SUSTAINABILITY

UPCYCLE STUDIOS & THE RESOURCE ROWS

SEPTEMBER 2020

NREP

LENDAGER GROUP

MOE

EXECUTIVE SUMMARY

LCA AND LCC ON UPCYCLE STUDIOS AND THE RESOURCE ROWS

SUSTAINABLE BUILDINGS

In 2015 NREP embarked on two significant sustainable housing projects in Copenhagen with a particular focus on resource optimization and reduction of embodied CO_2 through the use of upcycled building materials within a conventional budget for new constructions: Upcycle Studios and the Resource Rows.

This report presents a summary of the post-completion LCA and LCC analysis of the upcycle materials and the overall building projects. The analyses were conducted as part of the efforts to understand to what extent the specific upcycling solution employed achieved the intended outcomes compared to comparable new materials and to capture the learnings from these projects for the benefit of future projects.

LCA RESULTS

Despite significant first-time production challenges and project-specific limiting preconditions, the LCA demonstrated significant savings largely in line with expectations based on prior projects and testing. At product level the CO_2 savings ranged between 5-8% for concrete, 38% for brick walls, 44-88% for wood products and 87% for windows. At building level the LCA indicated reduction of embodied carbon of 32% for Upcycle Studios and 12% for Resource Rows. At building level the learnings are less clear because several confounding factors and unrelated design decisions impact the aggregate building level CO_2 footprint.

LCC RESULTS

The upcycle products in general were higher priced than benchmark and due to the more complex first-time process there were additional indirect costs. However, while not being directly competitive on cost in the first production line (based on expenses for development), the results from the latter phases of the projects and the learnings for how to readily optimize processes and design in future projects indicate that upcycled windows, wood products and brick walls should be able to compete directly on market prices already in the next iterations.

LOOKING TO THE FUTURE

To identify what solutions that should be developed further and carried forward to future projects with the potential to scale, the analysis needs to look at applicability in other contexts and consider a broader set of factors. The LCA/LCC complemented with evaluation of additional factors indicate varying degrees of impact, complexity, scalability and cost competitiveness for the different upcycling products that were employed. Overall the results indicate that upcycling solutions indeed have potential and should be explored further by the real estate industry as one of the tools to improve its resource efficiency and CO_2 footprint.

Upcycle product or material	kg CO_2-eq/unit	% CO_2 saved	Total waste saved
Upcycle Brick Wall	49 kg CO_2-eq/m^2	38%	459 tonnes
Upcycle Windows	380 kg CO_2-eq/m^2	87%	7 tonnes
Upcycle Window Panes**	17 kg CO_2-eq/m^2	32%	-
Upcycle Concrete	28 kg CO_2-eq/m^3*	5-8 %	904 tonnes
Upcycle Concrete Aggregate**	9 kg CO_2-eq/m^3	84%	-
All Wood Products	127 kg CO_2-eq/m^3****	44-88%	7 tonnes

*Best case

** Upcycle material

*** Compared to new bricks

**** Average saving of all wood products

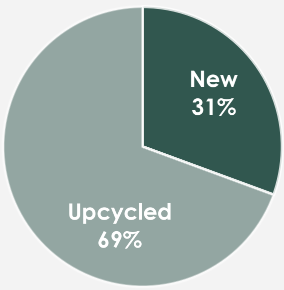
UPCYCLE STUDIOS

Embodied carbon: 32 % saving
Full lifetime: 45 % saving
8.08 kg CO_2 -eq/m² per year

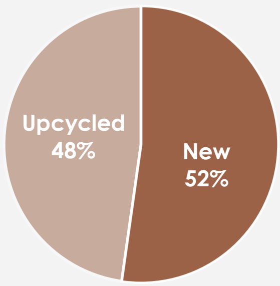
914 tonnes waste in total

Building operation per year:
72% saving
1.3 kg CO_2 -eq/m² per year

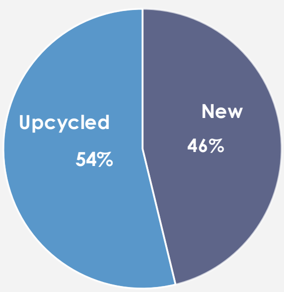
Material distribution by weight



CO2-eq distribution



Cost distribution



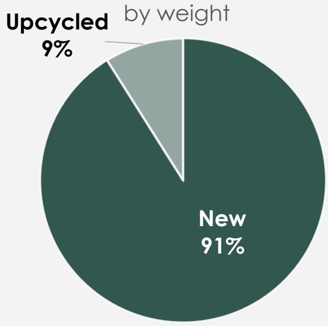
RESOURCE ROWS

Embodied carbon: 12 %
Full lifetime: 29 % saving
6.64 kg CO_2 -eq/m² per year

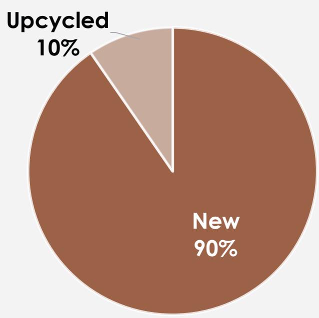
463 tonnes waste in total

Building operation per year:
48% saving
2.1 kg CO_2 -eq/m² per year

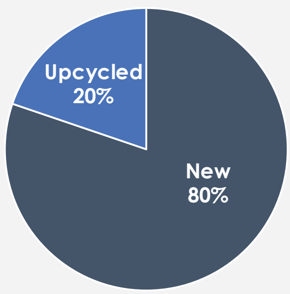
Material distribution by weight



CO2-eq distribution



Cost distribution



KEY LEARNINGS

TAKE AWAYS FOR FUTURE SUSTAINABLE PROJECTS

NEXT STEPS: UPCYCLE MATERIALS

We have achieved a positive environmental impact across upcycle materials in Upcycle Studios and Resource Rows already in first iteration, but the central question now is how we can build on existing learnings to improve environmental impact, decrease prices and scale upcycle solutions to achieve material impact.

Results from Upcycle Studios and Resource Rows demonstrate positive environmental impact across the upcycle materials employed in spite of first-production challenges. To increase future impact the central question is how we can build on these projects' learnings to create a path towards a future where improved upcycling solutions are adopted at scale and thus truly make a material difference.

- Sustainable value: CO_2 and waste optimization.
- Scalability: Potential for scaling solutions across projects
- Economy: Cost competitiveness (incl. maintenance).
- Risk: Sourcing of upcycle materials and performance of products
- Identity: Visualising the sustainable changes in projects to inspire others for change.

Based on the five evaluation parameters we find that the upcycle window and wood solutions employed have strong performance as is, while the brick and concrete solutions should be developed further to improve economy, risks and scalability.

NEXT STEPS: SUSTAINABLE BUILDINGS

The results from the LCA and LCC analyses show several impact categories across the lifetime of the building from the construction process to operations.

Looking at materials, we have a 32 % CO_2 reduction in Upcycle Studios and 12 % reduction in Resource Rows. Looking at both embodied CO_2 and CO_2 from operations across a 50 year lifetime we reach a 45 % CO_2 reduction in Upcycle Studios and 29 % in Resource Rows.

These numbers show clear gains from having a high focus on sustainability early in the design and construction process, but also a potential for increasing the impact further if we would have worked with specific impact measurements throughout the construction process.

For future projects we recommend repeating the use of upcycle materials to further reduce embodied CO_2 and waste creation while further minimizing CO_2 emissions through heat pumps, choosing sustainable materials, designing to minimize materials usage, working with raw materials to crate healthier indoor environments while easing future circulation potentials.

Find a none exhausted list of recommendations to increase sustainability in coming construction projects to the right.

	PARAMETERS OF IMPACT	Sustainable value 1 = Low & 5 = High	Scalability 1 = Low & 5 = High	Economy 1 = Low & 5 = High	Risk 1 = Low & 5 = High	Identity 1 = Low & 5 = High	Total score
MATERIALS	**BRICK**						
	Brick - As built	5	4	1	3	3	16
	Brick - New mounting	5	5	2	3	3	18
	WINDOW						
	Window - As built	5	5	4	4	4	22
	Window - Residential adaptation	5	5	3	4	4	21
	CONCRETE						
	Concrete	5	5	2	3	3	18
	WOOD						
	Wood indoor	5	5	4	5	5	24
	Wood outdoor	5	5	4	5	5	24

RECOMMENDATIONS FOR EFFORTS IN FUTURE SUSTAINABILITY BUILDING PROJECTS

BRICKS:

- Further develop upcycle brick solution as more traditional front brick wall based on cut out elements to improve process and results financially and environmentally.

CONCRETE:

- Optimize cement quantity for higher impact.
- Increase quantity in production to increased economic competitiveness.
- Use in hybrid constructions as core, floor separation, foundations, terrain deck etc.
- Source upcycle aggregate as close to construction project as possible from either infrastructure projects or demolitions.

WINDOWS:

- Increase amount of upcycle glazing (from 50% to a potential 81 %) to further improve impact and price.
- Scale upcycle window for commercial projects as replacement of traditional curtain walls.
- Develop format for residential projects achieving a 45 % CO_2 reduction compared to a wood/alu energy window.

WOOD:

- Facades and wood floors should be scaled.
- Wooden walls should be developed and implemented for healthier indoor climate, CO2 savings and CO2 storage.
- Replace concrete with wood where it makes sense (hybrid).
- Focus on minimizing wood treatment (heat treated / linseed oil).

- **Repeat:** Learnings from existing upcycle projects will lead to better impact and price, hereby raising the standard for sustainable construction and resource consumption going forward.
- **Increased focus on materials:** Optimise material usage by choosing the right sustainable materials for the right purposes.
- **Clear goals:** Be clear about the sustainable goals and use LCA and LCC throughout the process to achieve goals.
- **CO2 and material bank:** See constructions as a carbon bank postponing CO_2 emissions and waste production with up to100 years.
- **Strategic alignment:** Ensure upfront that your stakeholders and necessary actors are aligned with the vision and committed to a process that supports the sourcing and use of upcycling materials.
- **Active developer:** As the investor/owner the developer has the highest interest to succeed and needs to be active and involved throughout the process.
- **Identify and manage barriers up-front**: Regulations, site specific limitations or perceptions by key stakeholders.
- **Necessary scale:** The project specific nature of sourcing and production means that projects need to be of a certain size to achieve economies of scale and efficiency - the bigger the better (financially and environmentally).
- **Material access**: Gain continuous access to waste resource to ensure steady supply and scale is key.
- **Regulations:** Challenge the habits of the authorities, which far from always supports the sustainable choice.
- **Structures:** Use concrete where it makes the most sense, and replace with wood where possible. Optimize concrete constructions as much as possible by better design and choice of cement.
- **Minimize energy consumption:** to minimize biomass! Alternatively, be self-sufficient on electricity with e.g. heat pumps.
- **Minimize treatment:** Treat materials as little as possible to achieve a healthier indoor climate, less CO2 impact and easier circulation.
- **Certification:** Set requirements for certified construction, and set higher requirements for selected, important criteria.

TABLE OF CONTENT

CHAPTER 1
INTRODUCTION

PURPOSE

PURPOSE OF THIS REPORT

40 % OF THE WORLD'S CO_2 EMISSIONS & RAW MATERIALS CONSUMPTION

Currently, real estate is responsible for approximately 40 % of the global raw material consumption and 40 % of the worlds CO_2 emissions. Of new buildings, an average of approximately 50% of the life cycle CO_2 emissions is embodied carbon. Our raw materials consumption is not sustainable and if we are to reach the "below 2 degrees" goal of the Paris agreement and the Danish government's ambition of 70% reduction of CO_2 emissions by 2030, this has to change.

Addressing these complex challenges will require the industry to employ a broad range of solutions. Complementing other measures, one of the potential solutions is to increase the upcycling of existing waste materials that would otherwise have been discarded.

While the amount of existing and future waste material that could be upcycled into new construction is immense, upcycling practices will not scale until pioneering projects have tested and proven their economic and environmental merits. Upcycle Studios and the Resource Rows set out to employ a specific set of upcycled solutions for concrete, brick façades, wood façades, wood floorings and windows. These materials and construction elements make up the majority of the embodied CO_2 of current construction projects and they will continue to be used at large scale also in the future. Hence, even solutions with marginal improvements are worthwhile pursuing if they can be scaled.

Upcycle Studios and Resource Rows have already demonstrated large savings by only changing parts of the building components. Imagine the savings if we increase the number of upcycled materials per building - or the savings if the industry used upcycle materials in all new construction projects.

While we have much to further develop and improve, we want to share our imperfect journey and the findings from these two projects so that we can learn from others and others can learn from us as we jointly progress the agenda for a more sustainable future.

