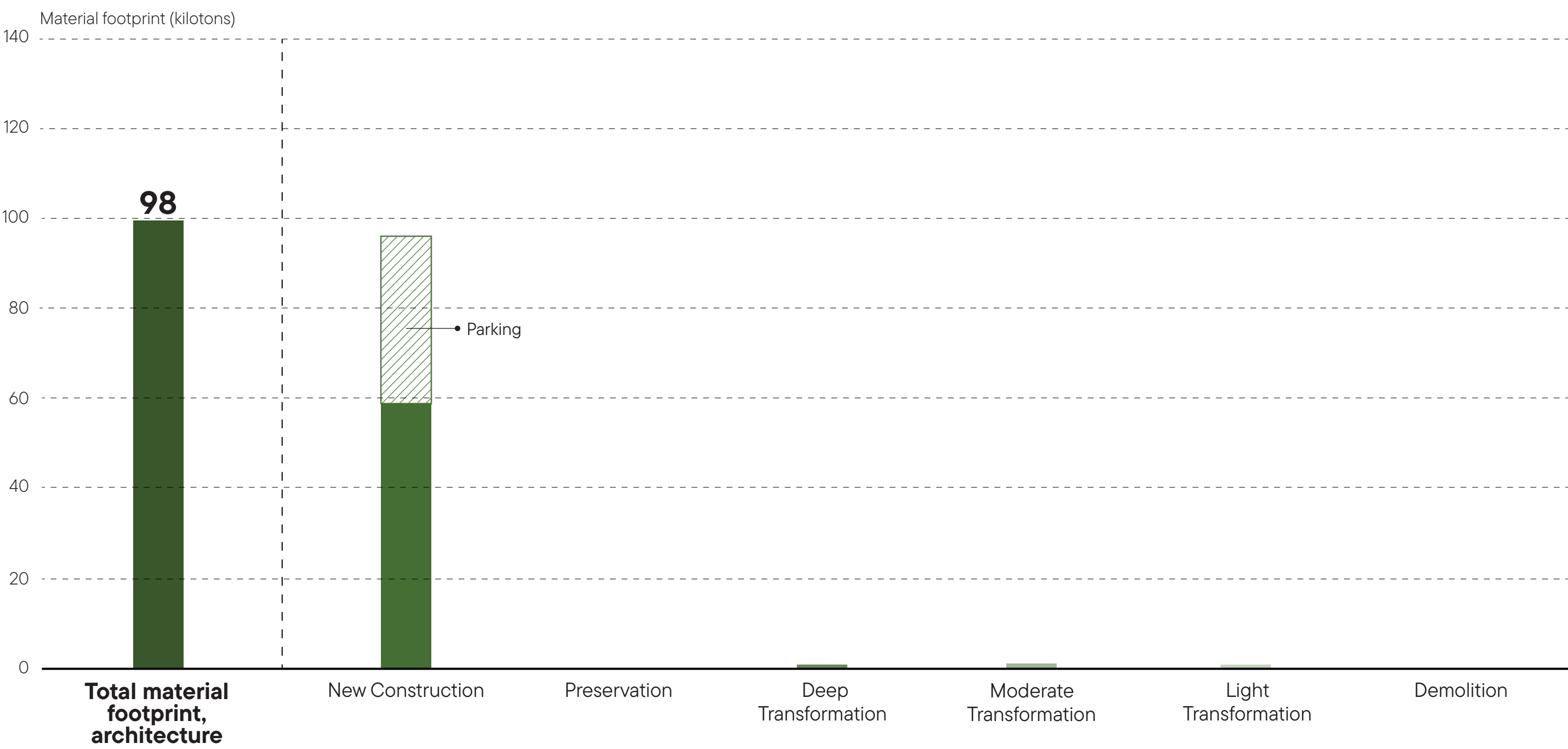
DETAILED CO₂ EMISSIONS - ARCHITECTURE

For a more detailed analysis of the architecture category of Scenario 1A, the following graphs show the distribution between the different construction activities - from new construction to demolition. The Softscapes sequester a part of the total emissions, therefore the total emissions are lower than the emissions shown here. The graph clearly shows, that new construction accounts for the largest share of emissions.



DETAILED MATERIAL FOOTPRINT - ARCHITECTURE

For a more detailed analysis of the architecture category of Scenario 1A, the following graphs show the distribution between the different construction activities - from new construction to demolition. The graph clearly shows, that new construction accounts for the largest share of material footprint.



Scenario 1b

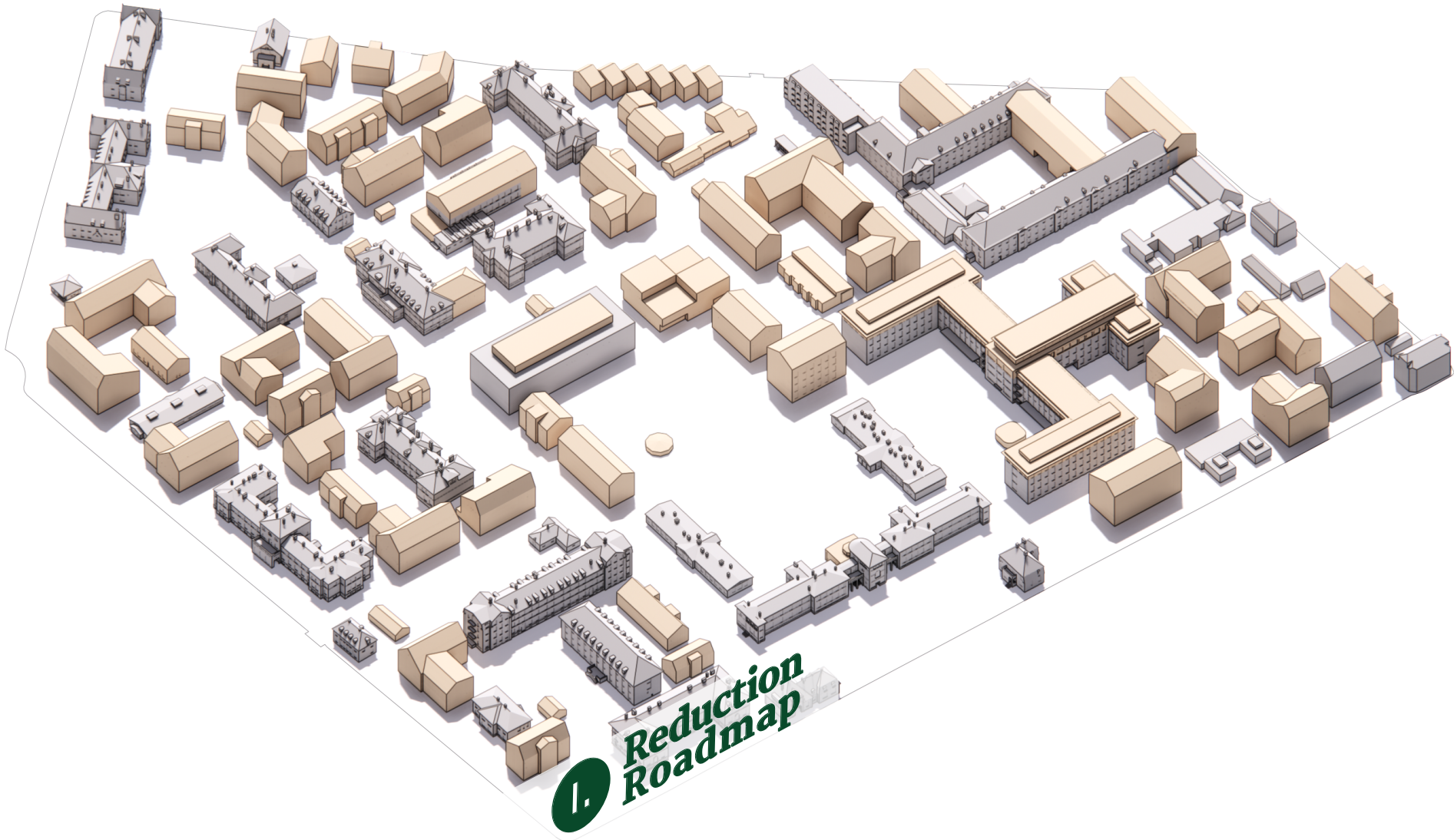
CURRENT PLANNING (REDUCTION ROADMAP)

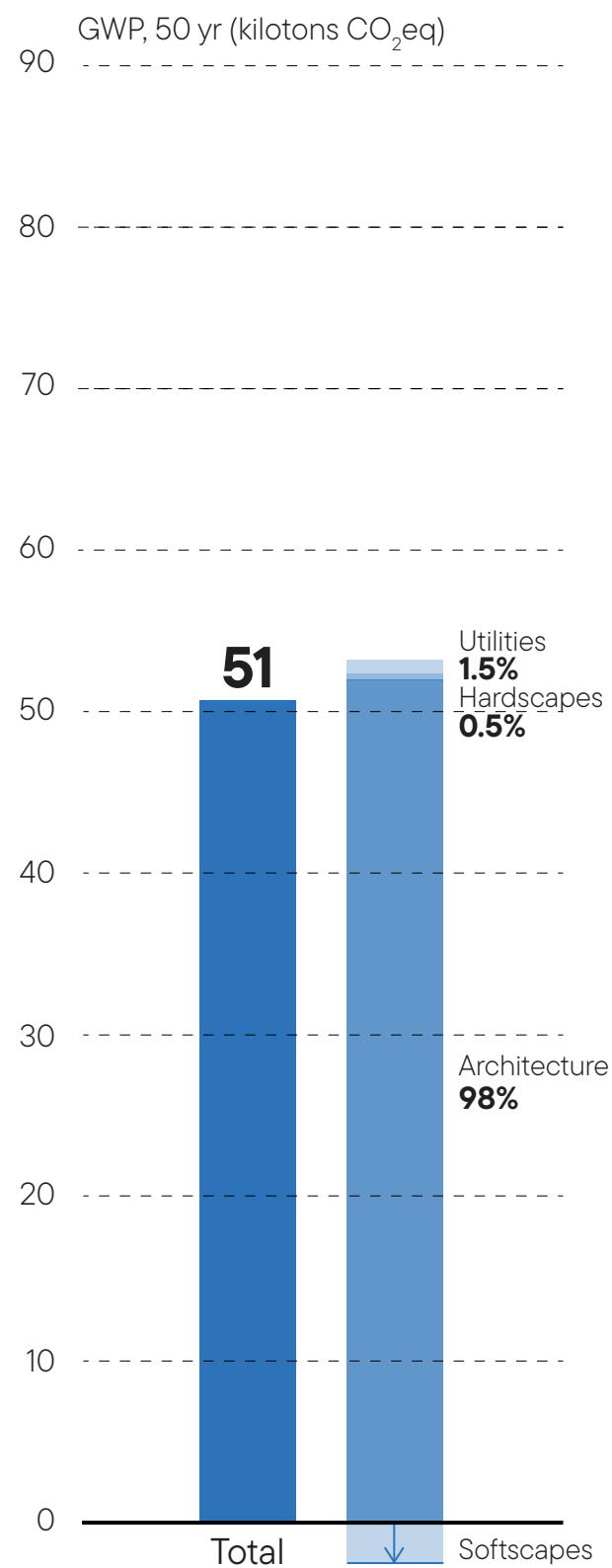
In Scenario 1B, the difference to 1A is only the selected sustainability class – Reduction Roadmap 2025 instead of BR25.

Scenario 1B results in 51 kilotons of CO₂ and 96 kilotons of material footprint. Since the sustainability class only impacts the Architecture category, the biofactor remains unchanged from Scenario 1A, as does the average of 47 m² per person.

Scenario Info	
Total m ² :	145.800 m ²
New construction:	77.000 m ²
↳ whereof parking basements:	12.900 m ²
Transformed:	55.000 m ²
Demolished:	14.150 m ²
Preserved:	13.800 m ²
Residents:	1950 people

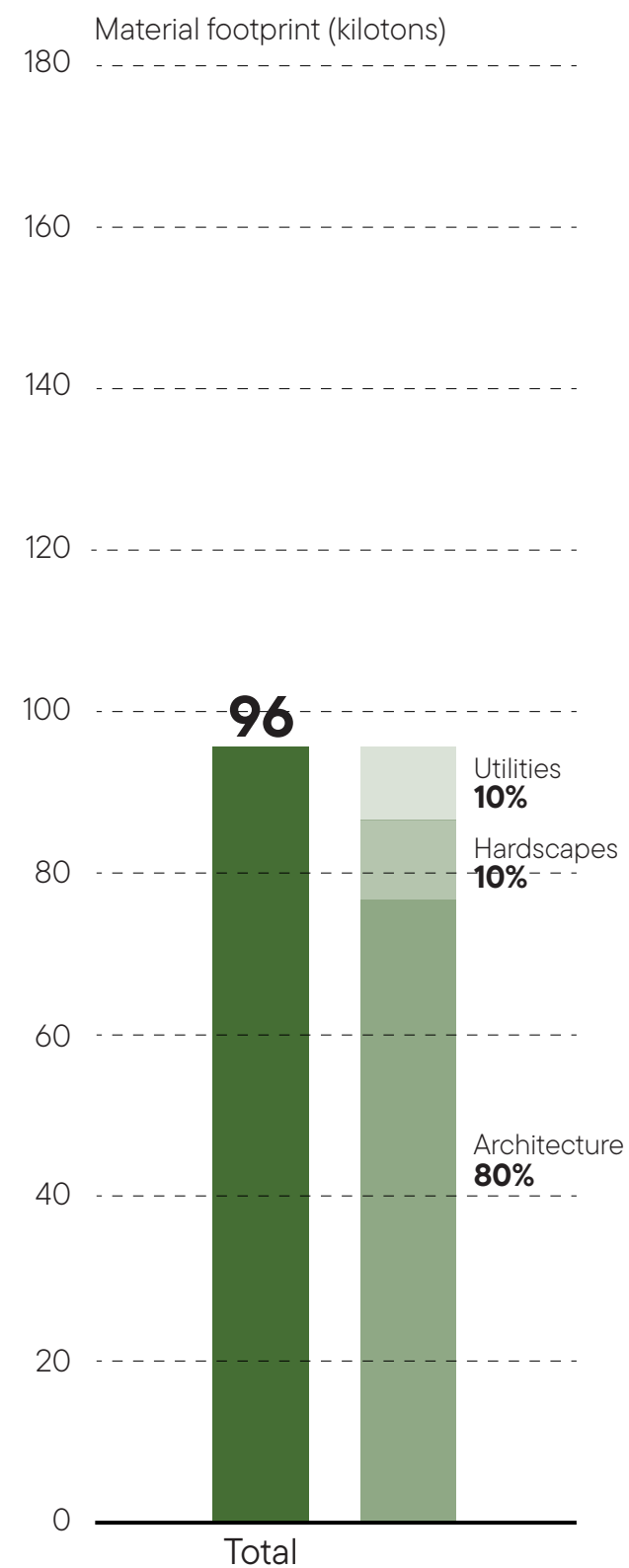
- New Construction
- Transformation



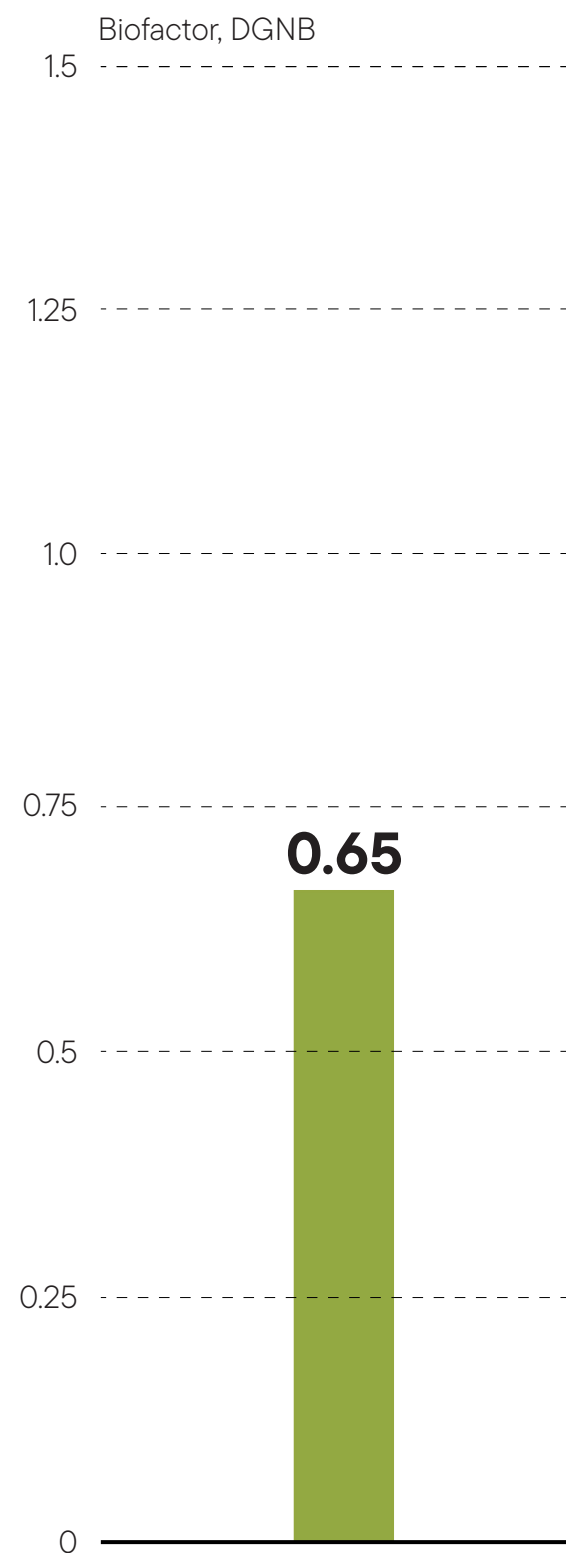


CO₂

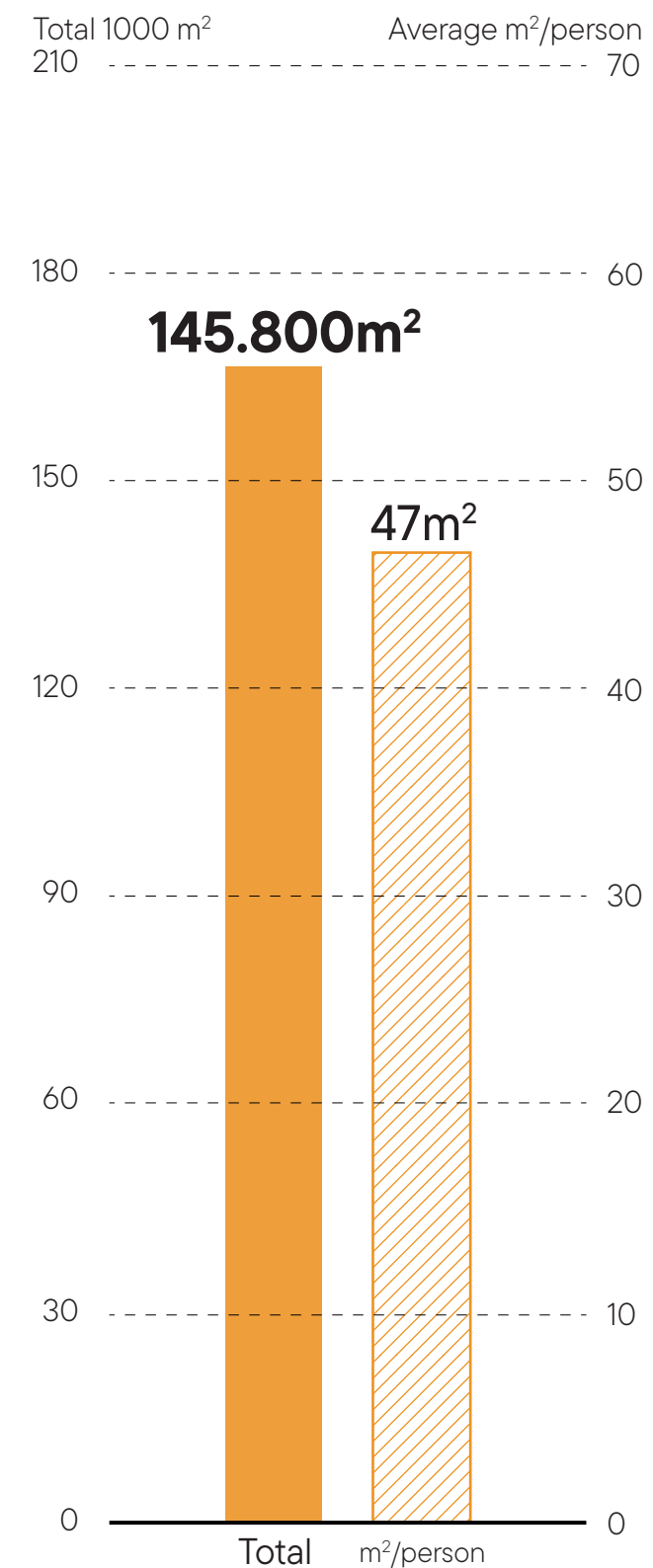
CO₂ emissions



Material footprint



Biofactor



m²

Building Area

Scenario 2

DEMOLITION & NEW BUILD (BR25)

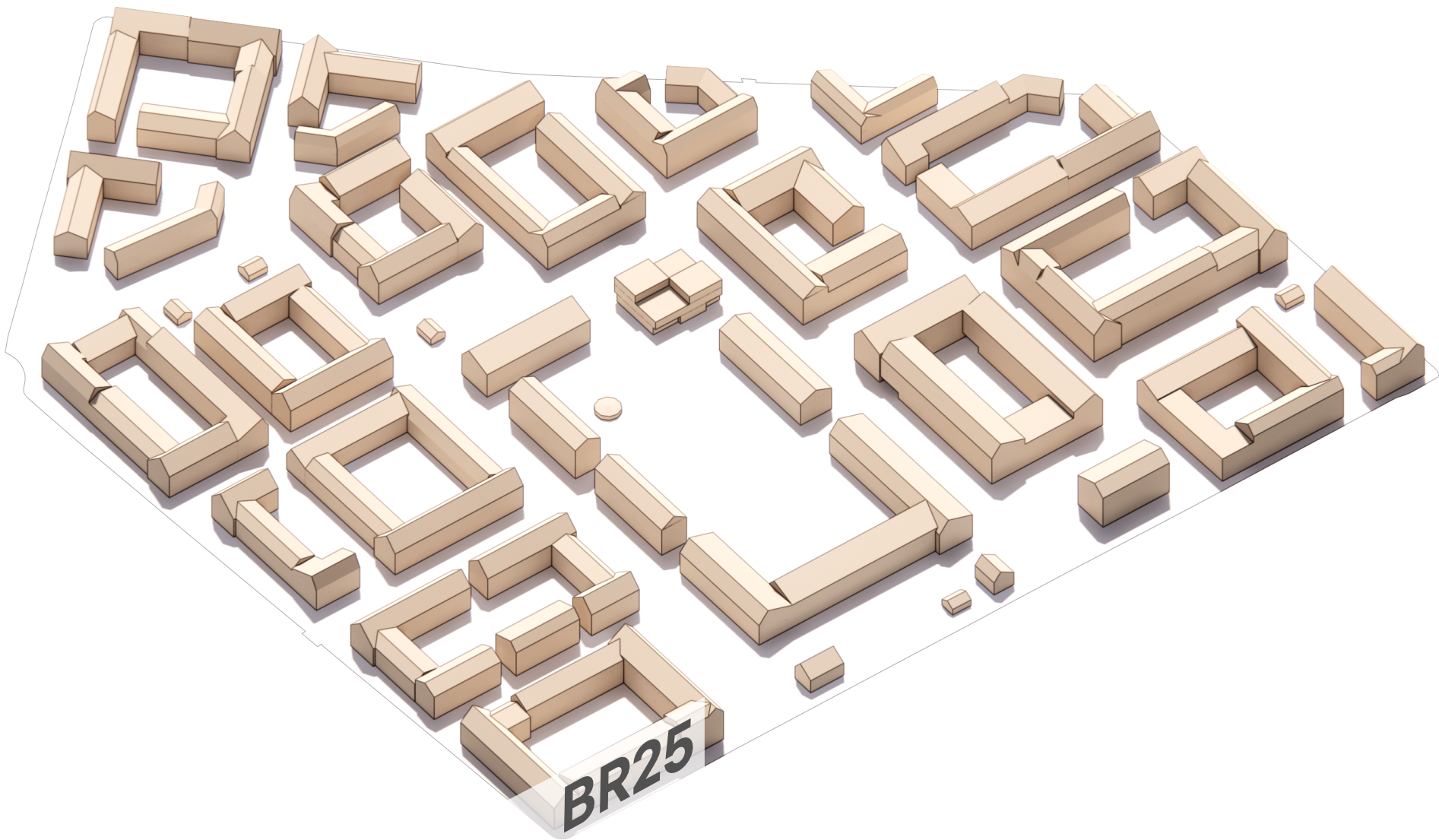
In scenario 2, all existing buildings are being demolished (as often the case for green-field urban development) and replaced with new construction as large courtyard buildings. The scenario complies with BR25. Trees have been removed where necessary for construction activity and a minimum of landscape architecture has been carried out.

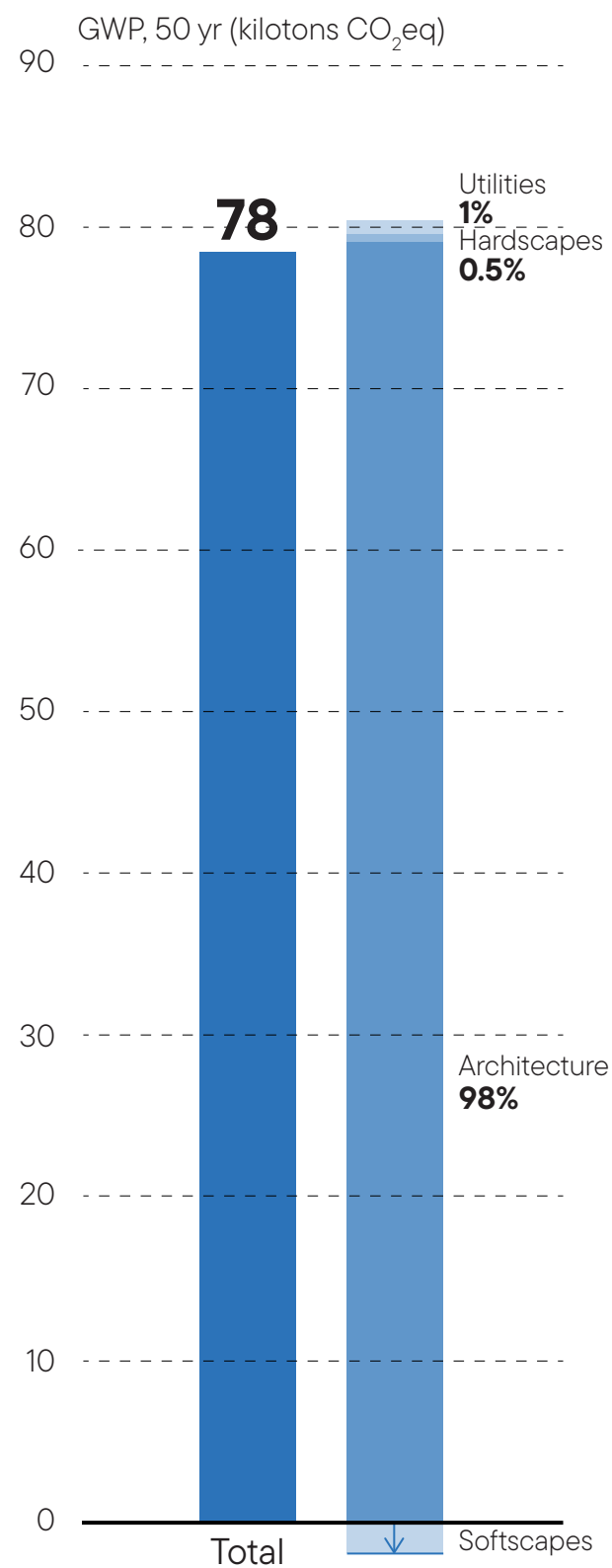
As a result, Scenario 2 produces 78 kilotons of CO₂ and 177 kilotons of material footprint. The limited landscaping also leads to a decrease in biofactor. **The square meters and functions in this scenario match those of Scenarios 1A and 1B.**

Disclaimer: This is a fictional scenario. The visualisation does not represent a design development and is not indicative of the m² listed below.