READING GUIDE

The report is structured as follows:

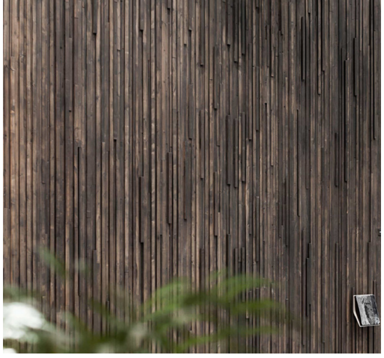
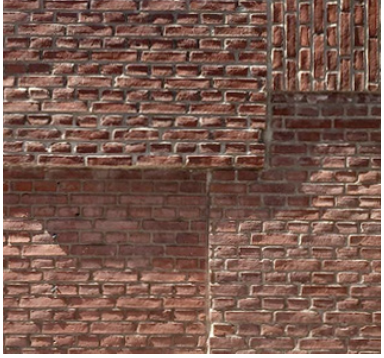
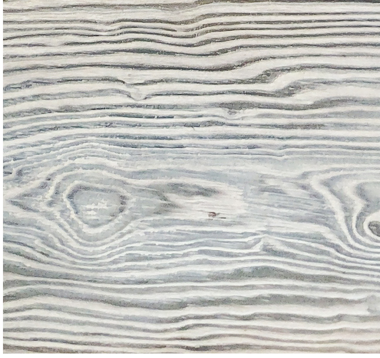
- **Chapter 1:** Clarifying how LCA and LCC calculations are conducted.
- **Chapter 2:** Reviewing impact on material and product level across LCA and LCC.
- **Chapter 3:** Reviewing impact on building level across LCA, LCC and energy efforts.
- **Chapter 4:** Concluding on the achieved impact.

PARTNERS

The report is based on calculations done by Lendager Group verified by LCA expert Morten Birkved, SDU, and quality checked by MOE A/S.

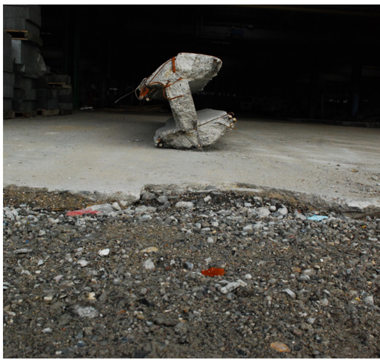
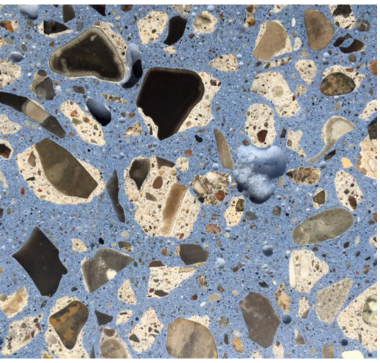
MATERIALS

For the two building projects we focused on circulation of the following materials:

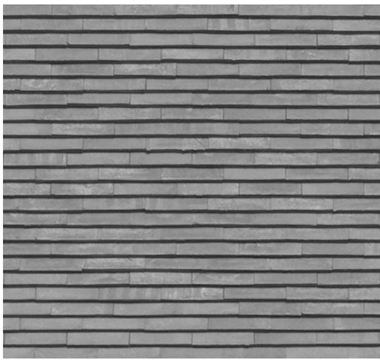
IN DENMARK, CIRCULAR ECONOMY CAN ...



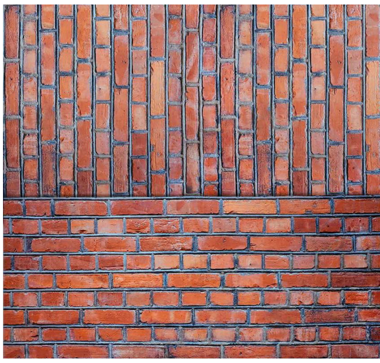
... CREATE MORE THEN 13.000 NEW JOBS



... REDUCE RESOURCE CONSUMPTION WITH UP TO 50%






... GENERATE 45 BILLION EXTRA DKK FOR GNP

WHY CIRCULATE MATERIALS?

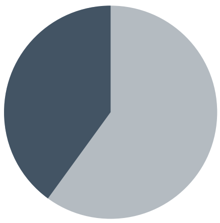
NATIONAL CHALLENGES

4.2
Earths

" IF EVERYONE LIVED LIKE DANES WE WOULD NEED **4.2 GLOBES.** "

Reference: WWF "I dag er jordens ressourcer opbrugt for 2018"

40%
of the resource consumption



" WITH ITS 4,3 MILLION TONNES, THE BUILDING AND CONSTRUCTION WASTE CONSTITUDED OVER ONE THIRDS OF DENMARK'S TOTAL WASTE IN 2016. "

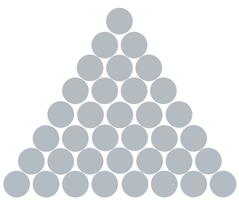
Reference: Miljøstyrelse "Affaldsstatistikken 2016"

4.3
million ton
waste

" 40 % OF THE RESOURCE CONSUMPTION IN DENMARK IS ACCOUNTED FOR BY THE CONSTRUCTION INDUSTRY. "

Reference: "Dansk Byggeri: Håndværkere skal gribe den digitale værktøjskasse"

In 2056
Denmark runs
out of gravel



" DENMARK RUNS OUT OF GRAVEL IN THE YEAR 2056, PROVIDING A BURNING PLATFORM TO RESOURCE SCARCITY ON CONCRETE GRAVEL. "

Reference: "Danmark er ved at løbe tør for grus: 'Et af de vigtigste råstoffer, verden har'"

CONCRETE, BRICKS, WINDOWS AND WOOD

One thing is circular construction, but why concrete, windows, bricks and wood? Below you find facts on why we need to rethink the way we utilise our current building materials.

BRICKS

- In Denmark, 199,000 tonnes of bricks are wasted annually.
- For each brick, 0.5 kg of CO_2 is emitted. This corresponds to 1 tonne CO_2 per 2,000 bricks.
- Growing urbanization is creating an increasing number of empty buildings outside the cities - many with bricks left with no value.
- Bricks with cement mortar cannot be reused directly since the mortar is stronger than the brick itself. Therefore, this type of masonry is only circulated via crushing.

WINDOWS

- In Denmark, approx. 32,000 tons of flat glass is wasted yearly. The majority is estimated to come from energy renovations.
- The global demand is expected to double from 2008 to 2023.
- We are running out of sand which is the most important resource in glass production.
- Flat glass waste is mostly circulated through downcycling to, for example, jars and bottles. If it cannot be melted, it will be crushed and used for glass wool.

CONCRETE

- More than 1 million tonnes of concrete waste is produced annually in Denmark (about 430,000 m^3).
- Cement production accounts for 8 % of the world's total CO_2 emissions - a figure that is expected to increase with urbanization.
- By 2056, all Danish municipalities will run out of gravel for concrete production.
- Today, concrete is mainly circulated via downcycling to roadfill.

WOOD

- 181,000 tonnes of wood are burned every year in Denmark leading to high CO_2 emissions.
- 130,000 tonnes of new wood is used in the Danish construction industry yearly.
- When circulating wood you prolong the lifespan of wood avoiding emissions of the embedded CO_2.
- Often, high quality wood is discarded due to minor flaws leading to unnecessary waste of highly usable materials.

LCA - LIFE CYCLE ASSESSMENT

METHOD - MATERIAL AND PRODUCT LEVEL

THE WHAT AND HOW OF LCA

Upcycling of materials and circular economy is driven by the potential of reducing the use of virgin materials, hereby reducing the environmental impact when producing new materials. Life Cycle Assessment, LCA, is an acknowledged method for quantifying the environmental impact of a given material, product, and building. An LCA covers the entire life cycle from cradle to grave/cradle to cradle divided into phases shown in the figure to the right. Within each of these life cycle phases, an LCA is divided into sub-phases covering all processes within each phase.

CONSISTENCY AND TRANSPARENCY

When performing LCA, various tools are available. Each tool is built upon a database with data for both production and disposal of materials. Here, GaBi and Ecoinvent are the two most acknowledged databases on the market today - especially due to their level of detail. Some programs are suitable for making LCAs on a detailed product level where others are more suitable for generic and overall LCAs on building level. Working with DGNB, LCAbyg with Ökobau database is often used to conduct LCAs on building level.

The multiple assessment methods underline the importance of consistency across different LCAs in order to make them comparable. Additionally, since LCAs are based on many assumptions, transparency is crucial in order to understand the results of the LCA. On the following pages we introduce the methods and tools used for conducting the LCAs in this report.

MATERIAL AND PRODUCT LEVEL ASSESSMENTS

In this report we will present LCAs on three different levels; 1) material, 2) product and 3) building. Product level is needed to conduct an LCA on building level. We further present LCAs on material level to clarify the impact of the separate materials circulated not taking any added virgin materials into account. The LCAs on material and product level are conducted as following:

Collection of data: Data has been collected from the manufacturers of each developed upcycle product in order to obtain accurate data. All used materials, energy, water, transport and waste during the production have been considered.

LCA modelling: The LCA has been conducted using the database Ecoinvent 3.4 in the open software OpenLCA version 1.8. Furthermore, the cut-off inventory system model has been used as a typical LCA assessment method on product level.

Included LCA phases: A1-A3 have been included for all materials and products. For concrete, A4 is also included since impact of the upcycle aggregate is found within that phase due to resource scarcity of local gravel.

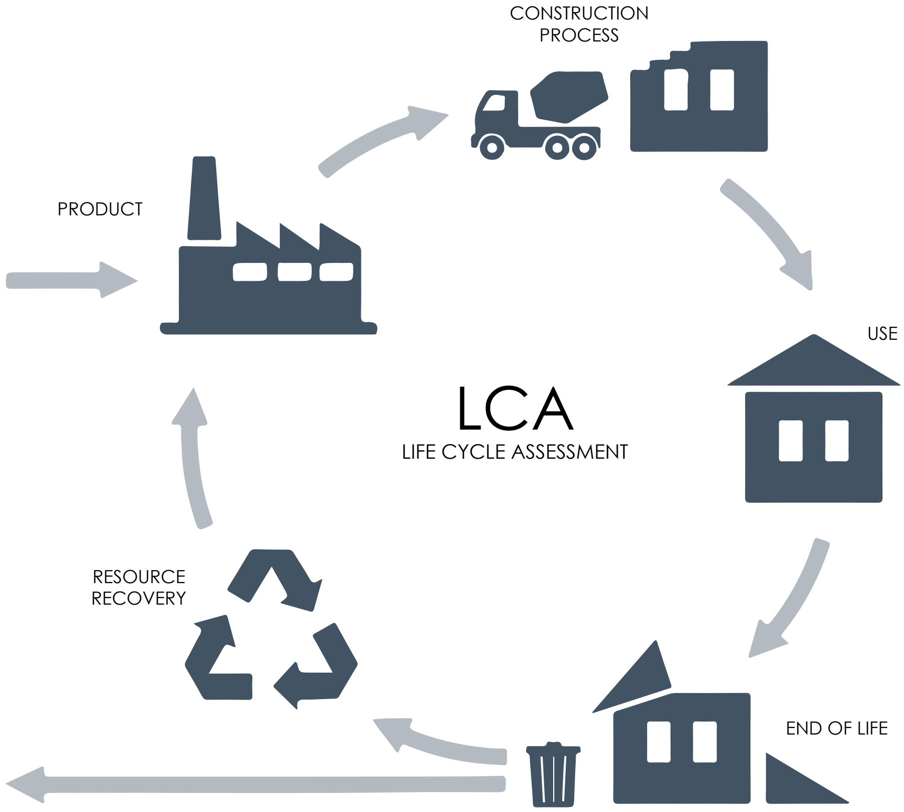
Biogenic carbon: When trees are growing, they absorb atmospheric carbon dioxide which is fixed in the wood as biogenic carbon. Performing LCA on wooden products includes taking the biogenic carbon into account. According to standards, the biogenic carbon should only be included when looking at the entire life cycle. Since the LCAs at product level only are looking at phase A1-A3, biogenic carbon has not been accounted for. However, this still means that there is biogenic carbon embedded within the upcycle wood products, leaving a potential for an even greater impact when reusing wood as you hereby continue the storage of the carbon absorbed in the wood.

LCIA method: CML 2 Baseline 2000. Since we only have EPD and LCAbyg data available for wood products, these will be investigated with the CML-IA baseline method corresponding to the data in LCAbyg and EPDs.

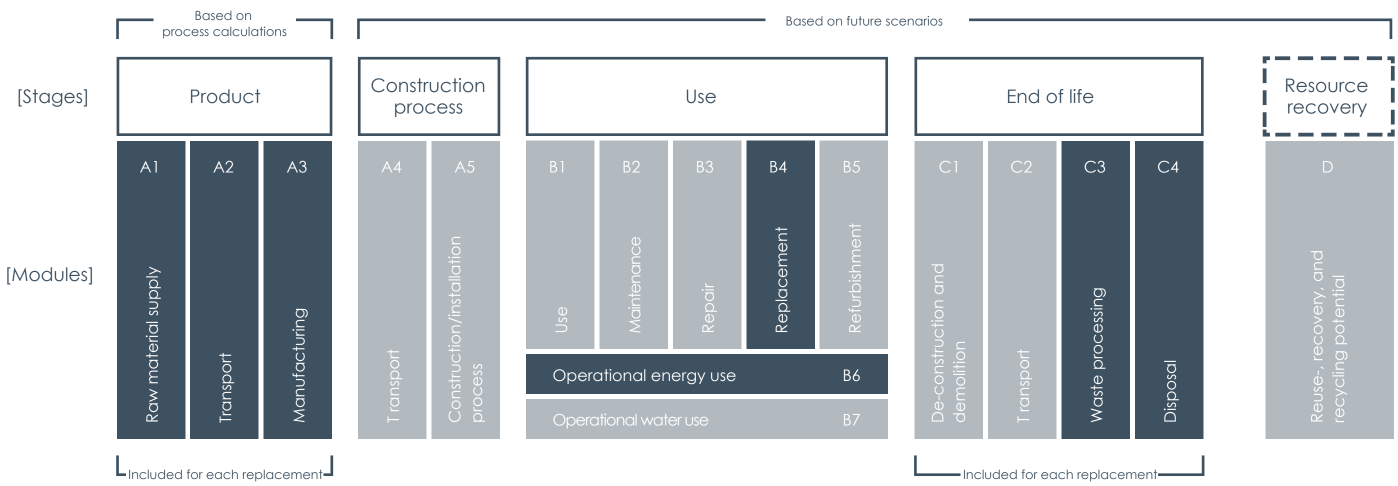
Benchmark: The benchmark of each product corresponds to how the given product would be built in a conventional way providing a similar architecture. Benchmark data has been provided by MOE A/S.