Scenario Info	
Total m ² :	145.800 m ²
New construction:	145.800 m ²
↳ whereof parking basements:	12.900 m ²
Transformed:	0 m ²
Demolished:	69.200 m ²
Preserved:	0 m ²
Residents:	1950 people

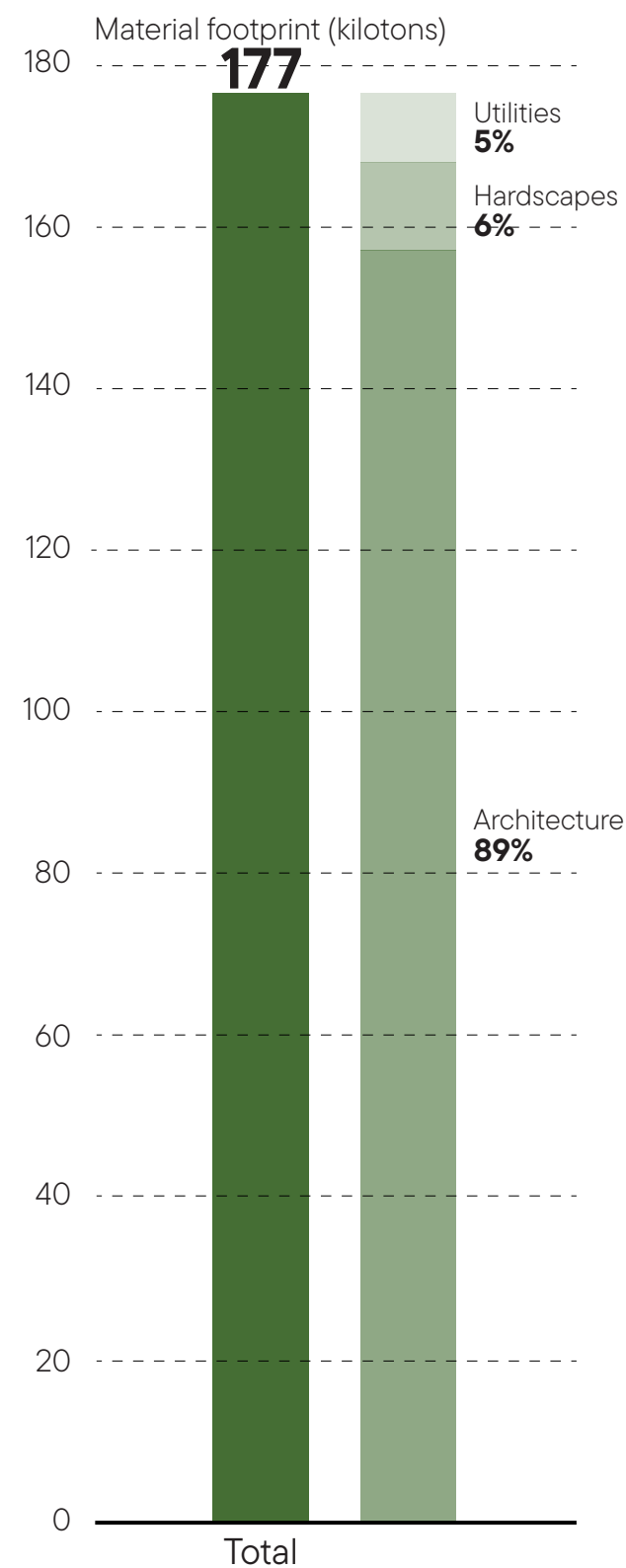
- New Construction
- Transformation



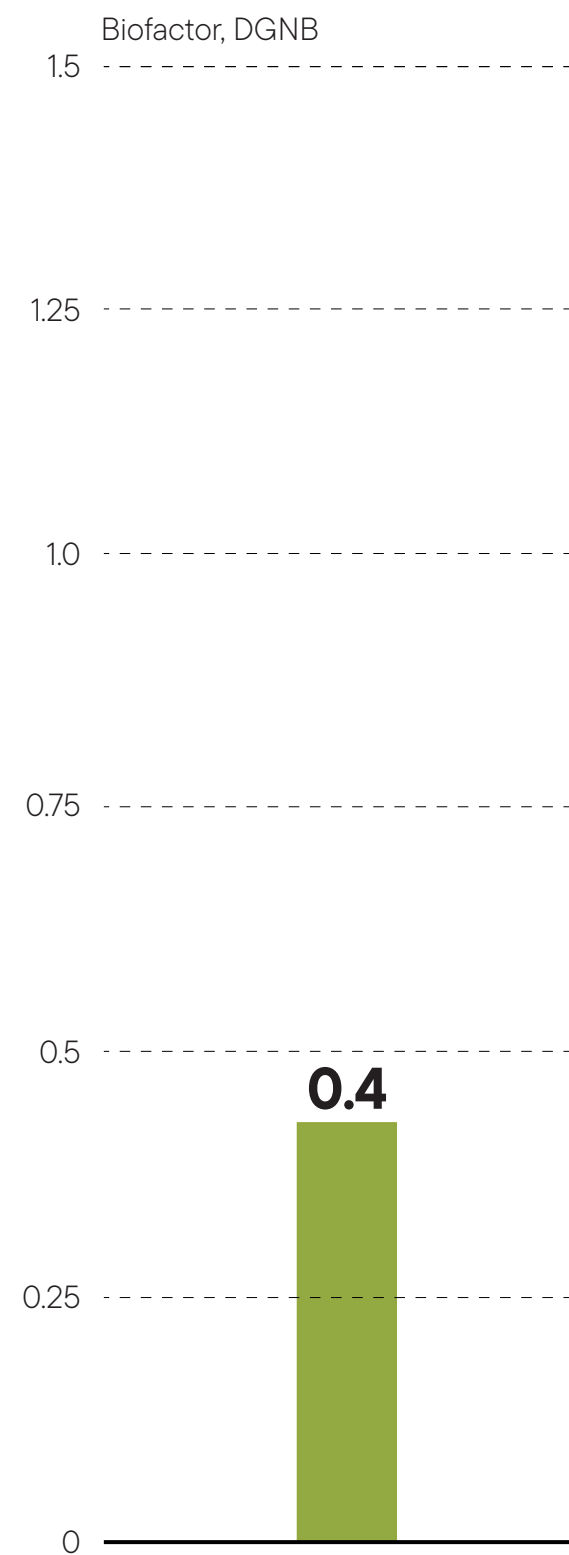


CO₂

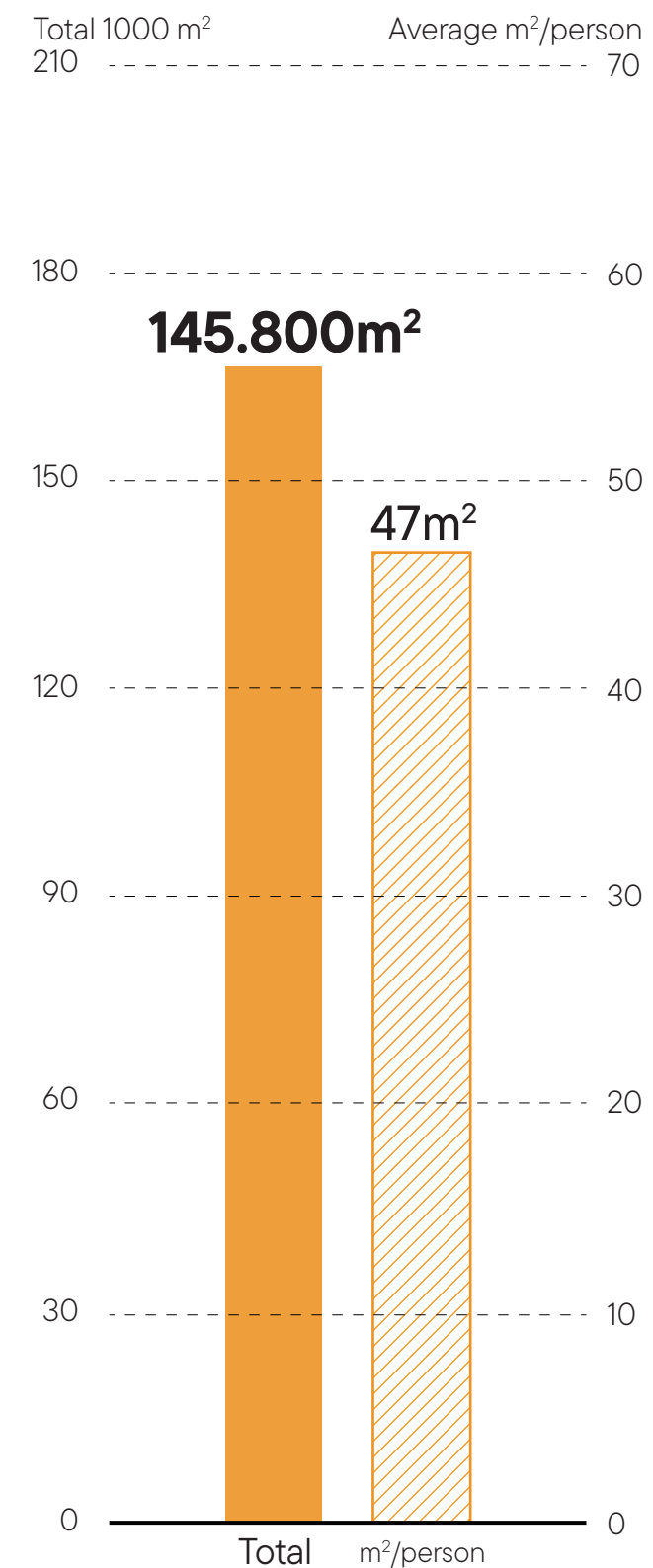
CO₂ emissions



Material footprint



Biofactor



m²

Building Area

Scenario 3

TRANSFORMATION (BR25)

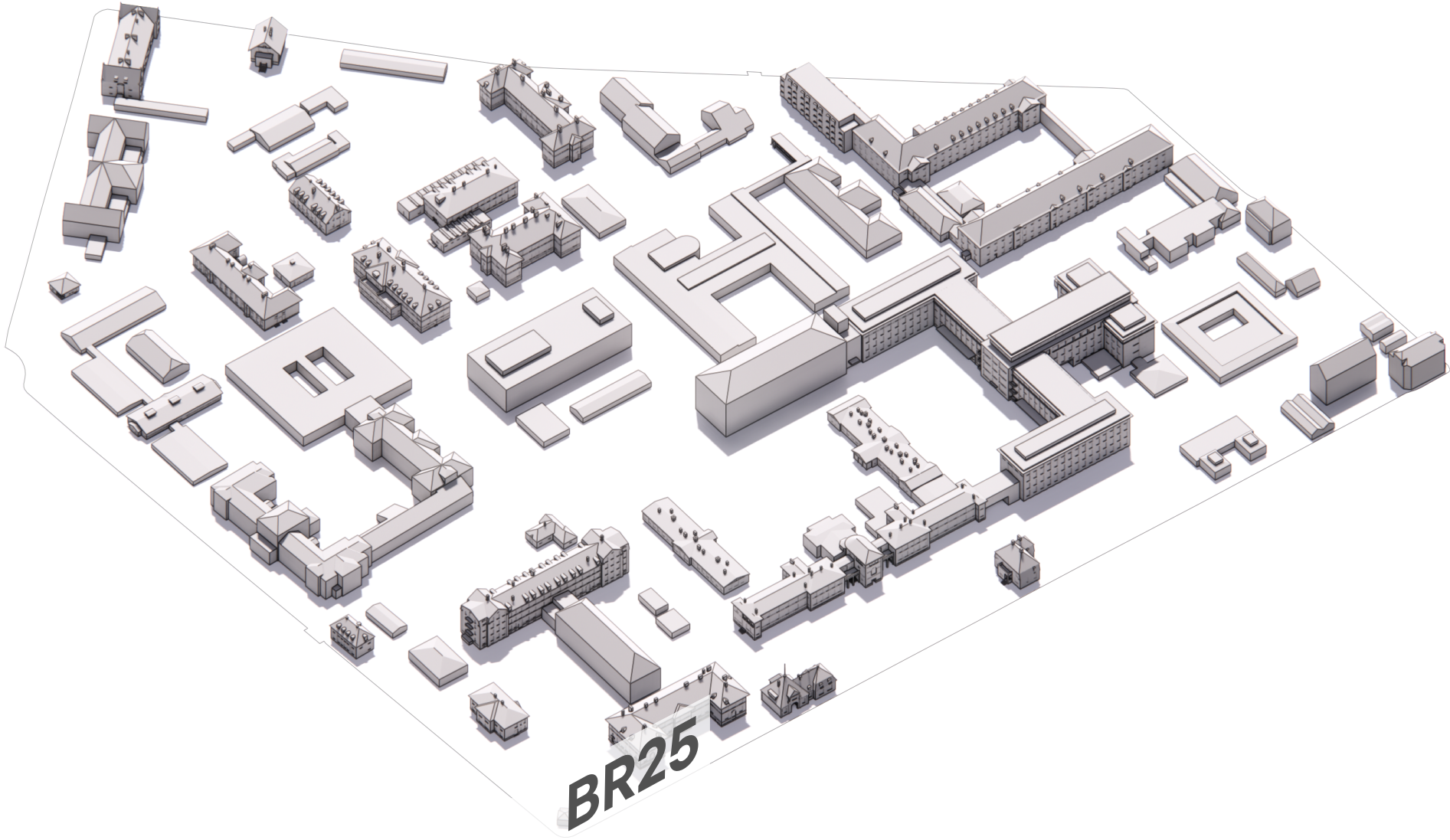
In Scenario 3, no buildings are demolished; instead, all existing structures are either preserved or transformed. This scenario also complies with BR25. For softscapes, the most carbon-sequestering options have been chosen, and a minimal amount of hardscapes selected, with the remaining site area rewilded. A 5-story parking house has been included.