Optimised scenario: Product LCAs are supplemented by LCA calculations of optimized scenarios. These calculations are based on identified potentials for improvements in as-built upcycle products. Improvements include increase of upcycle materials, improvement of production methods, increase of volume, improvement of product design and decrease of virgin materials. Each optimized scenario is explained in material sections in chapter 2.

Verification: The product specific LCAs on upcycle bricks, windows, and concrete have been verified by LCA expert Morten Birkved, SDU.



The life cycle of products and buildings (adapted from Dialogværktøj - Circularity City, VIA University College & SBi)



LCA phases and subphases (adapted from Bygningens livscyklus, SBi)

LCA - LIFE CYCLE ASSESSMENT

METHOD - BUILDING LEVEL

BUILDING LEVEL PROCESS

The modelling of LCAs on building level complies with the DGNB standards in accordance with the DGNB manual (DGNB System Denmark, Kategori: Ejendomme og rækkehuse v. 2016). The LCAs on building level are conducted based on the following:

Unit focus: For the LCA on building level we focus on one row house from Upcycle Studios and Resource Rows respectively.

Collection of data: The data has been collected by extracting amounts on all materials from the Revit model of the specific building. The level of detail is in accordance with the DGNB manual.

LCA modelling: The LCA has been conducted using the software LCAbyg version 3.2.0.4. When lacking products in the given database, these have been built as in LCAbyg version 4.0 BETA. The upcycle products have been implemented as EPD data for each product for phase A1-A3. In order to obtain product specific data in the right format, the data has been extracted from OpenLCA by using the LCIA method CML-IA Baseline and Cumulative Energy Demand. End of life phase C3-C4 for the upcycle products are modelled with the standard data for a similar product in LCAbyg.

Included phases: The analysis A1-A3, B4, B6, and C3-C4 (the ones marked in figure on the previous page).

Biogenic carbon: The biogenic carbon of wood products is calculated in accordance with the Danish standard; DS/EN 16449:2014.

Life span: 50 years including use of the building.

Benchmark: The benchmark building is made by replacing all the upcycle products with their corresponding benchmark product from product level. Hereby, a 1:1 benchmark is obtained which provides a picture of how the environmental impact of the buildings would have been without the upcycle products while reaching the same level of architectural expression. Furthermore the final LCA results of Resource Rows and Upcycle Studios will be benchmarked to 12 LCA calculations of row houses conducted by SBi as well as expectations for level of CO_2 emissions in the new Danish "frivillige bæredygtighedsorden".

Verification: The modelling of each building and benchmark building have been quality checked by MOE A/S.

IMPACT CATEGORIES

When assessing the environmental impact through an LCA, multiple impact categories are analysed. Impact categories vary across different LCA methods. The categories shown in the figure to the right are among the most common. The figure also applies a description of why each category is relevant for the environment.

Today, Global Warming Potential is the most used impact category which is why this category also will be highlighted in this report.

Category **GWP** Global Warming Potential
Unit CO_2 equivalents
Relevance When the amount of greenhouse gasses increases, the air temperature around the earth increases resulting in climate change.

Category **ODP** Ozon layer depletion
Unit R11 equivalents
Relevance Degradation of the stratospheric ozone layer that protects flora and fauna from the sun's harmful UV-A and UV-B rays.

Category **POCP** Photochemical oxidation
Unit C_2H_4 equivalents
Relevance Contributes in connection with UV rays to the formation of ozone near the earth (summer smog) which e.g. is harmful to our respiratory system.

Category **AP** Acidification
Unit SO_2 equivalents
Relevance Reacts with water and falls as "acid rain" which e.g. contributes to breaking down root systems and leaching plant nutrients.

Category **EP** Eutrophication
Unit PO_4^{3-} equivalents
Relevance Excessive nutrient supply promotes undesirable plant growth in fragile ecosystems, e.g. algae growth resulting in fish death.

Category **PEtot** Primary energy consumption
Unit MJ or kWh
Relevance High consumption of primary energy resources (before conversion) from fossil and renewable sources can contribute to resource scarcity.

Impact categories (adapted from Bygningens livscyklus, SBi)

LCC - LIFE CYCLE COSTS

METHOD - PRODUCT AND BUILDING LEVEL

THE HOW AND WHAT OF LCC

The purpose of LCC is to compare the Net Present Values (NPV) of different building solutions serving the same purpose/function; that is, to account for all costs arisen in different points in time, and express them in the present value of money; thus making them comparable. The scope of LCC can be either at product level, where NPVs are estimated per unit, or at building level, where NPV are totals.

Upcycle products involve completely new processes at all levels, also financially. In this context, the need for accounting arises; firstly, gaining insights into financial costs help spot improvement areas, secondly, it allows to benchmark against market alternatives.

The LCC analysis is carried out using two programs; LCCbyg and Microsoft Office Excel.

LCCBYG

The software used is LCCbyg version 2.2.52. The guidelines to estimate Life Cycle Costs are laid out in the DGNB manual (DGNB System Denmark, Kategori: Ejendomme og rækkehuse v. 2016). The assumptions used are as follows:

Calculation period:	50 years (DGNB standard).
Calculation principle:	Nominal interest rate and current prices.
Calculation rent:	Discount rate 5 % from year 0-71.

The software accounts for the building cost categories showed in the figure below.

LCCbyg is an NPV estimation tool applied to the building sector. Once the assumptions are defined, and the cost categories are selected, it is only a matter of introducing the data collected for the analysis. This takes us to the necessary estimation of unitary costs.

EVOLUTION OF PRICES

• General price development	2 %
• Drinking water price development	4 %
• Sewage water price development	7 %
• Energy price development	4 %
• District heating price development	3 %
• Natural gas price development	1,5 %
• Liquid fuel price development	4 %
• Solid fuel price development	3 %
• Electricity price development	3,5 %
• Taxes and tariffs price development	2 %
• Insurance price development	5 %
• Administration price development	2 %

Plot, Consultancy & Client Costs	Site and Structure	Furniture & eq.	Management	Supply	Cleaning
Site	*Substructure*	*Furniture & eq.*	*Taxes & tariffs*	*Water*	*Site*
Consultancy fees	*Primary Elements*		*Insurance*	*Heating*	*Buildings, externc*
Client Costs	*Completions*		*Administration*	*Electricity*	*Buildings, internal*
	Applied Finishes			*Other*	
	Sanitation & HVAC				
	Electrical services				

PRODUCT LEVEL PROCESS

Following we provide a description of the process and hypotheses made when conducting the LCC analysis on product level.

Cost structure analysis: Every expense registered for the development of the specific project is collected across material, supplementary material, production, production equipment, transport, storage, R&D, travel expenditures and management costs. Expenses are grouped into the following categories: Material, labour and other.

Benchmark: Based on function of upcycle products, the characteristics and properties of the benchmark product are defined in order to find a suitable alternative to compare against.

Comparative analysis of products: The upcycle solutions are compared to benchmark on an overall level. The results are expressed in the relevant units (DKK/m^2, m^3 or others). Benchmark data is based on Molio database.

R&D: The first-time nature of materials productions means that there was know-how developed both before and during the production process. R&D costs are not included in the unit cost.

Project management costs: Project management costs reflecting hours spent by internal architects, engineers and consultants is calculated at 10 % pr. product.

Future scenarios: All upcycle products presented here are based on first and second productions leaving room for future optimisations of amount of circulated resources and more efficient processes. For this reason we have included optimised scenarios to visualise the potentials.

LCC: The expense data is introduced in LCCbyg, which estimates the maintenance costs and generates a report with the alternatives presented.

BUILDING LEVEL PROCESS

The following provides a description of the process when conducting LCC on building level.

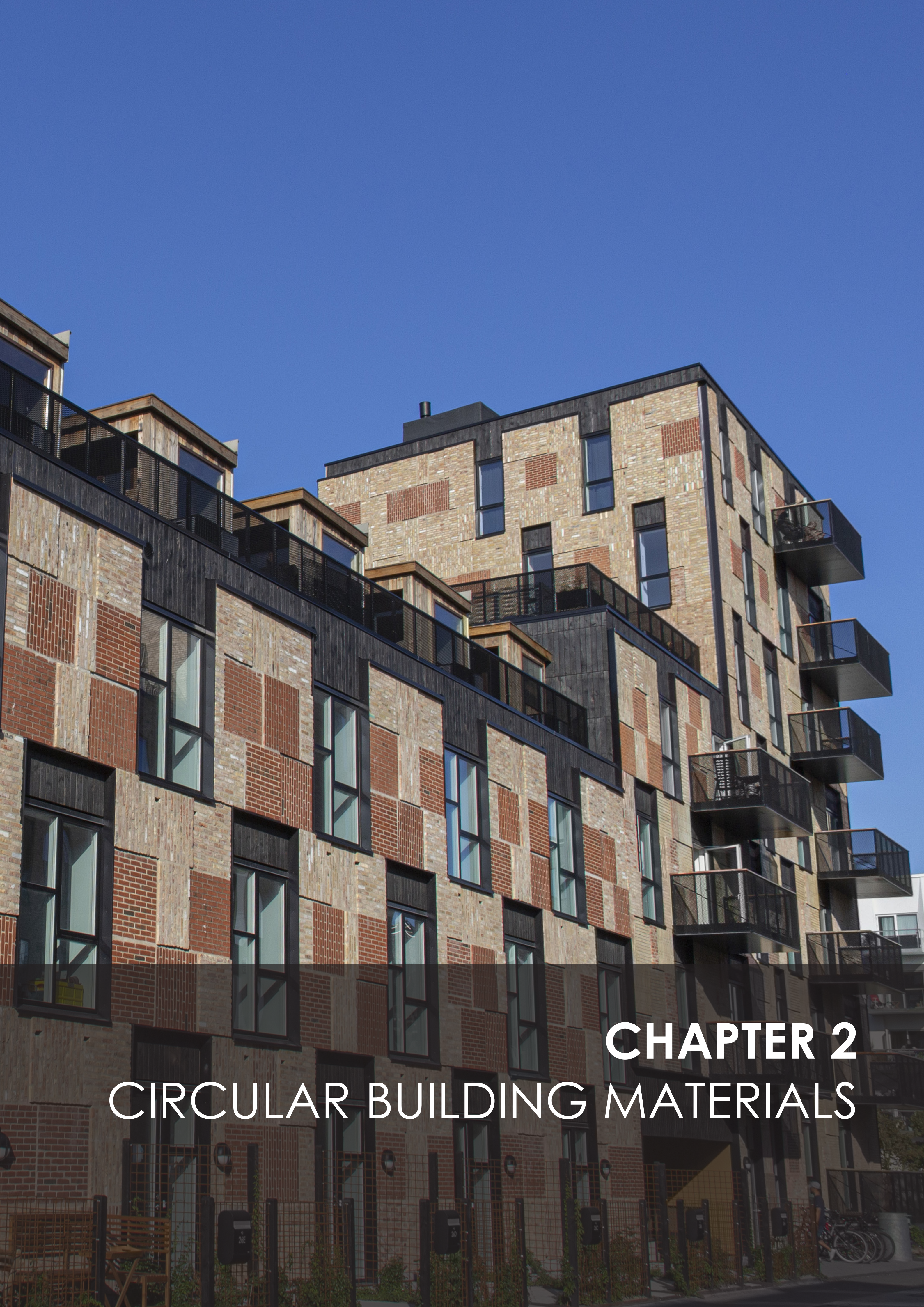
Collection of data: As upcycle materials only take up a part of the two building projects we have collected data on expenses for other materials through the developer, AG Gruppen, forming the basis of the building LCC calculations.

Benchmark: All benchmarks across product and building level match benchmarks from LCA to ensure baseline for comparison. The basis for the calculation of the benchmark building consists in estimating the LCC, if we were to replace those elements with market alternatives. In short, this means that the benchmark prices found for the product level are used, if lacking, primary source has been Molio price database.

EXPENSES VS. SELLING PRICE

It is important to clarify and underline that LCC on product level and building level are based on two different sets of data. LCC on product level is conducted on the basis of the material suppliers' expenses in development, production, transportation etc. while the data for LCC on building level is based on the actual selling price. The selling price is also visualised in the graphs on LCC product level to create transparency on potential differences.