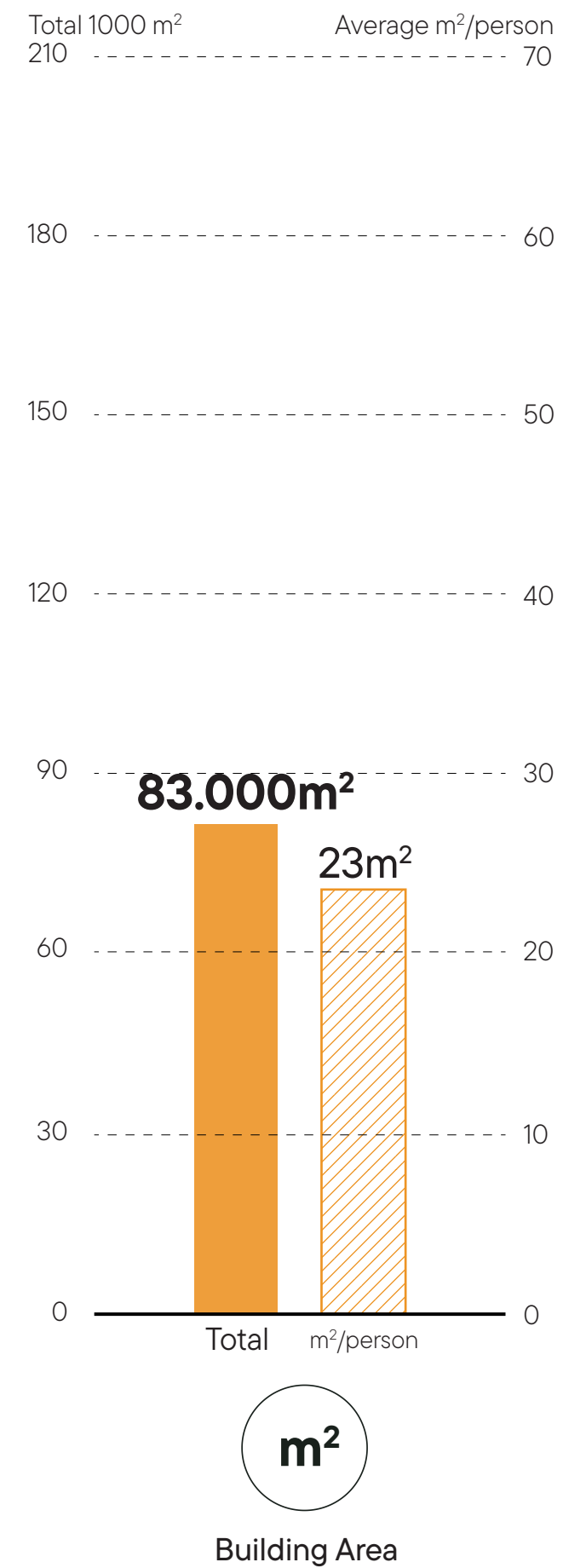
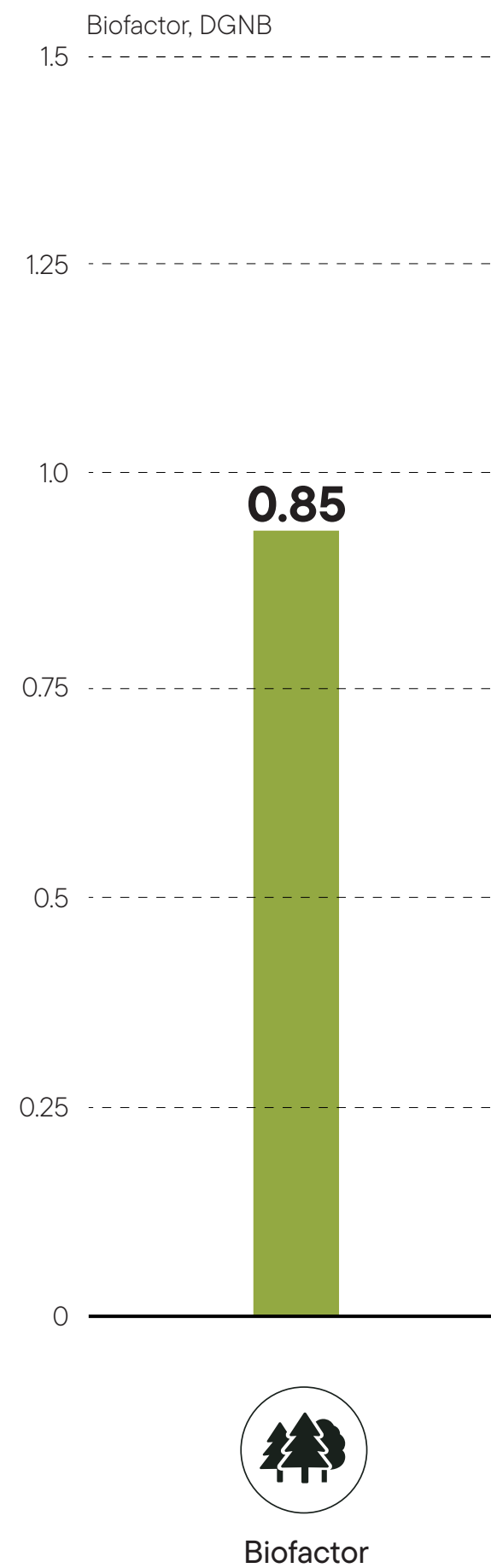
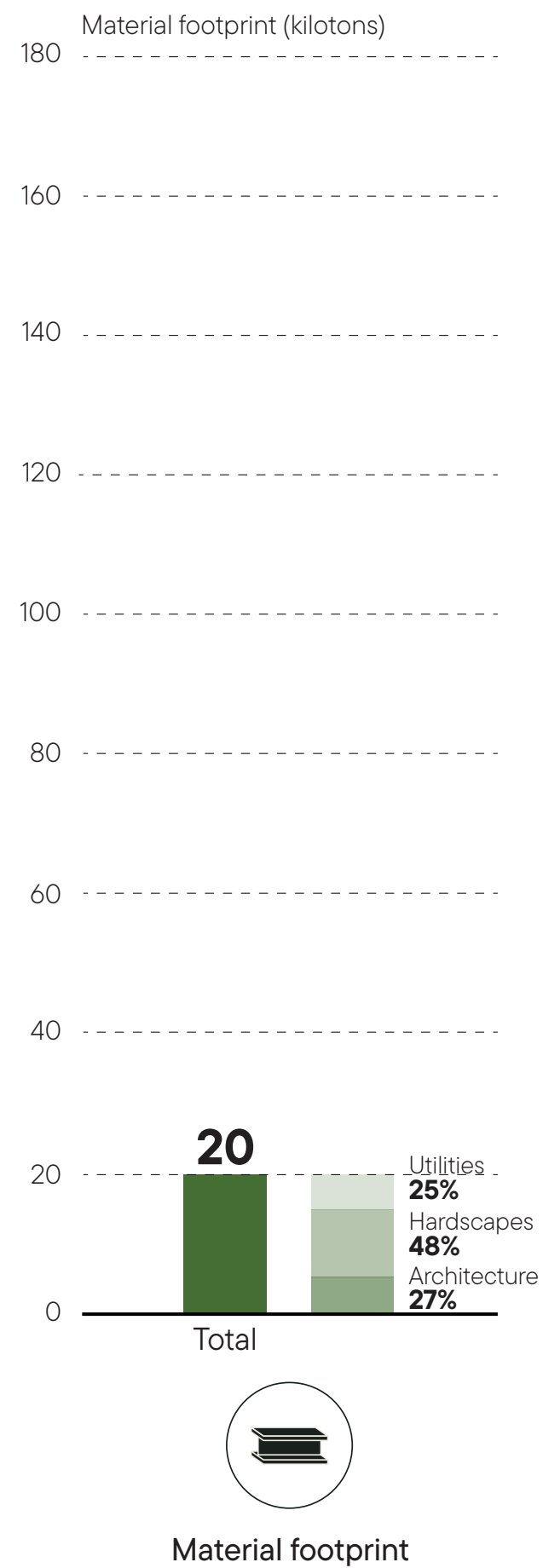
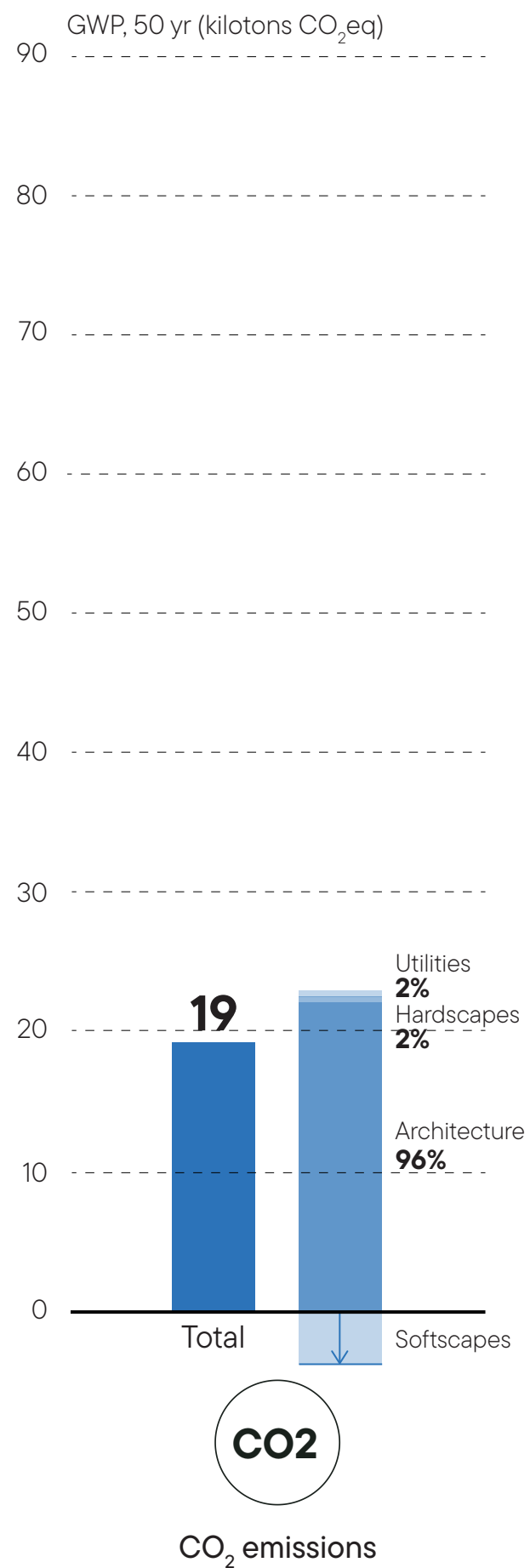
As a result, Scenario 3 leads to significantly lower carbon emissions (19 kilotons of CO₂) and material footprint (20 kilotons), while also raising the biofactor. For comparative reasons, this scenario also houses 1950 residents, and since it only has 83.000 m² of building space, this results in 23 m² per resident - much lower than the other scenarios.

Disclaimer: This is a fictional scenario. The visualisation does not represent a design development and is not indicative of the m² listed below.

Scenario Info	
Total m ² :	83.000 m ²
New construction:	0 m ²
Transformed:	69.200 m ²
↳ whereof parking basements:	6.000 m ²
Preserved:	13.800 m ²
Demolished:	0 m ²
Residents:	1950 people

- New Construction
- Transformation





Comparison of results

Comparing the results of the four scenarios shows a clear picture: both the choice of construction activities (transformation vs. demolition & new construction) as well as the sustainability class highly influence the results.

Scenario 2 results in the highest carbon emissions and material footprints, while also having the lowest biofactor. Scenario 1A, using BR25 as the sustainability class for architecture, has higher emissions and material footprints than Scenario 1B with the Reduction Roadmap 2025 limit.