26G
26F



CHAPTER 2
CIRCULAR BUILDING MATERIALS

UPCYCLE MATERIALS AND PRODUCTS

LCA AND LCC

IMPACT ON PRODUCT LEVEL

In the following chapter we will introduce the environmental and economic impacts of upcycle products across Upcycle Studios and Resource Rows. The environmental impacts are presented across a focus on CO_2 and waste minimisation.

Product level: LCAs are presented across all upcycle products used in Upcycle Studios and the Resource Rows as this was needed for the LCA calculation on building level.

Many products include both upcycle and conventional materials, why the first three LCAs on product level are supplemented by an LCA calculation on material level showing the embedded CO_2 in the specific material.

Furthermore, we have supplemented the LCA calculations with data on the amount of waste that has been eliminated through upcycling of wood, concrete, bricks and windows. This is done to visualize the impact across CO_2 and resource optimisation.

LCC calculations in building level are based on data from AG-Gruppen. Therefore, it has not been needed to conduct detailed LCC calculations on product level as is the case for LCA. That being said, we have included LCC results on selected products where LCC analysis was available from other projects. This provides an insight in not only the selling price, but as interesting the expenses held in developing these new building materials.

All products are presented through a benchmark comparison. When assessing the results, it is important to keep in mind what we benchmark against. Here, the aim has been to create a benchmark scenario having the same architectural quality while using conventional available products on the market. Choosing another benchmark will, of course, provide a different result. Benchmarks have been chosen and developed in close collaboration with MOE A/S for third party validation.

Product LCAs are supplemented by LCA calculations of optimized scenarios. These calculations are based on identified potentials for improvements in as-built upcycle products. Improvements include increase of upcycle materials, improvement of production methods, increase of volume, improvement of product design and decrease of virgin materials. We have online included improvement realistic for implementation in next iteration of products. Each optimized scenario is explained in material sections below.

Impact of waste mitigation of wooden products is presented as total numbers across upcycled wooden products.

Upcycle bricks:
- LCA on material level and product level
- LCC on product level

Upcycle windows:
- LCA on material level and product level
- LCC on product level

Upcycle concrete:
- LCA on material level and product level
- LCC on product level

Offcut douglas facade:
- LCA on product level

Offcut douglas wall cladding:
- LCA on product level

Offcut douglas floor:
- LCA on product level

Offcut oak floor:
- LCA on product level

Upcycled terrace:
- LCA on product level

Upcycle burned facade:
- LCA on product level

Upcycle roof top houses:
- LCA on product level

UPCYCLE BRICKS

UPCYCLE BRICKS

INTRODUCTION

IMPACT OF UPCYCLE BRICK

On the following pages we will present the impact of upcycle brick for the facades in Resource Rows. This wil be presented across an analysis of;

1. LCA on material level
2. LCA on product level
3. LCC on product level
4. Waste minimisation

But before we dive into the impact parameters, here is a descripton of the product and performance:

PRODUCT DESCRIPTION

The upcycle brick wall is an exterior wall construction with a brick facade consisting of 100 % reused bricks. The reused bricks are a mix of cut brick elements from buildings ready for demolition and reused bricks, all casted together on a concrete back plate in a pattern creating a unique aesthetic expression.

Type and use: The brick wall for the row houses consists of a prefabricated front wall with reused bricks and concrete mounted with steel brackets on a wood construction. The load of the prefabricated front wall is carried by itself.

Material source: The cut brick elements originate from large unbroken facades in two former brewing houses in Carlsbergbyen (Stødpuden and the Matrix Building) and two schools in Aarhus. Here, a completely new technique for harvesting bricks in cement mortar has been developed, allowing bricks from the 1960's that could not be used again because the mortar is stronger than the bricks why it is difficult out separate out the bricks without breaking them, to now be circulated. In combination with the cut brick elements, recycled bricks and waste from Gamle Mursten is used.

Quantity: 2,914 m^2 brick facade have been erected in the Resource Rows. Here, approximately half of them are placed at the row house facades facing the street.

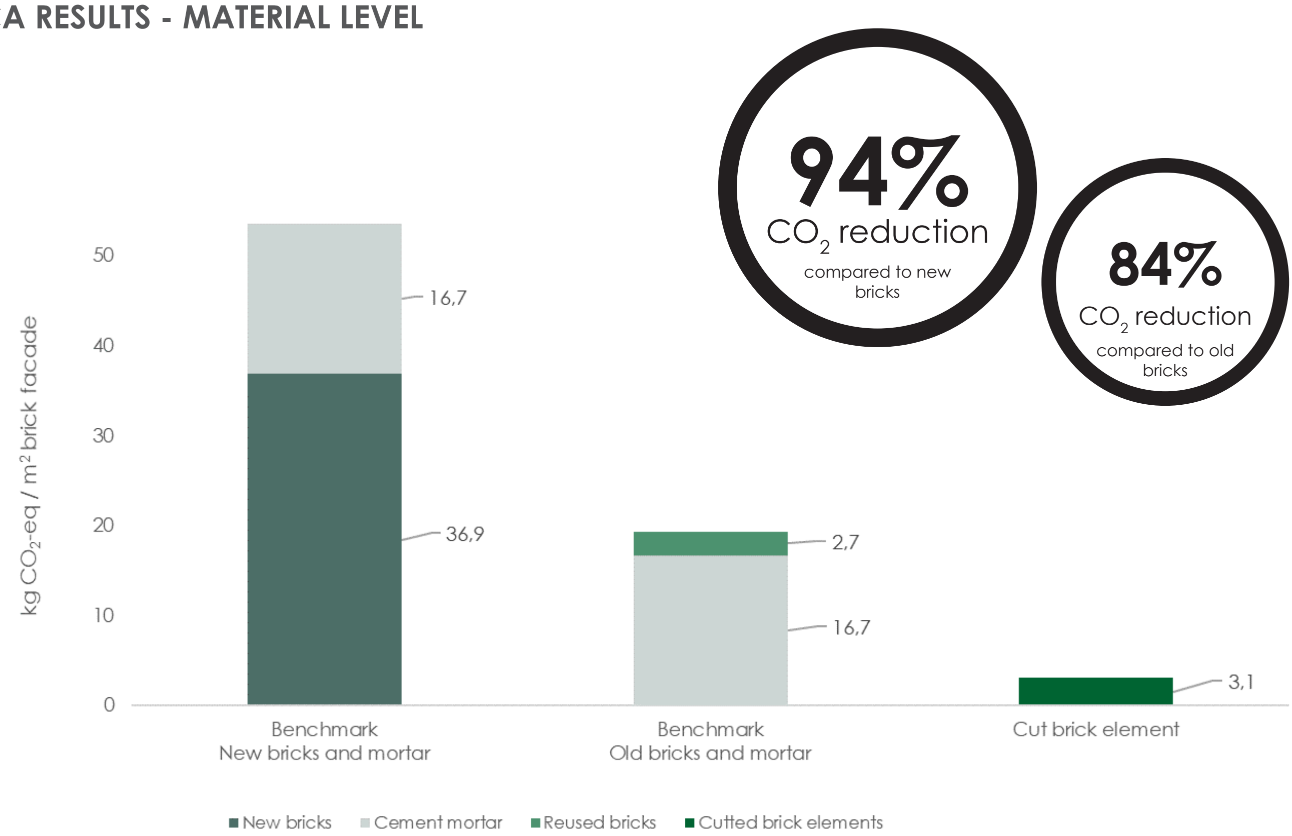
Performance: 50-100 years of lifetime expectancy.

Size: The final prefabricated front walls varies in size from 2.3–15 m^2.

Design: The combination of different brick colors due to available sources carries the story of an upcycle brick wall. The brick front wall consists of brick elements placed in a pattern with recesses in which the elements are rotated with both horizontal and vertical brick patterns creating a unique architectural expression that can be adapted to specific design wishes.

UPCYCLE BRICK WALL

LCA RESULTS - MATERIAL LEVEL



BRICKS

Bricks are one of the most widely used construction materials in Denmark and have strongly impacted architectural design and history. Sociological trends are shifting populations towards cities, leaving behind empty buildings in less dense areas. Since the 1960's, cement mortar being stronger than the bricks have been used making it impossible to disassemble the bricks and mortar. The availability of this waste material allows for new ways of expression while preserving historical and aesthetical values.

Declared unit: 1 m^2 outer wall with brick facade.

Included processes: The processes included are the production of new materials as well as preparation and handling of reused materials.

Benchmark: Here, two benchmarks are presented when comparing cut brick elements with alternatives. The benchmarks are 1) new bricks and cement mortar and 2) reused old bricks from Gamle Mursten and cements mortar.

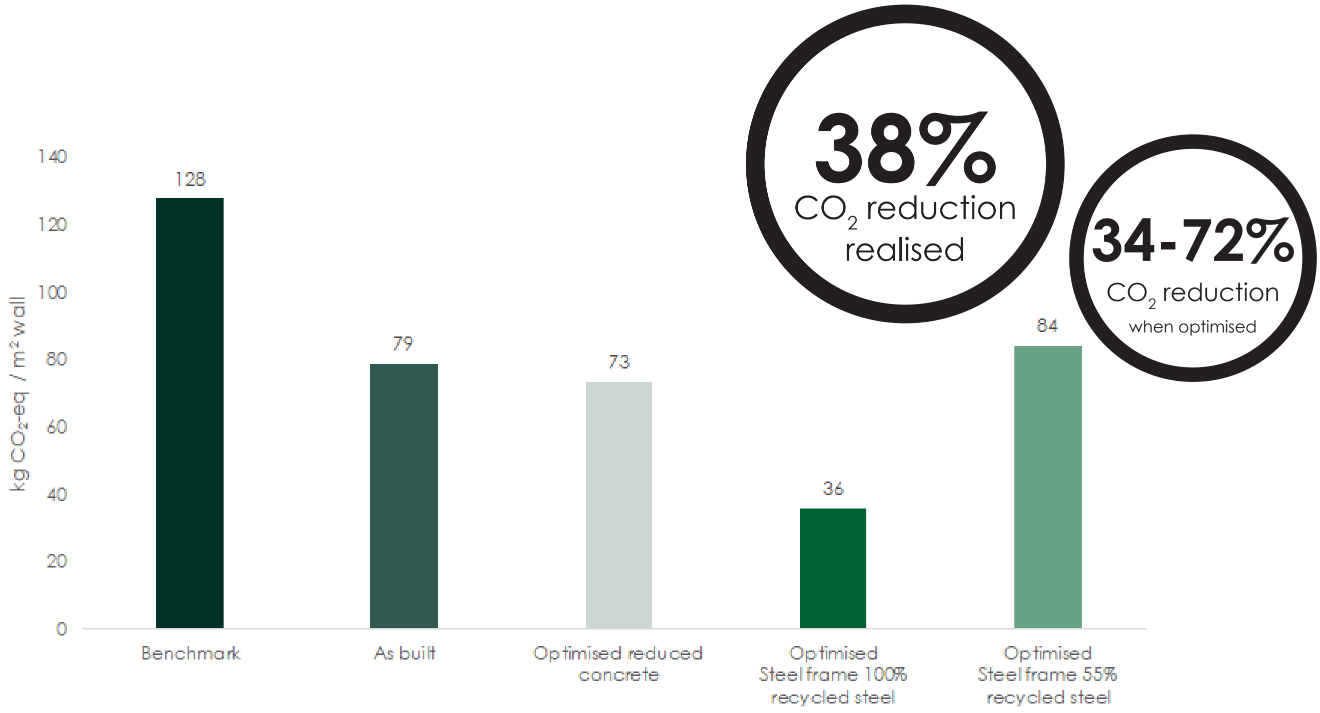
RESULT: 84-94 % CO_2 reduction: When comparing the production of cut brick elements with the benchmarks, we obtain different levels of CO_2 savings. Having only cut brick elements instead of the conventional benchmark with virgin materials, we save 94 % CO_2 whereas we save 84 % when comparing with recycled bricks and new mortar. The two benchmarks include the use of virgin mortar while the upcycle brick elements do not. The principle for doing so is that the cut elements are not placed element by element on top of each other but instead casted directly into a loadbearing concrete plate. Assessing the results, it is seen how the CO_2 emissions of producing/processing both new and reused bricks are extremely high compared to cutting brick elements. This proves the necessity of further upcycling with the newly developed method.

Optimised scenario: The optimised scenario will be to only use cut brick elements for the brick facade instead of mixing cut brick elements with materials from Gamle Mursten.

The potential is even higher: In 2019 SBi published a report showing the CO_2 emissions of conventional brick walls being 66.36 kg CO_2-eq /m^2, which exceeds the benchmark used for this analysis. This was not included in the analysis as the report is based on another LCA methodology and therefore cannot be directly compared, yet it shows an even higher potentail saving for upcycling bricks.

UPCYCLE BRICK WALL

LCA RESULTS - PRODUCT LEVEL



UPCYCLE BRICK WALL

The upcycle brick wall for the row houses at the Resource Rows consists of a facade made of reused bricks casted in concrete and mounted with steel brackets on a standard wood construction. The reused bricks consist of 55 % cut brick elements from demolition mature buildings, 22.5 % waste from Gamle Mursten, and 22.5 % reused bricks from Gamle Mursten.

Declared unit: 1 m² of upcycle brick wall.

Included processes: The processes included are the production of all new materials, potential transport of materials to manufacturer of the brick facade, water and energy consumption for manufacturing the brick facade, cutting and transporting the brick elements with pallet lifter and truck. Furthermore, the LCA also accounts for the production of the aggregate handling the cut elements and special made pallets for transporting the cut elements. The concrete used is modelled according to the concrete recipe from TCT including waste during manufacturing. A flowchart showing the included processes more specific can be found in appendix 3.

Benchmark: The benchmark is a conventional shell wall with new bricks, insulation and a loadbearing concrete back wall with lower transportation.

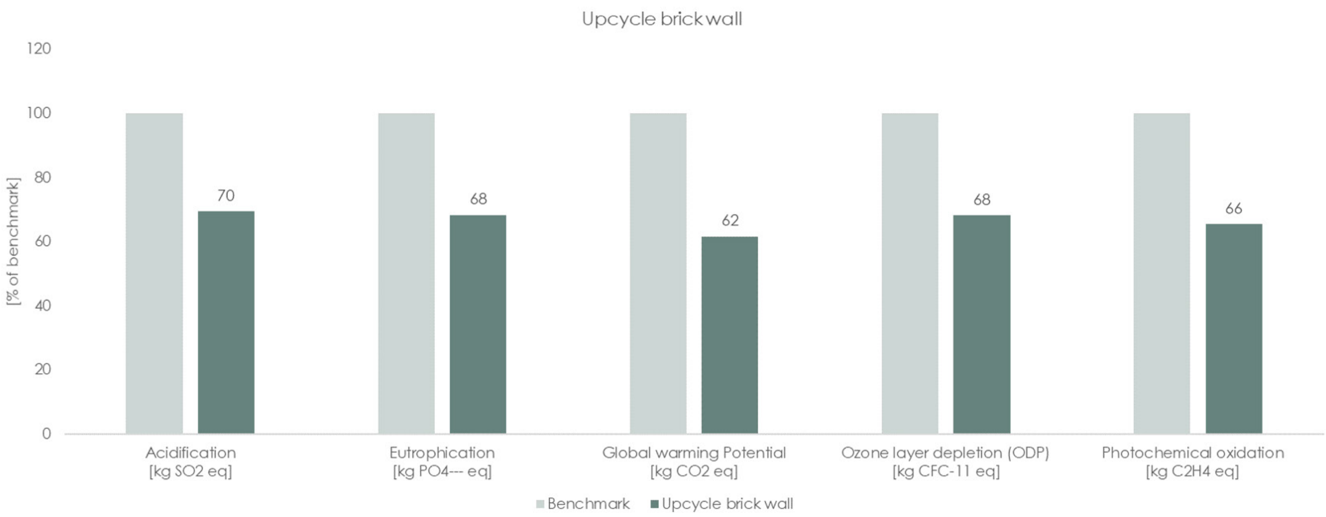
RESULT: 38 % CO_2 reduction: Comparing the upcycle brick wall with benchmark, a CO_2 saving of 38 % has been obtained.

Optimised scenario: Three optimised scenarios are included due to investigation of other structural possibilities. In all three scenarios, 100 % cut brick elements are used. Scenario 1) has a 7 % reduction of the concrete behind the cut brick elements, 2) and 3) has substituted the concrete behind the cut brick elements by a steel frame holding the cut brick elements where scenario 2) has a 100 % recycled steel frame and 3) has a 55 % recycled steel frame (market average). Scenario 1), 2), and 3) has a potential CO_2 saving of 43 %, 72 %, and 34 %, respectively, when comparing with benchmark.

Bricks, concrete, and steel: Recycling bricks as a cut brick element has a positive impact when looking at CO_2 and resource consumption. However, the way these elements are further handled and mounted is crucial to the final CO_2 potential of the upcycled product. A steel frame is only preferable over concrete when having a high recycling percentage of the steel. Aiming for a recycled steel frame behind the bricks, an optimised upcycle brick wall has the potential of lowering the CO_2 emissions with 72 % compared to benchmark. A fourth option could also be to change the wall design so that the windows are not in checkered pattern but rather in columns eliminating the need for extra steel structure (not part of calculations presented above).

UPCYCLE BRICK WALL

ACROSS IMPACT CATEGORIES + WASTE



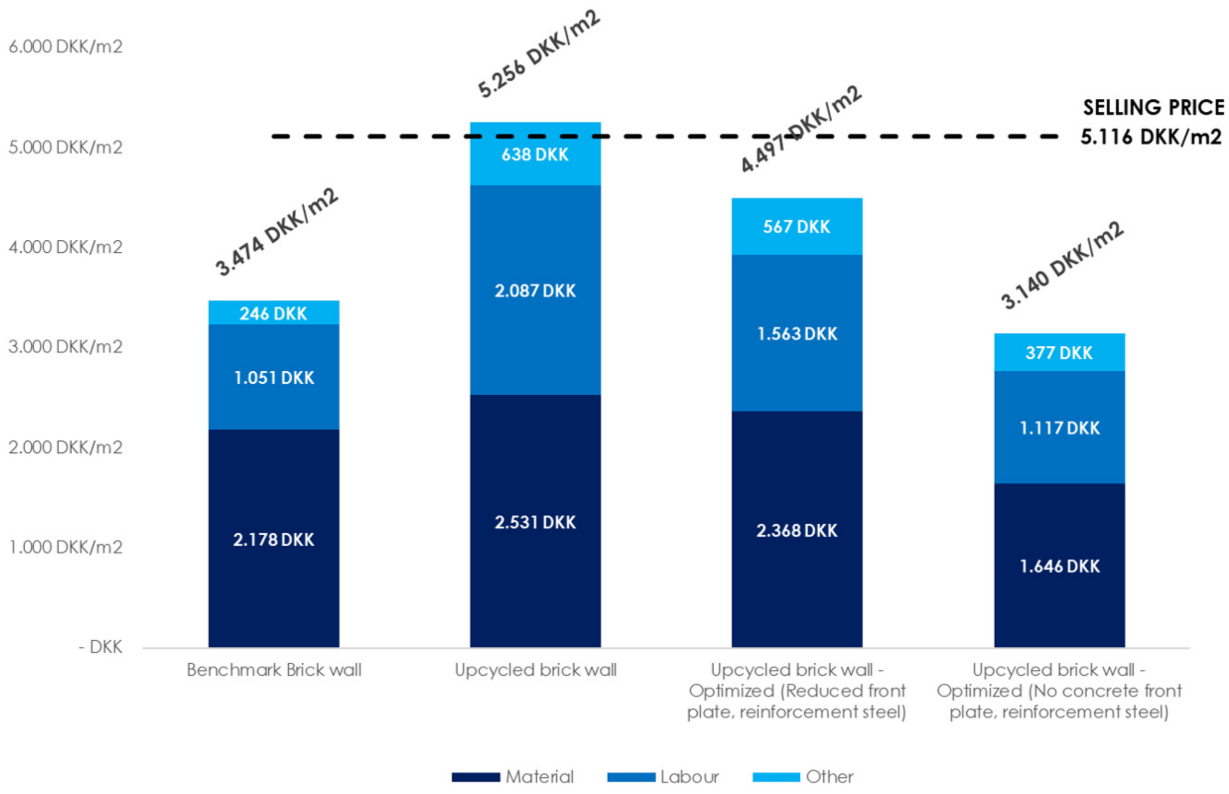
Impact category	Product	
	Benchmark	**Upcycle brick wall**
Acidification [kg SO2 eq]	0,372	0,258
Eutrophication [kg PO4--- eq]	0,127	0,087
Global warming Potential [kg CO2 eq]	127,767	78,799
Ozone layer depletion (ODP) [kg CFC-11 eq]	6,61E-06	4,52E-06
Photochemical oxidation [kg C2H4 eq]	0,030	0,019

ACROSS IMPACT CATEGORIES

The table and graphic above show the environmental impacts that occur in the production of 1 m² upcycle brick wall at the Resource Rows and 1 m² corresponding to conventional shell-walled outer wall. From this it can be seen that the upcycle brick wall perform significantly better in all impact categories.

UPCYCLE BRICK WALL

LCC RESULTS - PRODUCT LEVEL



LCC UPCYCLE BRICK

The graph above expresses the cost structure of upcycle brick, two optimised scenarios, and benchmark. The bars reflect the split in the following expence catagories: material, labour and other costs. Costs include installation, given that the bench-mark and upcycle processes are different from each other.

Benchmark: The benchmark consists of a concrete back wall, a layer of insulation and a front layer of bricks, as defined in the LCA analysis. The brick price is based on "Blødstrøgen" by Randerstegl, with same thickness and similar aesthetics as the upcycle brick wall. The prices used for the insulation and con-crete are the same as for the upcycle brick wall. Considering that these elements are not upcycled nor produced by Len-dager, they already serve as a benchmark.

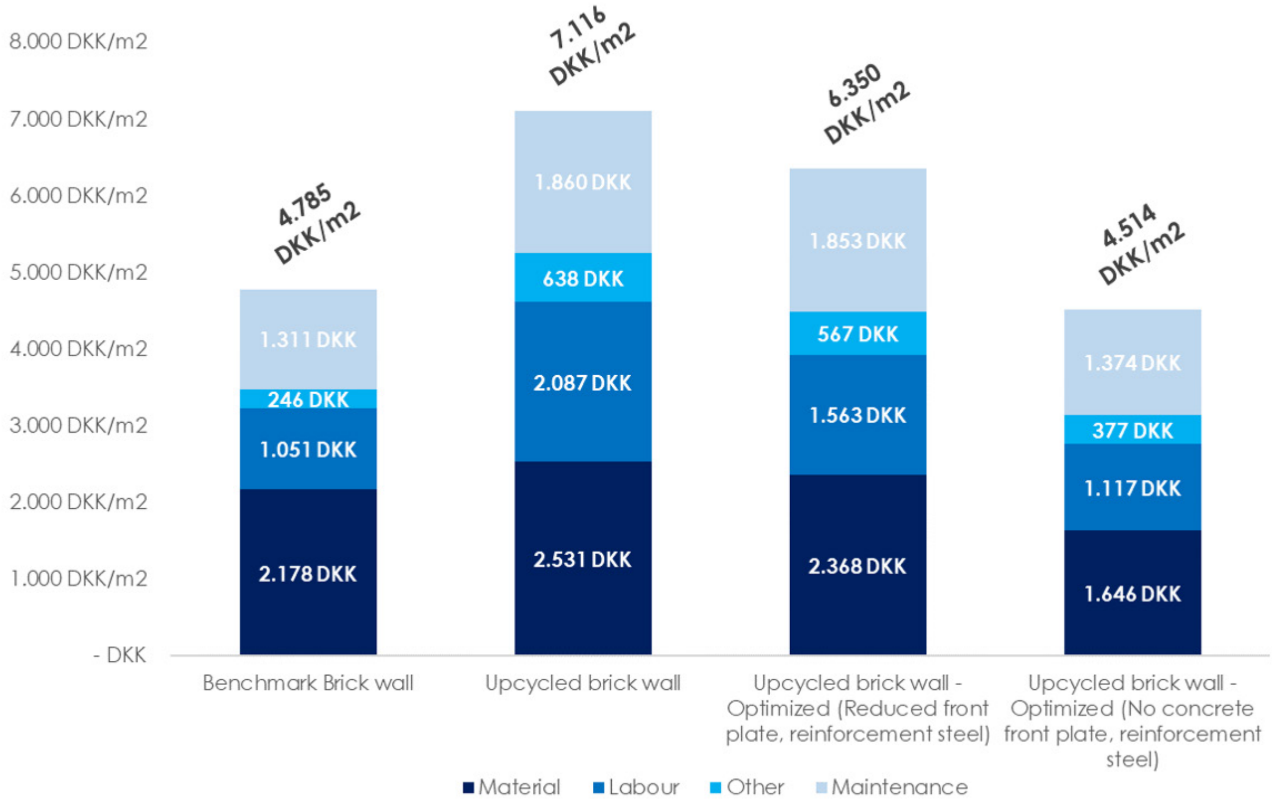
Upcycle Brick Wall: The present cost structure of upcycle brick wall reflects all production costs, excluding R&D and 90% of project management costs, as seen before for other products. The wall consists of cut brick elements as well as loose bricks casted on a concrete plate and supported by a wooden layer containing insulation.

Optimised scenario: There are two future scenarios forecasted, the first is based on the premises that the average thickness of the concrete layer can be reduced by 7%, and second, the optimised wall will not use loose bricks. The second scenario, goes further and assumes that there will be no need to cast the cut elements on a concrete plate. These improvements in the process can make the upcycle solution competitive with market alternatives.

Result: The technical differences between the benchmark and the upcycle brick wall make the latter appear expensive. This is largely because the upcycle wall has a wide range of additional elements, such as reinforcement steel, brackets and further use of concrete, adding to the cost per m^2.

UPCYCLE BRICK WALL

LCC RESULTS - PRODUCT LEVEL



Furthermore, the value of the upcycle brick wall is also significantly higher due to the unique design and impact justifying the higher cost. That being said the optimised scenarios show a potential for significant changes should the product be directly competitive on price.

Selling price: Looking at the selling price it is marginally lower than expenses for the production and mounting of the elements. Improvements in the optimised scenarios can allow a close to direct benchmark with conventional brick wall.