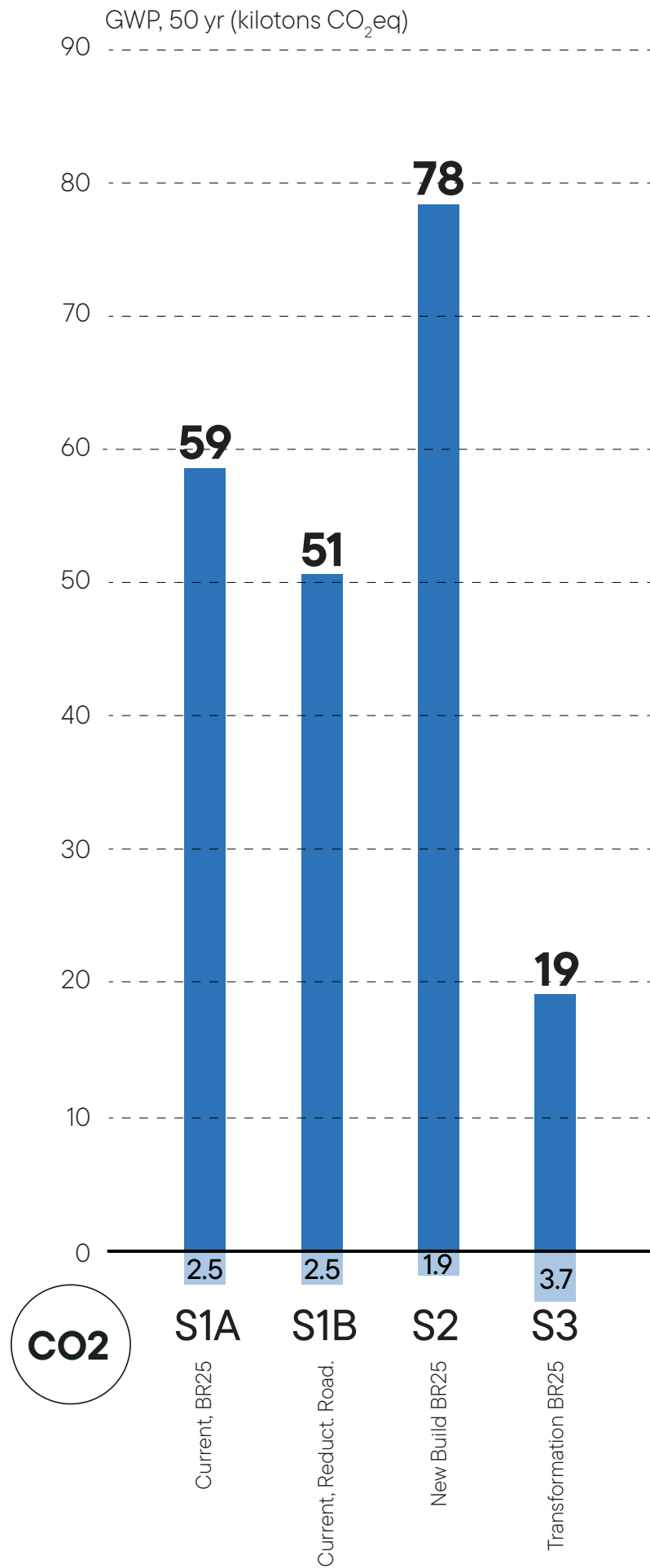
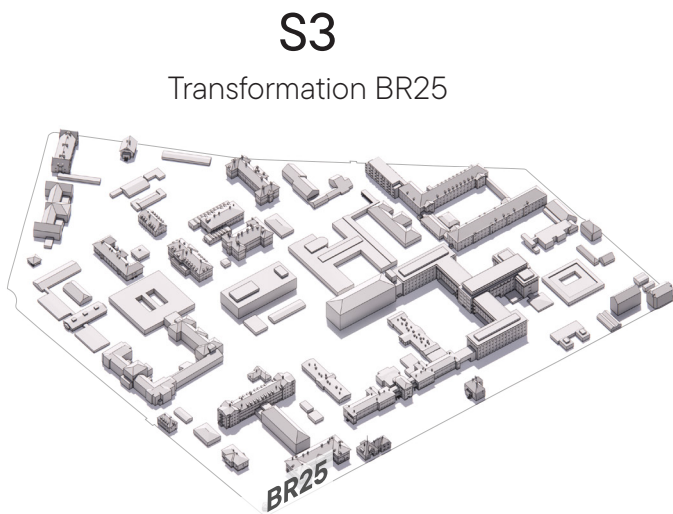
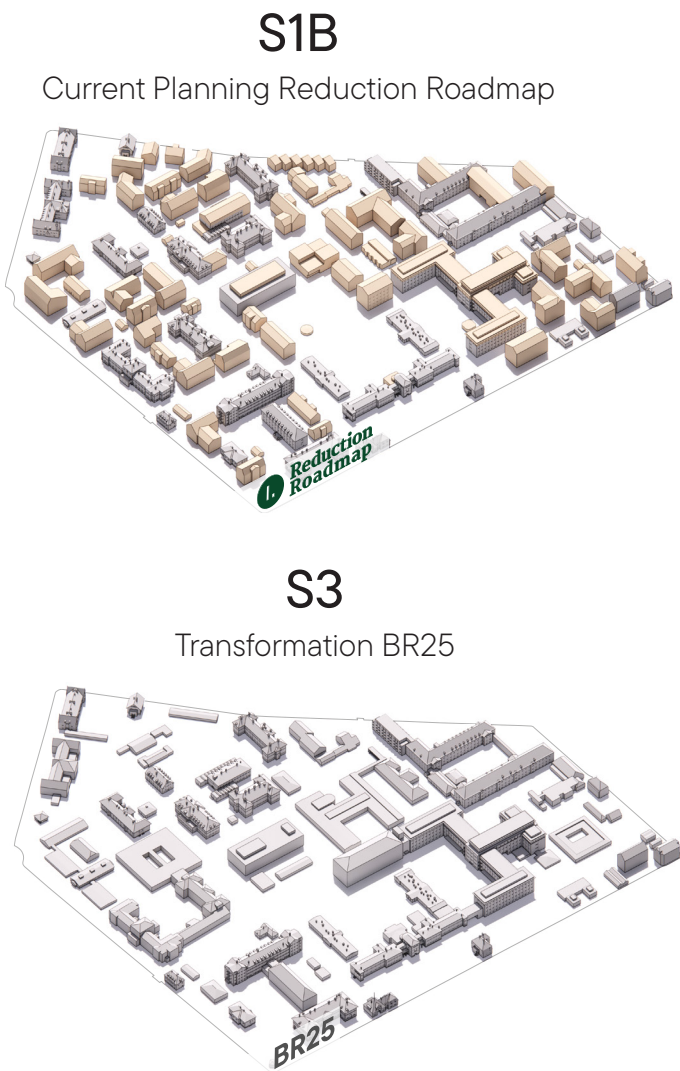
In contrast, Scenario 3, focused solely on transformation and preservation with significantly fewer square meters built, generates the lowest impact and the best biofactor. With a significantly lower total m² and the same amount of residents, the 47 m² per resident from the other scenarios drops to 23 m² per resident in this scenario.

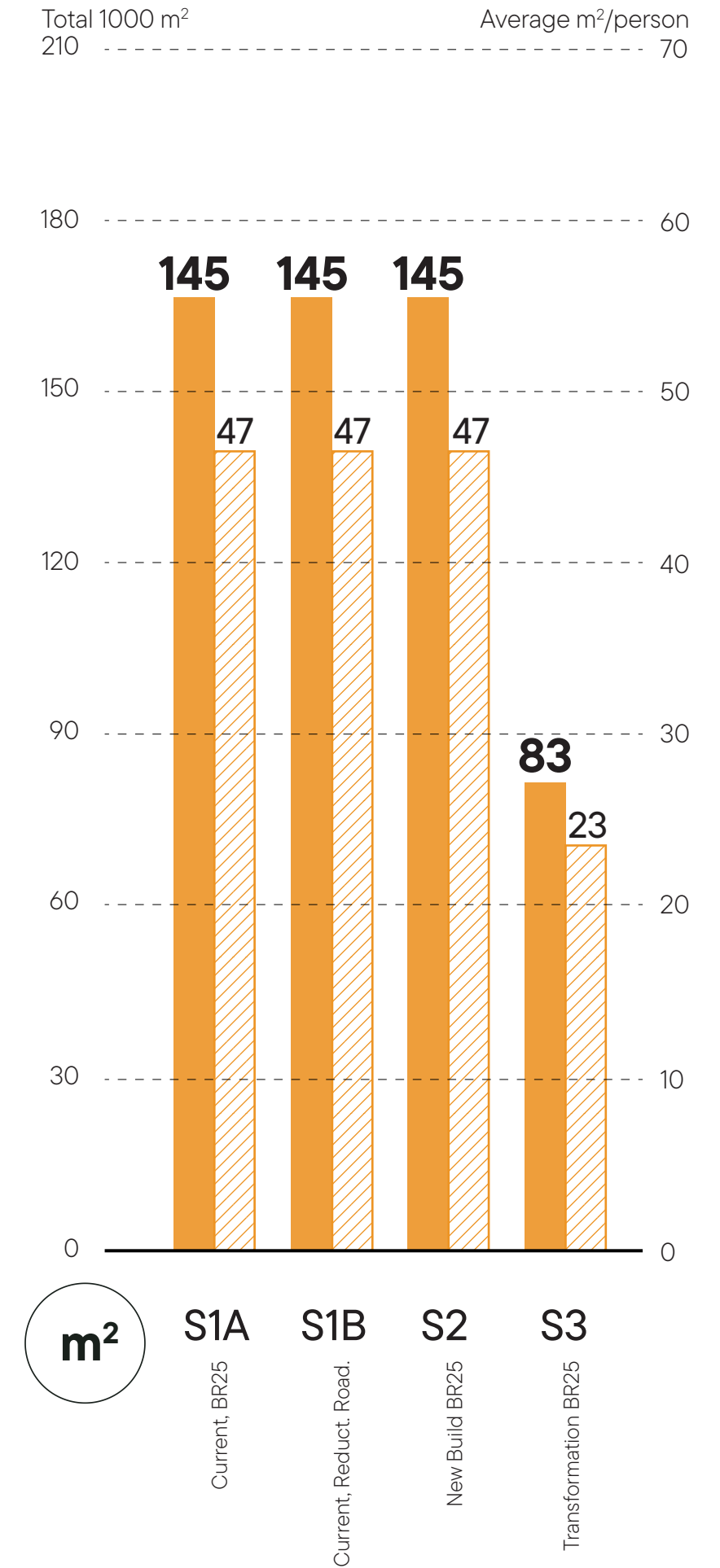
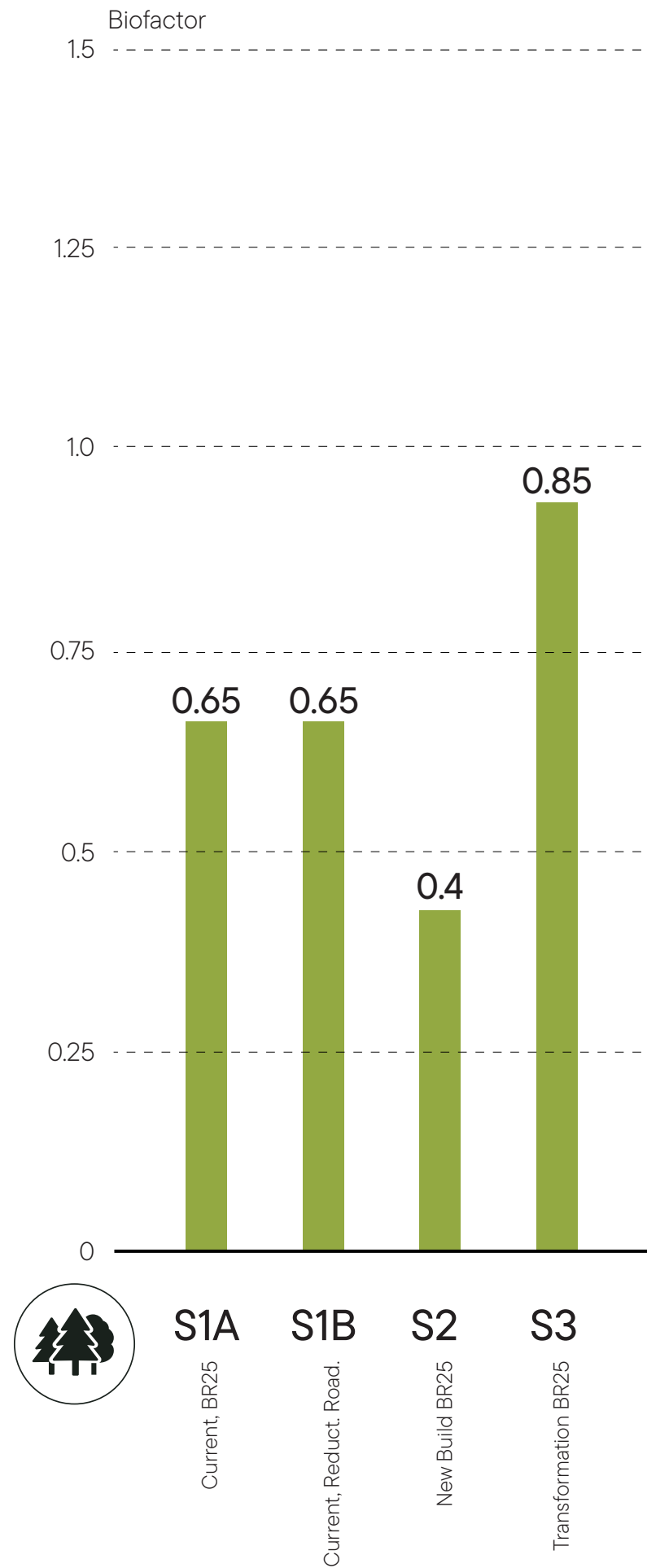
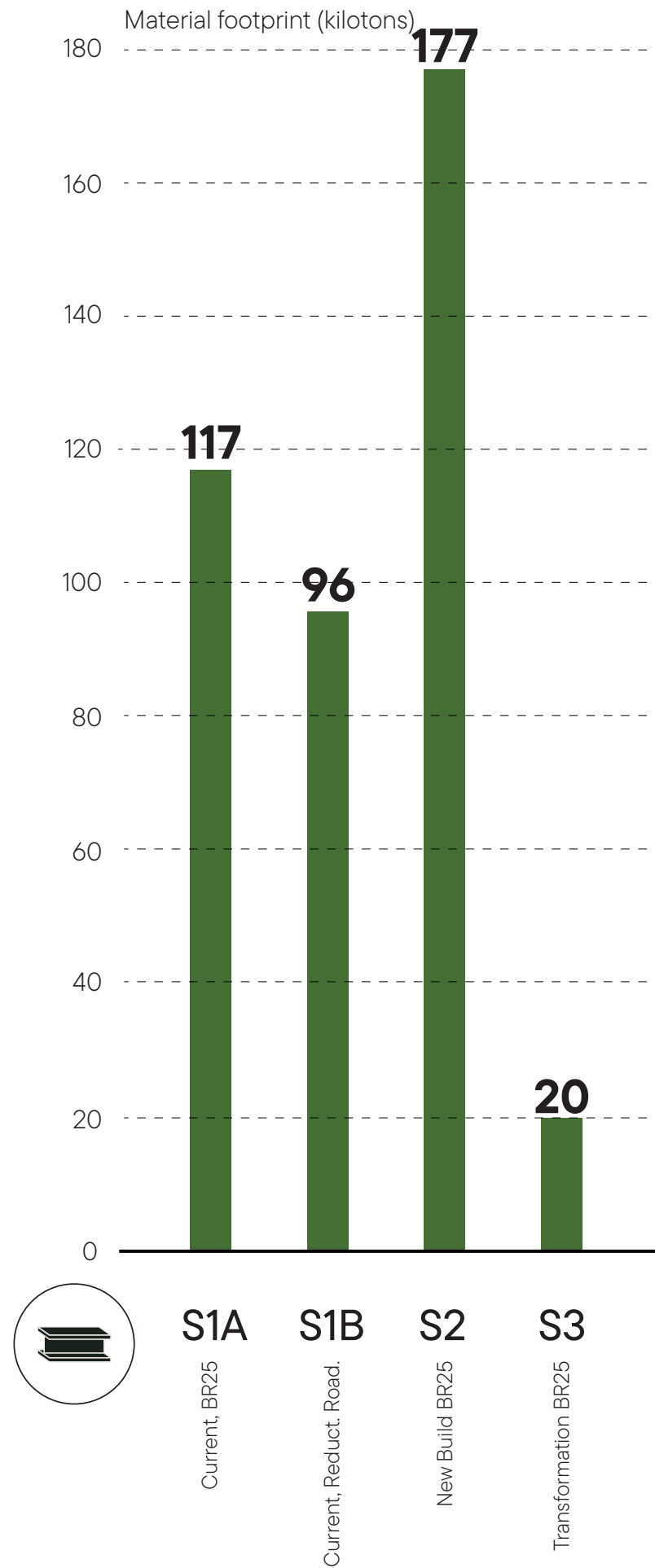
In conclusion, transforming urban areas rather than new construction is the most effective way to reduce climate impact and material consumption. In addition, the choice of sustainability class for new construction has a major impact on the overall impact, illustrated here by the difference between BR25 requirements and Reduction Roadmap targets.

- New Construction
- Transformation

Disclaimer biofactor

For the biofactor assessment of all scenarios, the DGNB method was applied. While this method differs significantly from the one used in the Frederiksberg Hospital project, it was chosen to streamline the process, as Urban LCA is intended for general assessments of urban development projects. As an exception to the standard DGNB approach, the average tree area was adjusted from 20 m² to 50 m², reflecting the unique age and size of the trees on this particular site. Nevertheless, the method used, the results show the same trend: Scenario 3 has the highest biofactor, with Scenarios 1A and 1B scoring well, while Scenario 2 has a low biofactor.





CO₂ emissions over time

To enable a comparison of total CO₂ emissions over time, we have divided them into three stages: initial emissions from construction, emissions during the use stage, and those from final demolition (end-of-life).

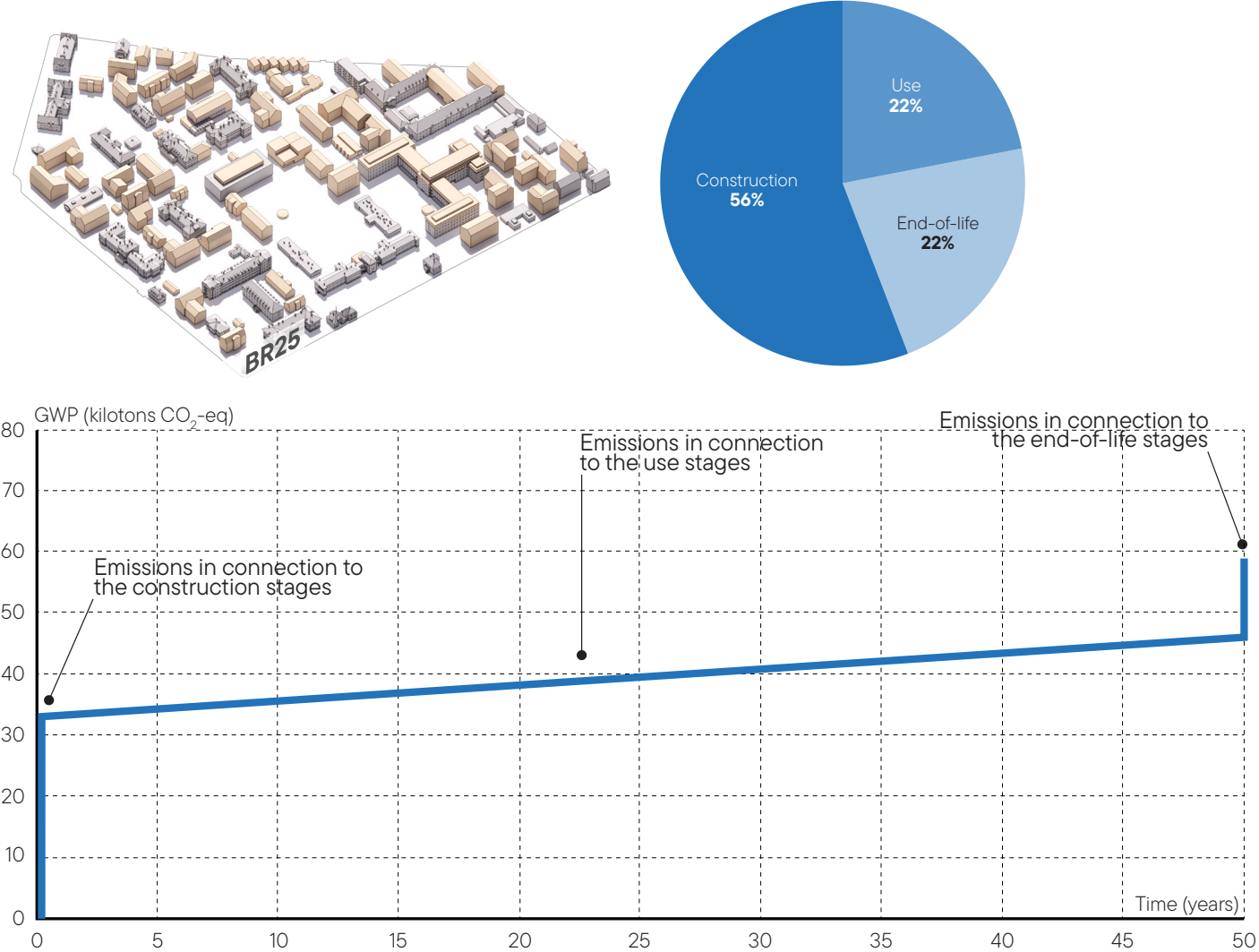
In Scenario 1A, with its total emissions of 59 kilotons CO₂, slightly more than half arise from the construction stage. The remainder is split between the use stage and end-of-life stage. With 51 kilotons CO₂, Scenario 1B follows a similar distribution.

In Scenario 2, which involves the demolition of all existing buildings and extensive new construction and 78 kilotons CO₂, approximately 75% of emissions occur during the initial construction stage, with the remaining 25% distributed between the use and end-of-life stages.

In contrast, Scenario 3—the transformation scenario—shows a markedly different pattern: only 20% of the total 19 kilotons CO₂ occur in the construction stage, while around 50% are associated with the end-of-life stage.