It is important to state that the expenses in delivered upcycle brick wall and optimised scenario do not include any kinds of margins for the supplier. These numbers are only based on costs.

Cost structure: The costs between benchmark and upcycle brick wall are very similar on material level, while expenses almost double on labour costs due to a high level of manual labour on cutting out bricks. In the optimised scenarios the manual labour is improved through more efficient processes and higher level of experience speeding up the work across cutting and producing element.

Maintenance: Maintenance and replacement costs are dependent on the type of material and the price of the product. In the case of upcycle brick wall the difference in maintenance reflects difference in materials in the back wall (construction). Benchmark and upcycled brick wall optimised (no concrete) both have a concrete back wall needing lower maintenance than upcycled brick wall and upcycle brick wall optimised (steel) that are based on a wooden construction. Hence, the maintenance costs for the upcycled brick frontwall are the same across all four scenarios.

UPCYCLE BRICK WALL

SUMMARY OF IMPACT

RESOURCE OPTIMISATION

With the amount of upcycle brick wall erected in the Resource Rows, the environment has saved 459 tonnes of waste - only by circulating the brick. Waste that would otherwise end up crushed or deposited in the wild. In addition, the tonnes of saved waste is a clear indicator of the amount of virgin resources saved alone in this project.

UPCYCLE BRICK WALL
RESULTS FOR RESOURCE ROWS

	AS BUILD	POTENTIAL IF BUILD PER OPTIMISED SCENARIOS*
CO_2	3 tonnes CO_2 -eq /rowhouse 38 % saving	5 tonnes CO_2 -eq/rowhouse 72 % saving
$	-101,574 DKK/rowhouse 51 % more expensive	19,038 DKK/rowhouse 10 % saving
Waste	459 tonnes waste in total	459 tonnes waste in total

* Best case

UPCYCLE WINDOWS

LENDAGER GROUP

UPCYCLE WINDOWS

INTRODUCTION

IMPACT OF UPCYCLE WINDOW

On the following pages we will present the impact of upcycle windows for the construction of Upcycle Studios. This will be presented across an analysis of;

1. LCA on material level
2. LCA on product level
3. LCC on product level
4. Waste minimisation

Before we dive into the impact parameters, here is a description of the product and performance:

PRODUCT DESCRIPTION

Upcycle window is a completely new window element based on a two layered framing each with recycled double glazing from building renovations and demolitions supplemented with new double glazing and safety glazing. When the two layers of double glazing are gathered as one layer, an air tight room between the glazings gathers heat and contributes to a high performance. In this way, old windows can be reused and still meet the 2020 requirements.

Type and use: The upcycle window is a double frame window with up to 50 % recycled double layered windowpanes in the current best case scenario. The frame is made of pine and treated with linseed oil. When a door is included in the window element, it is made of new triple layered glazing. Reusing two layered windowpanes in a double frame allows the use of two layered virgin windows as supplement hereby saving one layer of glazing in the virgin windowpanes, while still meeting the 2020 requirements.

Material source: The windowpanes are double glazed and originate from a general housing association in Aalborg.

Quantity: 870 m^2 upcycle windows have been delivered for Upcycle Studios distributed in a total of 57 window sections.

Performance: The lifespan expectancy of a window is normally 25 years. The remaining lifespan of the reused glazing is tested by the Danish Technological Institute to be 24-36 years from now, hereby meeting the expected lifespan of new glazing. This indicates that windows normally are changed before their actual end of life. The upcycle windows are DVV-labelled meaning that they as a minimum comply with the standards for products and production defined in the Window Industry's Technical Regulations for Danish Window Verification.

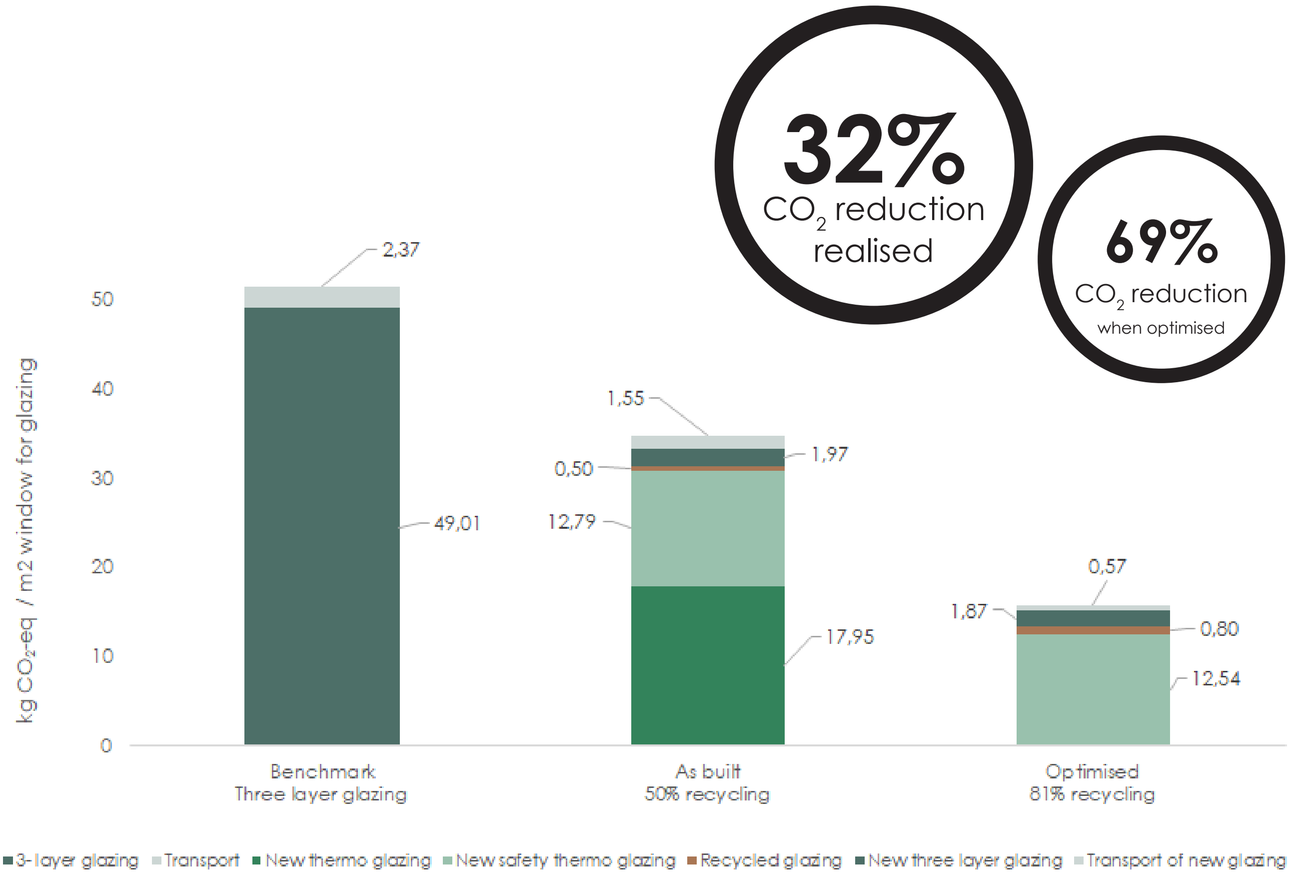
- **U-value:** 0.69 W/m^2K (area weighted average)
- **G-value:** 0.49
- **Energy efficiency:** The windows meet the official guarantee for window's energy efficiency from DS / EN 10077-1.

Size: A window section at Upcycle Studios differs between 4-30 m^2. The size can be adapted to the specific building and the recycling rate can be increased by designing the window based on accessible resources for circulation.

Design: The upcycle windows express the upcycle story by letting the two layers of panes go past each other - highlighted by the interior frame being unstained and the exterior painted black.

UPCYCLE WINDOWPANES

LCA RESULTS - MATERIAL LEVEL



WINDOWPANES

Windowpanes are currently being replaced across Denmark in order to live up to 2020 energy requirements and are therefore often discarded before their functional end of life. Alongside this, the world's resources of sand is running dry[1] which is the most important resource in glass production. As the demand for windows is expected to double in 2023 relative to 2008 levels[2], we need to improve the use of the glass that is already in use.

Declared unit: Window glazing for 1 m^2 window. The glazing represents how the windows are as built in Upcycle Studios best case scenario consisting of 50 % recycled panes, alongside new safety, thermo and three layered glazing.

Included processes: The processes included for the upcycle glazing is transport and cleaning of reused glazing as well as manufacturing and transport to Krone Vinduer of the new glazing.

1 https://www.dr.dk/nyheder/verden-er-ved-loebe-toer-sand
2 https://www.statista.com/topics/4108/glass/

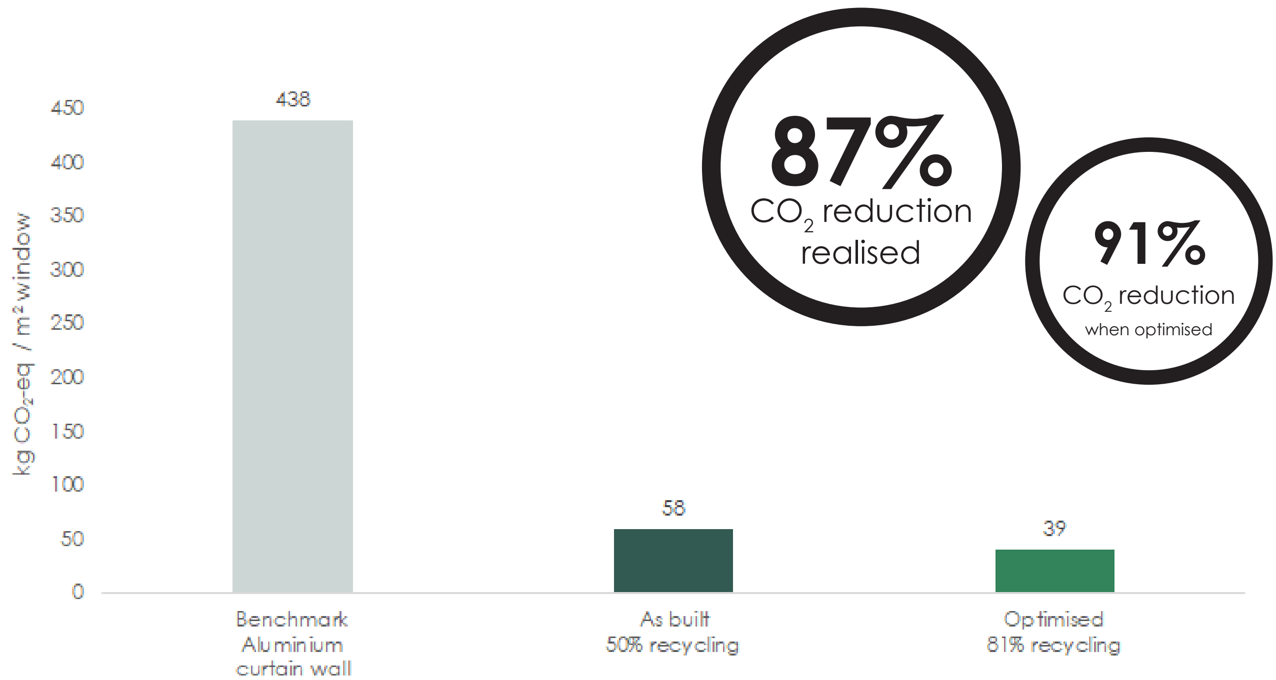
Benchmark: The windowpanes are benchmarked with a tripple layered glazing transported from the manufacturer to Krone Vinduer.

Result: 32 % CO_2 reduction: Comparing the CO_2 emissions of virgin windowpanes with using 50 % upcycle windowpanes shows a reduction of 32 %. Looking at the graph above it becomes very clear that the actual production of new three layer glazing is a very CO_2 heavy process making up for most of the benchmark impact. This is also clearly shown in the upcycle windowpane analysis showing a quite high impact from the use of new glazing compared to the recycled glazing that has close to no negative impact.

Optimised scenario: An optimisation of the as build glazing for the upcycle window will be to add more reused glazing. Here, a recycling percentage of 81 % glazing will be realistic still having new safety glazing and new tripple glazing as a door. This gives a CO_2 saving of 69 % compared to the benchmark windowpane.

UPCYCLE WINDOWS

LCA RESULTS - PRODUCT LEVEL



UPCYCLE WINDOW

For Upcycle Studios, upcycle windows in double frames are delivered in various sizes. In this report, the focus is on the large window section of 27 m² which achieves a recycling factor of 50 % at its best case scenario.

Declared unit: 1 m² of a 27 m² window section that meets the 2020 requirements for windows.

Included processes: The processes included are production of new materials, preparing and cleaning the recycled panes, transport to Krone Vinduer, and energy and nails for manufacturing of the final window section. Additionally, the steel brackets for wind support are included as well as waste at Krone Vinduer. A flowchart showing the included processes more in detail can be found in appendix 2.

Benchmark: The benchmark is a conventional curtain wall with three layered glazing window in aluminium frames from Schüco. Due to wind pressure and load on the large window, some aluminium frames are reinforced with steel. This benchmark obtains a similar structural strength and architectural expression as the upcycle window in Upcycle Studios.