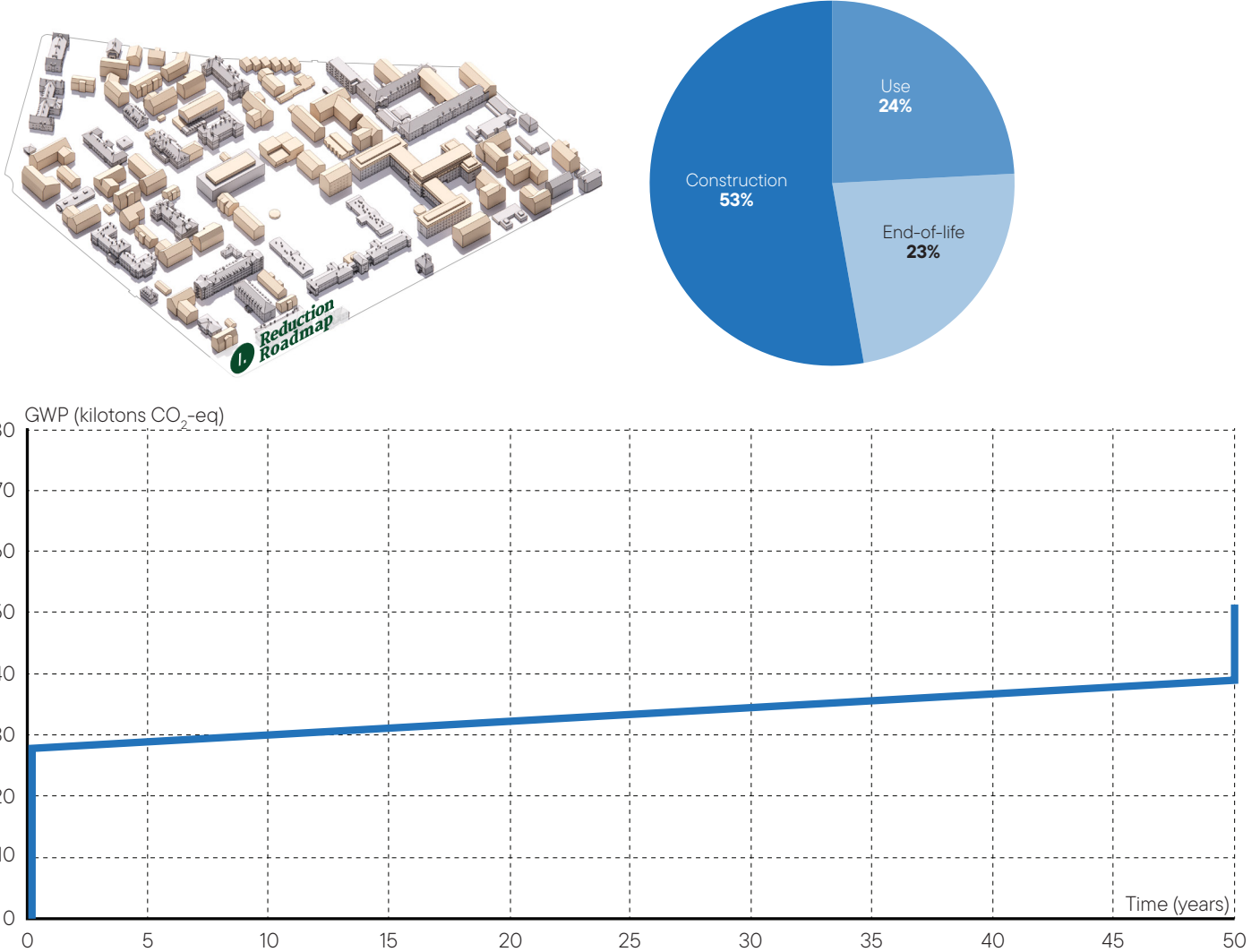
S1A

Current Planning BR25



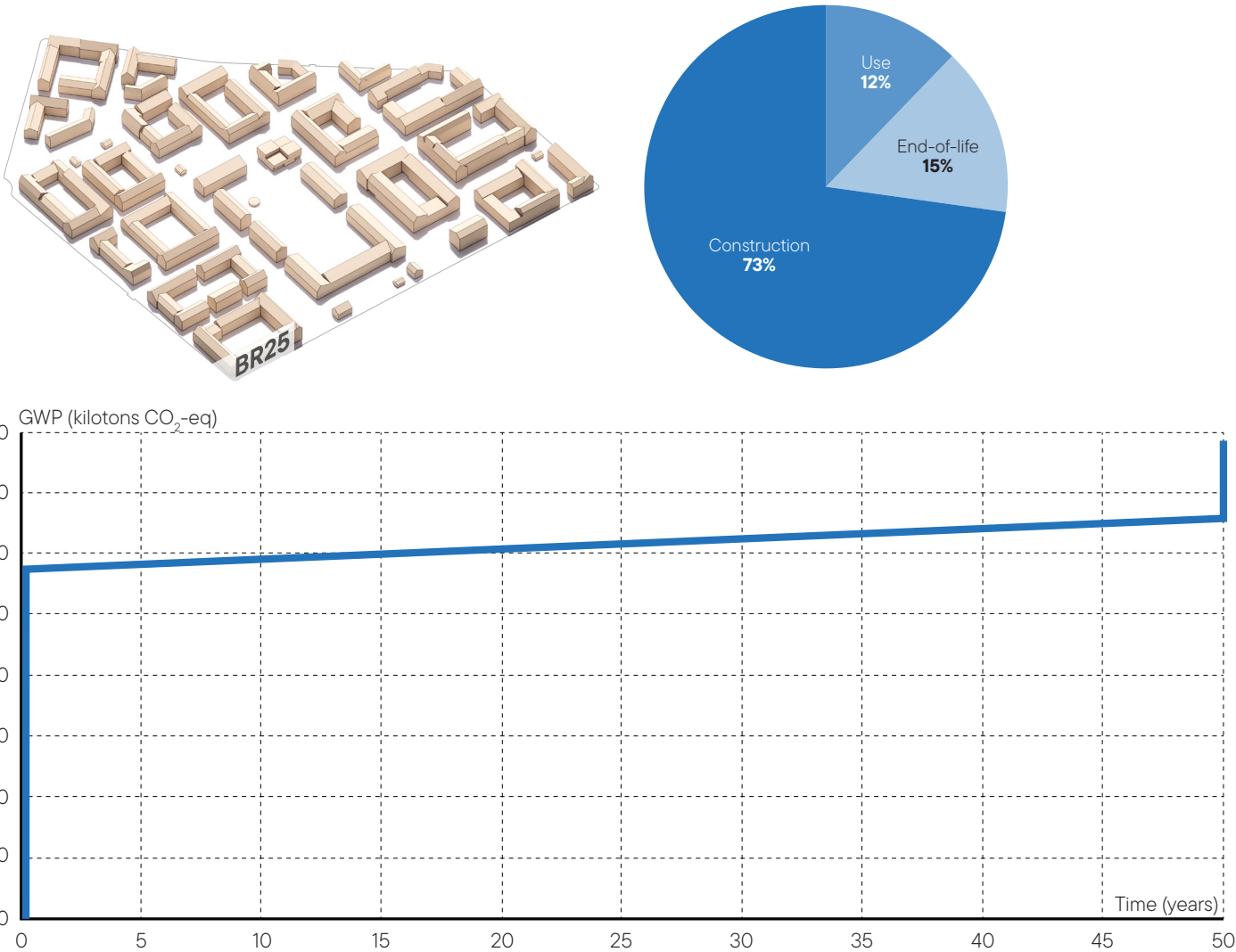
S1B

Current Planning Reduction Roadmap



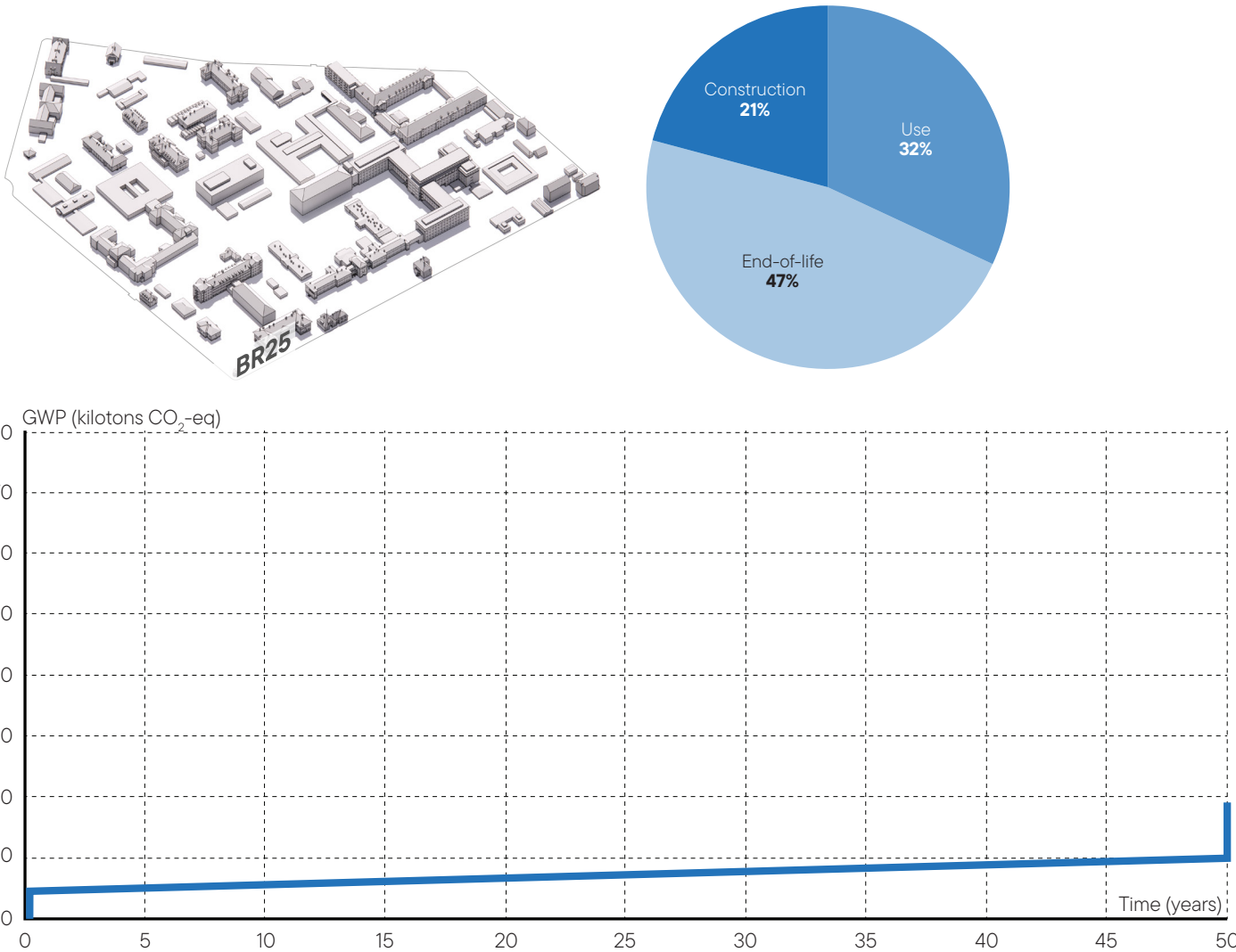
S2

Demolition & New Construction BR25



S3

Transformation BR25



04

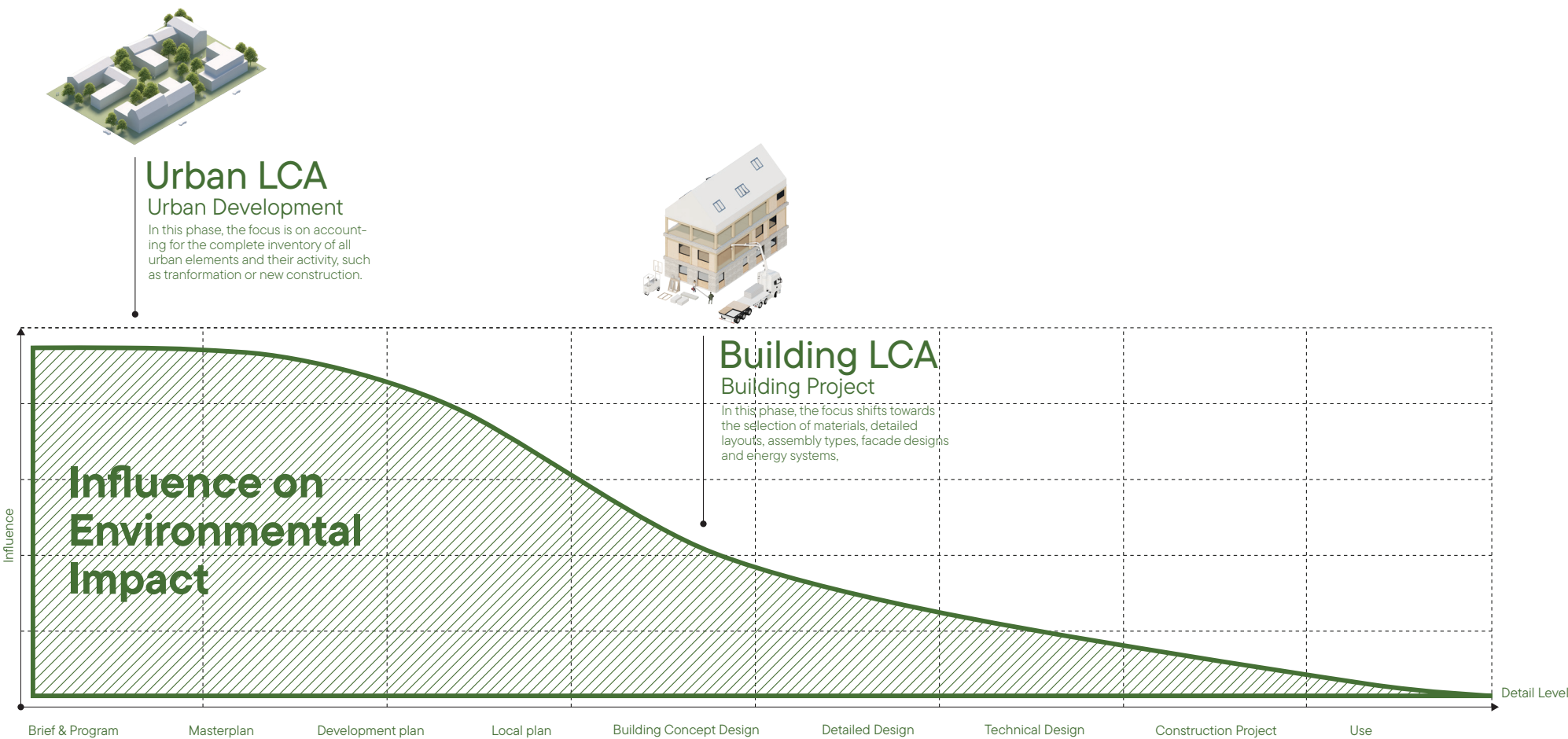
Next Steps

From Urban LCA to Building LCA

As an early phase design tool, Urban LCA does not require information such as building materials, assembly types, or energy systems. This allows for emission results in a planning phase where this information is often not yet available or likely to be revised later. Naturally, this leads to some uncertainty about the accuracy of the results and leaves a wide margin for all given results. For instance, at the building scale, selecting biogenic materials like rammed earth would lead to significantly lower carbon emissions compared to materials such as concrete.

Thus, once urban decisions—such as overall functions and programs, construction types (e.g., transformation vs. new construction), or landscape strategies—are finalized and the urban development shifts to individual building projects, the intended use of Urban LCA concludes. At this stage, the results from Urban LCA are no longer accurate enough, and planners must transition to Building LCA tools such as LCAbyg as well as Bio-diversity tools.

In this project’s case study, the Frederiksberg Compass assists planners in navigating the development phases and can help progress towards more precise tools. Nonetheless, it is crucial to revisit Urban LCA and the results to monitor the targets throughout the design and construction process.



Areas for Future Research

Part of the Urban LCA project was to identify what new knowledge and data is needed and thus identify areas for future research. We have therefore also investigated which elements have reliable data and can be used in Urban LCA and which cannot yet be quantified. The beta version of the tool thus forms the basis for continuous further work. Below we have listed some relevant future directions.

Data Gaps

As described in detail in the appendix, some elements haven't been included in the tool due to the unavailability of reliable data. For example, the environmental impact from utilities is included for pipes and associated excavation work. It has not been possible to find data for utility infrastructure such as transformer stations or heating plants. However, the Plan22+ project ForsyningsLCA has been initiated. Once this project is completed, it is expected that the data provided can be integrated. Similarly, the environmental impact options of high, moderate, and low in the hardscapes and softscapes categories do not have different values.

It is expected for related data to become available in the near future, which would give the opportunity to include those elements in the tool and give an even more holistic account of urban development impact.

Absolute targets and benchmarking

The planetary boundaries are absolute, physical limits. Relative reductions in carbon emissions and biodiversity impact are therefore insufficient to return to the safe operating space.

While the sustainability classes of the reduction roadmap in this tool (for 2025, 2027, and 2029) are consistent with climate science and have allocated a carbon budget on a national level, this does not apply to the obtained results of the Urban LCA tool. Even though our initial scenarios clearly indicate that Transformation (S3) is the most favourable option we cannot confirm whether it aligns with planetary boundaries.

A carbon budget, as defined by climate science, has not been allocated to the tool's outcomes or the Frederiksberg Hospital project. Additionally, no biodiversity targets—either on-site or off-site—have been established. Future work should address these gaps.

Additional biodiversity loss indicators

To estimate the impact on biodiversity, we have chosen to measure the material footprint of all construction activities.

Other indicators highlight different aspects of biodiversity, yet calculating these requires extensive data and analysis, which is challenging due to a relatively sparse data foundation. Thus, the decision has been made to use the indicator material footprint. This indicator is simple, as it only relates to the weight of the material used. Although there is a high correlation between material footprint and ecological impact (0.73)[1], the former does not include energy consumption and can therefore not give a full picture of a developments impact.

Future versions of Urban LCA could identify and include additional indicators – for example Biodiversity impact through species.year/ m²/ year.

Biodiversity Regeneration

All investigated scenarios in this report emit carbon and leave an off-site biodiversity impact, raising the question: What if we had to regenerate the biodiversity loss caused by urban development?

As an initial investigation, we conducted additional calculations beyond the tool's capabilities, comparing three scenarios as seen on the right. For all scenarios, we have assessed the needed forest regeneration from the biodiversity loss. We have also displayed the resulting CO₂ sequestration.

In scenarios 1A and 2, large forest areas are needed for regeneration due to the high material footprint. In contrast, scenario 3 (transformation) requires less regeneration due to its lower material impact.

It is important to note, that biodiversity regeneration should not be seen as a compensation scheme. All construction must adhere to science-based targets, which BR25 does not meet.

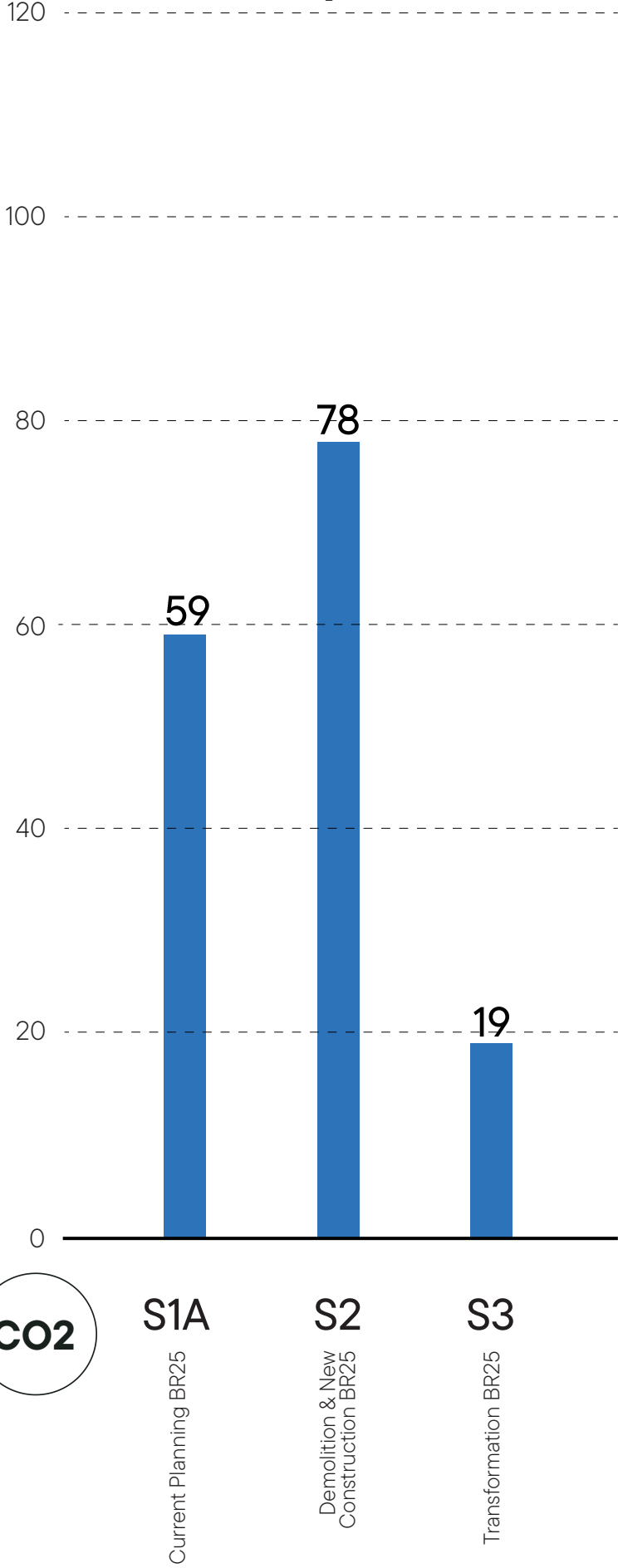
We would be excited to further investigate biodiversity regeneration and integrate it into a future version of the tool.

Local production of energy and building materials

Generally, generic data has been used as a basis for the Urban LCA tool. This means that locally produced energy and building materials may have a lower climate footprint than estimated in the Urban LCA tool. Conversely, building materials produced very far from Denmark may have a higher climate footprint than estimated. As a possible future development, more specific solutions, such as low-temperature district heating based on local renewable energy sources, can be integrated, if the simplicity and clarity of the tool is not impaired.

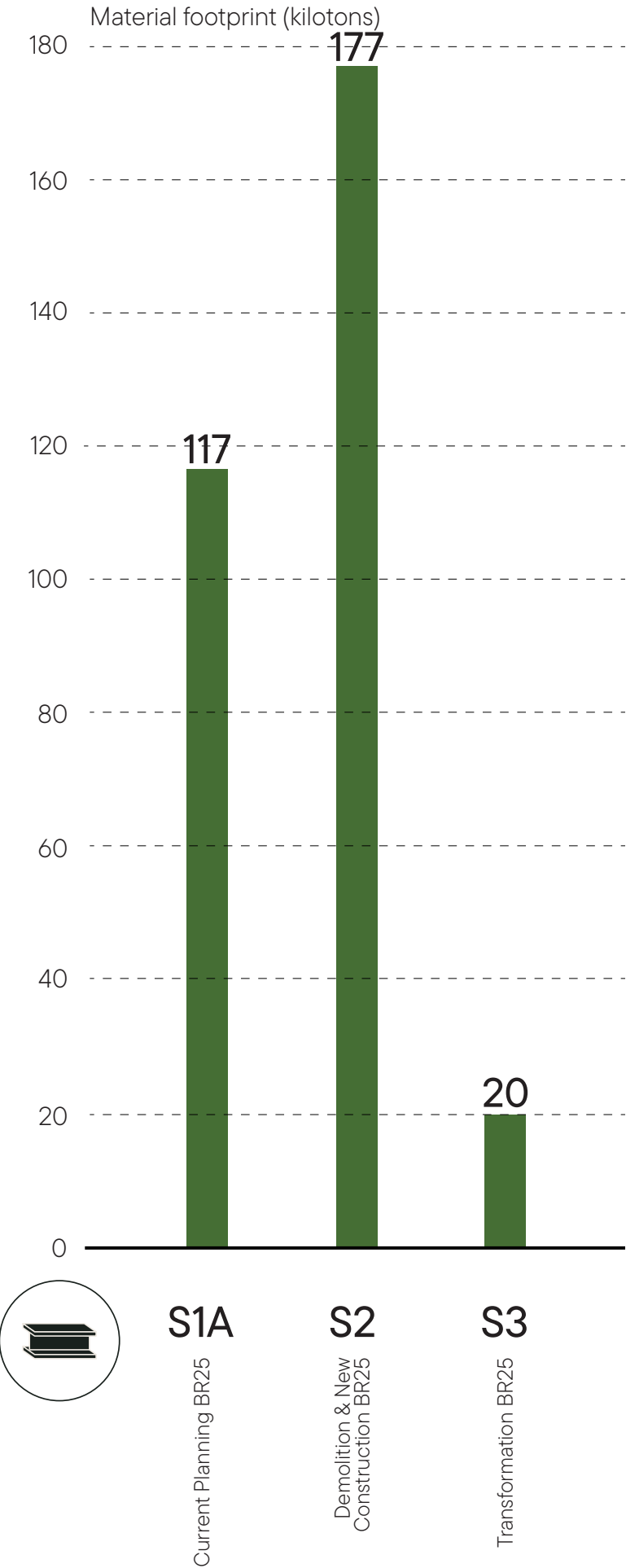
CO₂ emissions

GWP, 50 yr (kilotons CO₂eq)

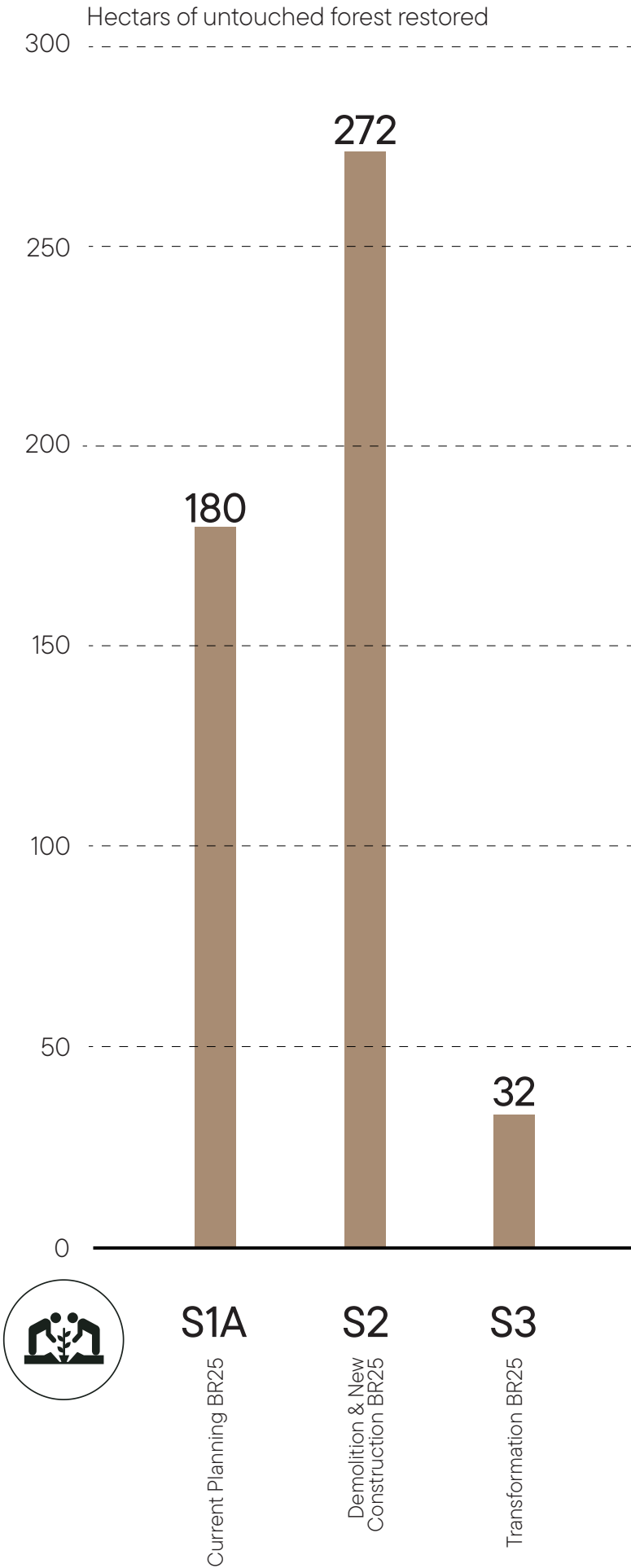


Source [1]: E. van der Voet, L. van Oers og I. Nikolic, »Dematerialization: Not Just a Matter of Weight,« Wiley: Journal of Industrial Ecology, pp. 121-137, Oktober 2004.

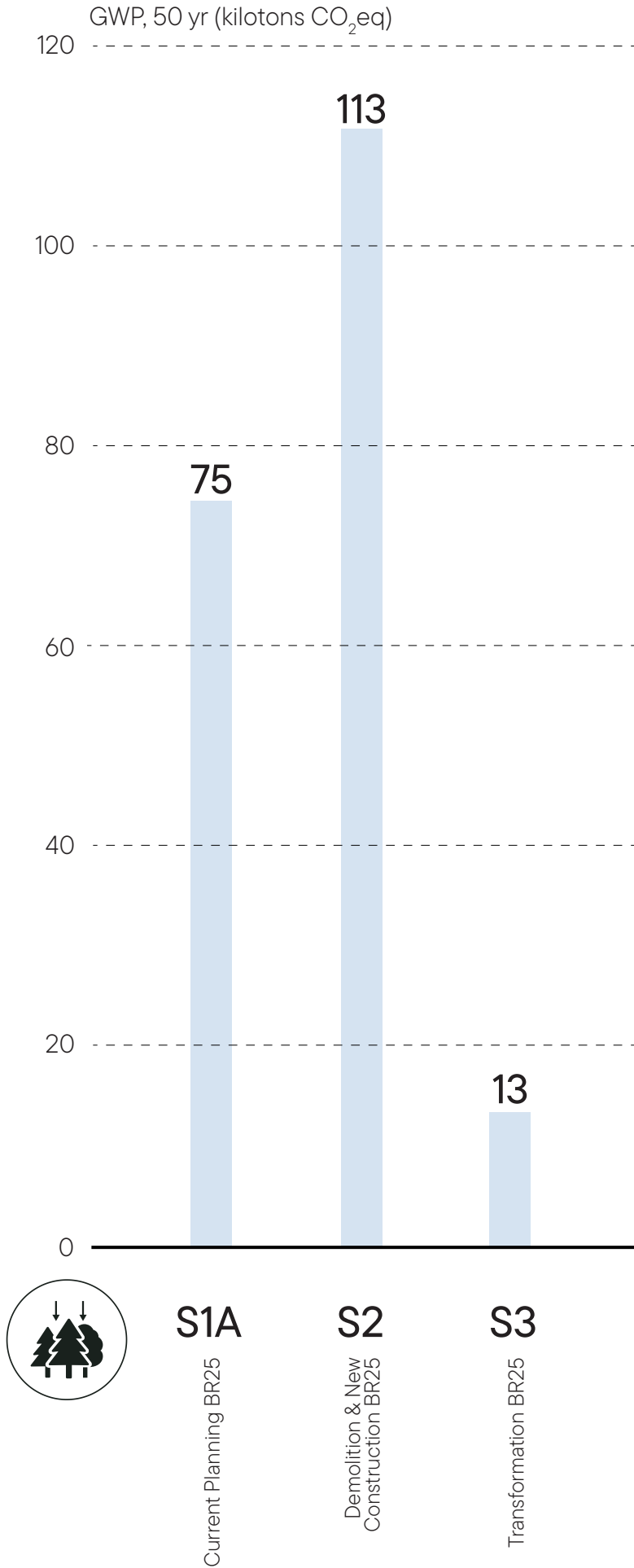
Material footprint



Needed forest regeneration



CO₂ sequestration from forest regeneration



Project Team



Urban LCA

- A design tool for carbon & biodiversity assessment on the urban scale

June 2025, Beta version

Prepared by

Artelia: Rasmus Søgaard, Ronnie Holgersen, Steffen Maagaard
EFFEKT: Fabian Lecker, Dani Hill-Hansen, Otto Hallstrup, Kasper Reimer,
Tina Lund Højgaard, Adrian Dahlberg, Virginie Le Goffic

Supported by



Plan22+ is a five-year effort from the Plan- og Landdistriktsstyrelsen and Realdania, which aims to support municipalities’ climate work by developing new knowledge and tools to meet climate goals through physical planning.

Read more on:

www.plan22.dk

Feedback

The tool and the accompanying report serve as a beta version of how to measure carbon emissions and biodiversity impact on the urban scale – it is not a final answer, but rather an innovation push into a field with many unknown factors. Much will be missing for a holistic assessment and there will certainly be mistakes as well. We depend on your valuable feedback, corrections, and knowledge for the future development of this tool. Please reach out to us!

Fabian Lecker, fl@effekt.dk

Ronnie Holgersen, roho@arteliagroup.dk

Publications mentioned in this report

Doughnut for Urban Development: A Manual. Edited by Dani Hill-Hansen and Kasper Guldager Jensen. 2023. Copenhagen. The Danish Architectural Press. www.effekt.dk/doughnut-for-urban-development

Refshaleøen Development Playbook. Effekt Architects. 2023. www.effekt.dk/refshaleoen-development-playbook

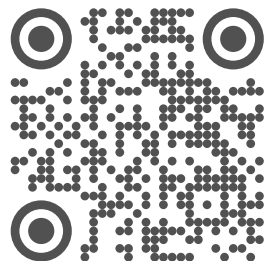
Reduction Roadmap (2022) Reduction Roadmap: Preconditions and Methodologies. Version 2 – 7. September, 2022. www.reductionroadmap.dk.

Reduction Roadmap (2024) Beyond the Roadmap: A transition plan for the Danish building industry. Version 2. 14. November, 2024. www.reductionroadmap.dk

Further references can be found in the separate appendix.

To reference this report

Urban LCA – A design tool for carbon & biodiversity assessment on the urban scale. Version 0.3. June, 2025. www.effekt.dk/urbanlca



The Urban LCA tool, the appendix,
and this report are an open resource
(copyleft) and available for download
and use here: www.effekt.dk/urbanlca