RESULT: 87% CO_2 reduction: Comparing 1 m² of the upcycle window of 50 % reused glazing with the benchmark window, a saving of 380 kg CO_2-eq is obtained corresponding to a saving of 87 %. This result is very significant - especially as it is based on a first-time-production.

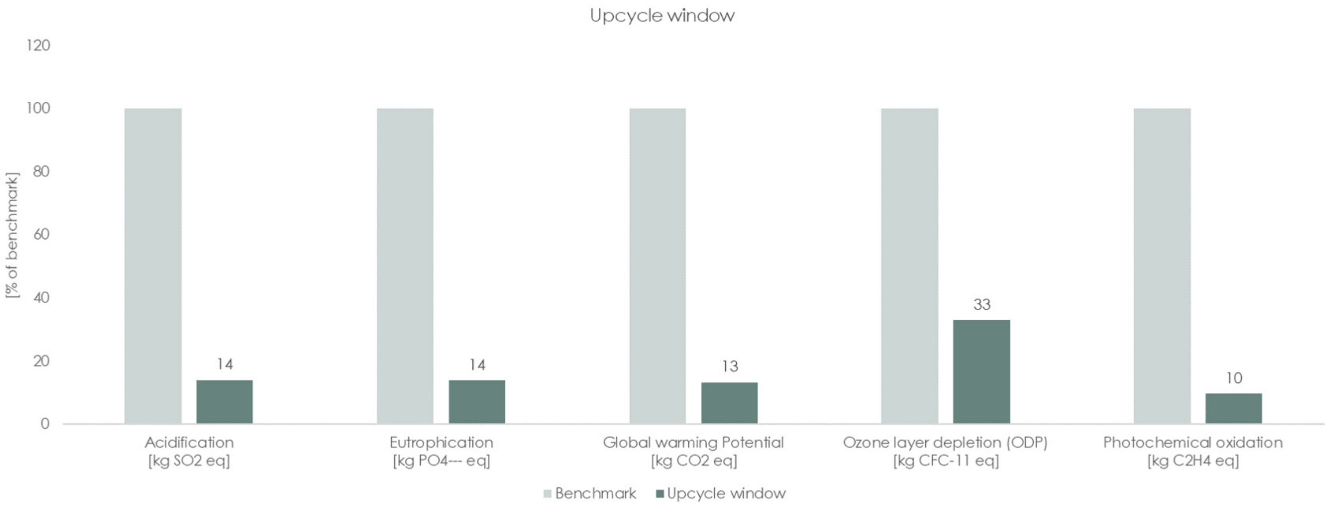
Optimised scenario: As described under material level, an optimised upcycle window can achieve a 81 % recycling rate for the windowpanes due to experience and optimisation opportunities using a newly developed design tool. Implementing these future optimisations and keeping the wooden double frame, it can enable a saving of 91 % in CO_2 emissions.

Reused glazing and wood frame: The analysis shows that the largest CO_2 savings come from 1) using reused glazing supplemented with new double glazing instead of new triple glazing and 2) using wood frames instead of aluminium. The need for aluminium is lowered in the upcycle window due to the strengths of the double layered framing allowing wood to be used instead.

The remaining lifetime of the reused glazing indicates that panes generally are changed before they reach their end of life. This proves the need to keep circulating well functioning glazing and keep improving on the innovation of upcycle windows as it is extremely important in order to reach full utilization of the earth's resources.

UPCYCLE WINDOWS

ACROSS IMPACT CATEGORIES



Impact category	Product	
	Benchmark	Upcycle window
Acidification [kg SO2 eq]	2,491	0,349
Eutrophication [kg PO4--- eq]	0,652	0,091
Global warming Potential [kg CO2 eq]	438,091	58,145
Ozone layer depletion (ODP) [kg CFC-11 eq]	1,80E-05	5,94E-06
Photochemical oxidation [kg C2H4 eq]	0,164	0,016

ACROSS IMPACT CATEGORIES

The diagram and table above show the environmental impacts that occur in the production of 1 m^2 upcycle window for Upcycle Studios benchmarked with a corresponding 1m^2 curtain wall (benchmark). This shows that upcycle window outperforms benchmark on all parameters.

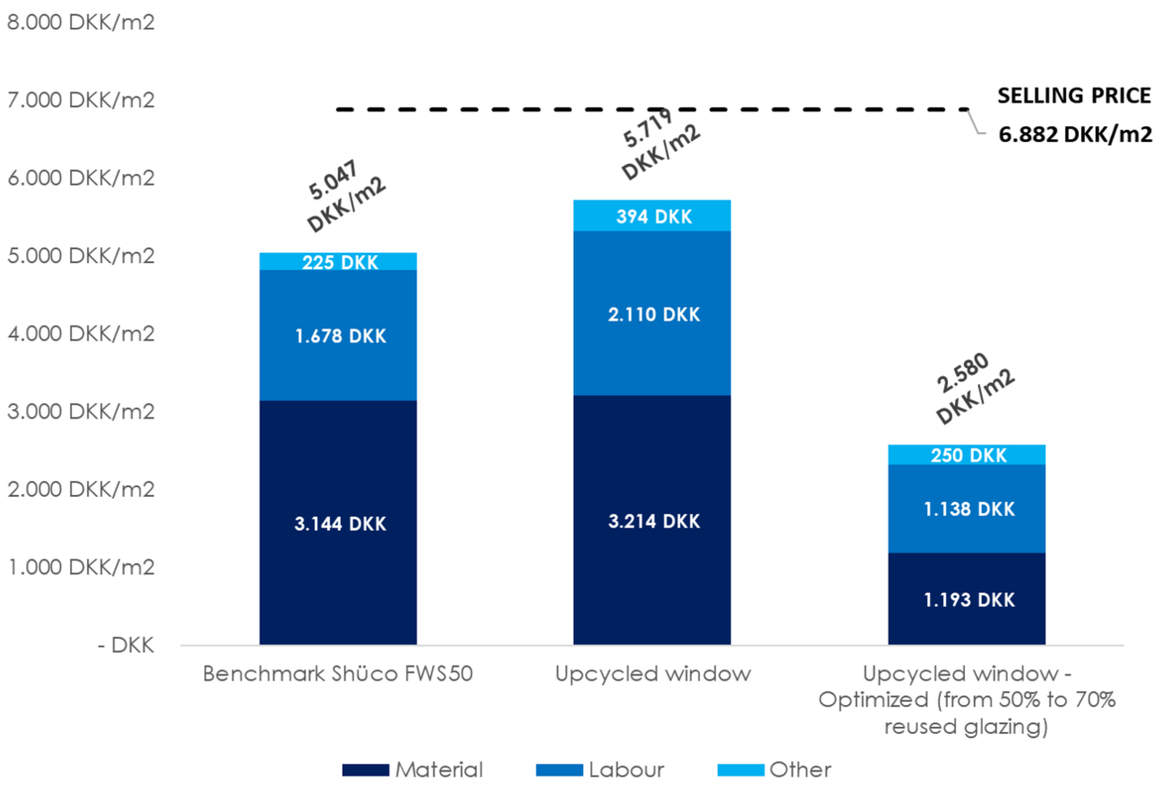
AMOUNT OF UPCYCLE GLAZING

The LCA on product level is based on a 50 % share of recycled glazíng, while the optimized scenario has an 81% recycling rate. The expectation of increase in recycling rate in future inventions is due to:

1. Increase in energy renovations leads to an increase of relatively young window glazing for recycling,
2. Positive results on tests of remaining lifetime indicating a longer lifetime of the glazing of windows than normally expected, leading to an increase of the pool of materials for upcycling
3. Due to first time production, we were restricted by a precautionary principle limiting the amount of recycled glazing to 50 %. Due to quality and performance of upcycle windows precautionary principles are expected change in future interventions.

UPCYCLE WINDOWS

LCC RESULTS - PRODUCT LEVEL



LCC UPCYCLE WINDOWS

The graph above expresses the cost structure of upcycle window, optimised upcycle window and benchmark. The bars reflect the split in the following expense categories: material, labour and other costs. As opposed to the concrete estimations, costs include installation, given that the two processes are different from each other.

Benchmark: The chosen benchmark is the facade solution offered by Schüco, the FWS50 curtain wall in aluminium frame. While the size of upcycle windows range from 4-30 m2, both LCA and LCC is focused on the windows installed in the south face of Upcycle Studios, that is 27 m^2. For this reason, and due to its' size, the benchmark necessarily needs to be a curtain wall capable of bearing the weight of a facade. Furthermore, the benchmark accounts for the additional costs of having three operational windows and one door.

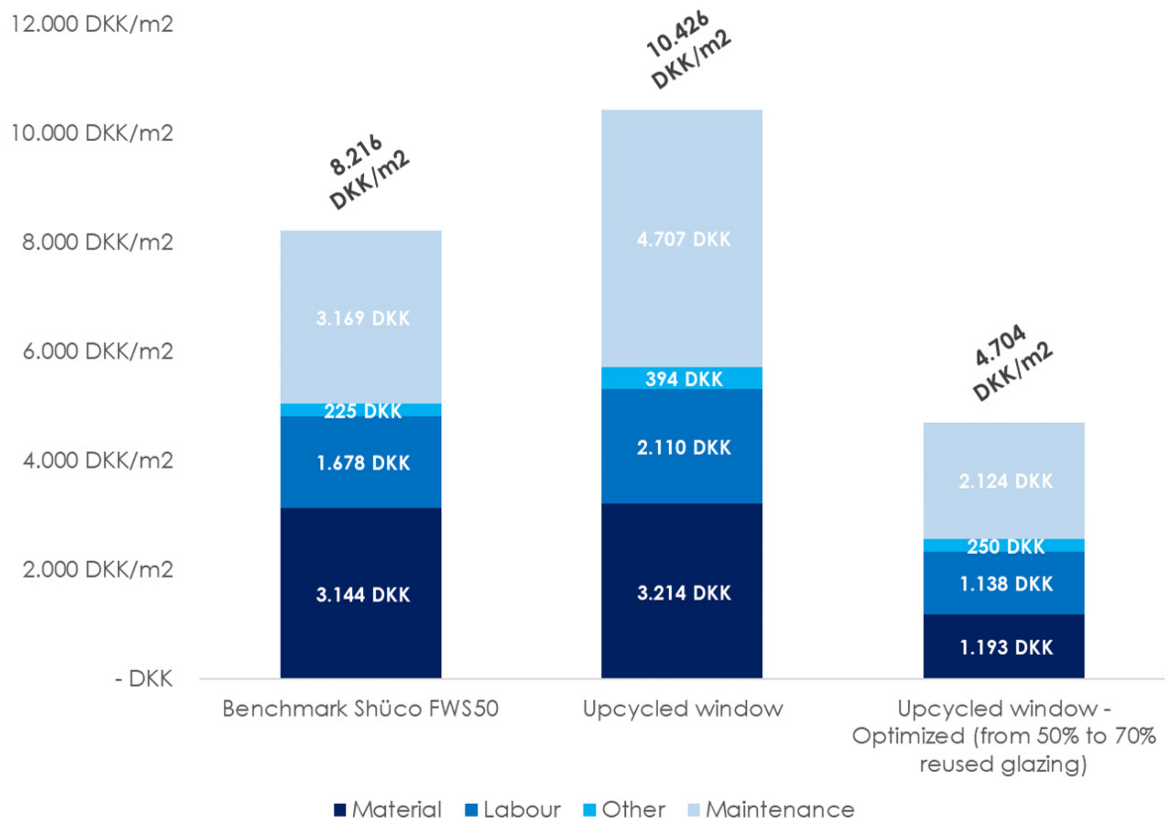
Upcycle window: The present cost structure of upcycle windows reflect all production costs, excluding R&D and 90% of project management costs, as proceeded with upcycle concrete. They have a 50/50% distribution between reused and new glazing.

Optimised scenario: The optimised cost structure is based on the assumption that the mounting of the glazing in the frame will be done in the factory, not on site, heavily reducing labour costs. Furthermore, the share of reused glazing will be increased from 50% to 70%, reducing a big share of the total expenses per m^2.

Result: The expenses on upcycle window ends up being close to DKK 700,- more expensive per. m^2 compared to benchmark. Though this is an increase it is not significant as upcycle windows expenses are based on a first-time-production while benchmark is based on a strong and known industry player. Looking at the expenses for producing the optimised scenario the product becomes very competitive strengthening the potential for scaling the solution.

UPCYCLE WINDOWS

LCC RESULTS - PRODUCT LEVEL



Selling price: Looking at the selling price it is higher than benchmark reflecting the higher value of a specially design and newly developed window. That being said, improvements in the optimised scenarios will allow to heavily outperform the benchmark product.

It is important to state that the expenses in delivered upcycle window and optimised scenario do not include any kinds of margins for the supplier. These figures are only based on costs.

Cost structure: The cost structures between benchmark and upcycle window are very similar leaving a bit higher expenses for materials, labour and others in the delivered upcycle window. This is due to fairly high acquisition costs of windows for circulation as timing did not allow a market search for other sources with same amount and quality as sourced for this project. Furthermore, the expenses for virgin two-layered glazing was significant why there is both an environmental and economic incentive for further optimisation.

Maintenance: Maintenance and replacement costs are dependent on the type of material. In short, it is the net present value of two cash flows: on the one hand, the yearly maintenance costs, estimated as a percentage of the acquisition price; on the other hand, replacement costs, estimated at 125% of the acquisition costs that are to be paid at the end of the products life cycle. In the case of windows, the life span of frames and glazing are <50 years, thus, maintenance costs are higher than acquisition as they account for 1 replacement plus yearly maintenance

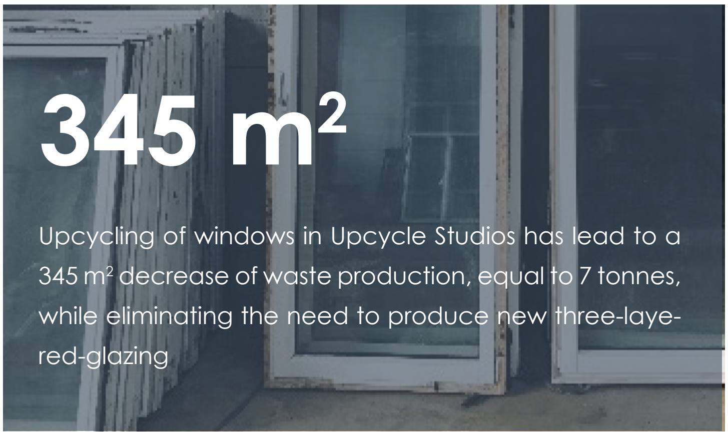
While similar to the benchmark in acquisition costs (material, labour and other), the maintenance costs are higher. This is due to the fact that aluminium frames (benchmark) in general have smaller maintenance costs than wooden frames (upcycle window).

UPCYCLE WINDOWS

SUMMARY OF IMPACT

RESOURCE OPTIMISATION

In addition to the CO_2 savings achieved by upcycling the window panes, a saving of resources has also been achieved. The upcycling of window panes has resulted in a saving of 7 tonnes of waste that has been upcycled instead of being downcycled, incinerated or landfilled. This minimises the need to produce new, virgine panes that pose a significant environmental impact.



UPCYCLE WINDOW
RESULTS FOR UPCYCLE STUDIOS

	AS BUILD	POTENTIAL IF BUILD PER OPTIMISED SCENARIOS
CO_2	16 tonnes CO_2 -eq/rowhouse 87 % saving	17 tonnes CO_2 -eq/rowhouse 91 % saving
$	-29,232 DKK/rowhouse 13 % more expensive	107,315 DKK/rowhouse 49 % saving
Waste	345 m² waste in total	559 m² waste in total

UPCYCLE CONCRETE

UPCYCLE CONCRETE

INTRODUCTION

IMPACT OF UPCYCLE CONCRETE

On the following pages we will present the impact of upcycle concrete for the construction of Upcycle Studios. This will be presented across an analysis of;

1. LCA on material level
2. LCA on product level
3. LCC on product level
4. Waste minimisation

But before we dive into the impact parameters, here is a description of the product and performance:

PRODUCT DESCRIPTION

Upcycle Concrete is construction concrete developed for load-bearing constructions. 100 % of the coarse aggregate is recycled giving the final concrete a recycling percentage of 45 %.

Type and use: The structural concrete is included in the class SCC meaning passive C25/30 CC2 and is designed for use as interior walls, floor slabs and terrain deck. Upcycle concrete is mixed on site and in situ casted.

Material source: The recycled aggregate is crushed concrete. The concrete used as aggregate originates from the subway construction in Copenhagen.

Quantity: 837 m^3 upcycle concrete has been delivered for the construction of Upcycle Studios.

Performance: The contractor required for two types of upcycle concrete for floor slabs and interior walls, respectively. Both in passive environmental class with the strength C25/30 certified in accordance with DS / EN 206-1: 2000 and DS 2426: 2011.

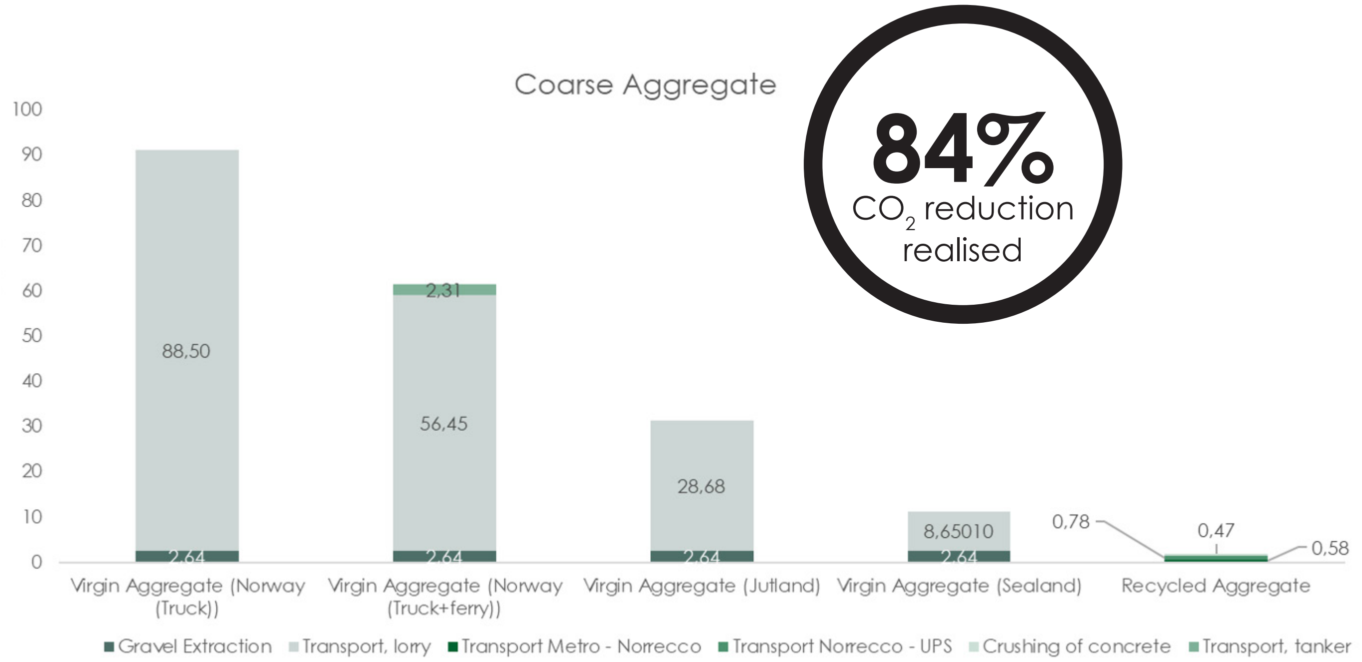
Strength requirements: In Upcycle Studios, the characteristic compressive strength after 28 curing days ranged from 35.7-46.9 MPa which is why the concrete meets the same requirements as virgin concrete in the same strength class with a characteristic compressive strength of minimum 31 MPa. Actually, the strength in the same class is higher for the upcycle concrete due to restrictions on a first time production.

Coarse aggregate: The crushed concrete meets the general requirements for aggregates in DS 2426 as well as additional specifications, cf. DS/EN 12620.

Air content and E-module: The air content is measured in the range of 5.7–8.7 % which corresponds to the air content of virgin concrete that is around 6-7 %. The E-module is 28 GPa after 28 days which matches what can be expected of a traditional concrete of a similar strength.

UPCYCLE CONCRETE AGGREGATE

LCA RESULTS - MATERIAL LEVEL



CONCRETE AGGREGATE

Concrete is the most used material in the world after water. According to Niras' projections, Region Hovedstaden will run out of gravel in 2027, Sealand in 2032 and Denmark in 2056[1]. Therefore, we need to find alternative materials to be used as aggregates for concrete which is why Lendager Group has developed a new type of coarse aggregate made of crushed old concrete from demolitions and left over productions.

Declared unit: 1 tonne of coarse aggregate ready to be used on the construction site.

Included processes: The processes for the upcycle concrete aggregate include the transport from the sourcing site Norrecco, the electricity used for crushing it into the desired size and the transportation to the construction site of Upcycle Studios.

Benchmark: As aggregate makes up 45 % of concrete products, it is an essential ingredient concerning volume. Today we can source aggregate locally, but as we are running out locally, the need of transport will grow.

In the graph above we have included four potential benchmarks based on aggregate sourced from respectively Norway (by truck or by truck and ferry), Jutland (Aalborg), Sealand, and Copenhagen (recycled aggregate). With the various benchmarks we truly see the importance of minimising transport and sourcing locally. All benchmarks include new coarse aggregate; extraction of virgin gravel from a gravel plant and transportation to the construction site.

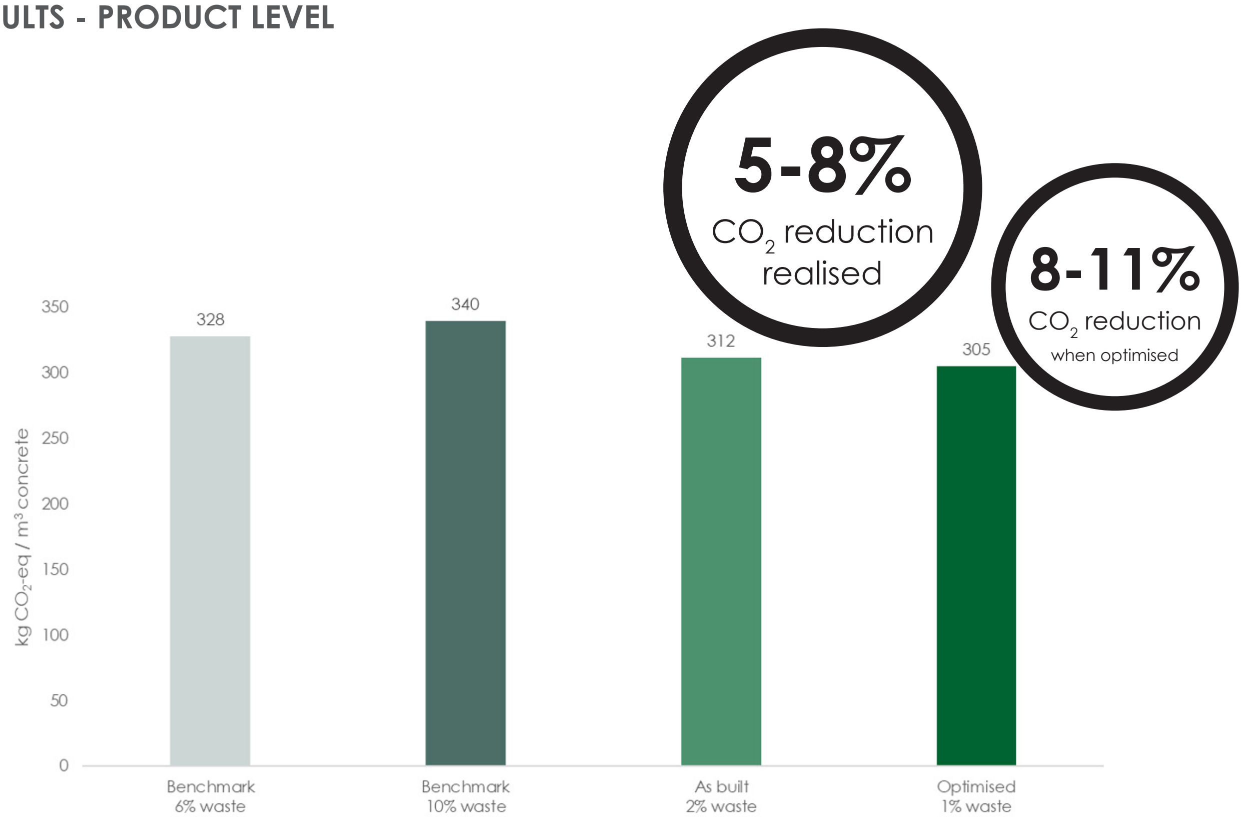
Result: 84 % CO_2 reduction: Comparing the CO_2 emissions from extracting virgin gravel from Sealand with using upcycle aggregate, a reduction of 84 % is seen. Only looking at the CO_2 emissions from the extraction of the gravel exceeds the full production of upcycle aggregate. This is partly due to the sourcing of upcycle aggregate very close to the construction site which circular economy allows. Furthermore, we see a minimal amount of energy used to crush the concrete into the finished, usable aggregate. See graph above.

Based on a combination of the predicted future lack of virgin gravel combined with the high achieved CO_2 saving on material level it is clear that there is a growing important impact on using recycled concrete as aggregate.

1 https://www.dr.dk/nyheder/indland/danmark-er-ved-loebe-toer-grus-et-af-de-vigtigste-raastoffer-verden-har

UPCYCLE CONCRETE

LCA RESULTS - PRODUCT LEVEL



UPCYCLE ON-SITE CONCRETE

An upcycle construction concrete was used in Upcycle Studio produced from a mobile mixing plant on site.

Declared unit: 1 m^3 ready-mixed concrete in strength class 25 MPa, passive environmental class (passiv miljøklasse) ready for use on the construction site including waste. A waste percentage of 2 % for upcycle concrete and 6-10 % for conventional concrete has been used due to difference in amount of waste in industrial and on site production.[1]

Included processes: The processes included are production of all materials, transport from manufacturer to construction site and energy consumption for mixing as well as for light and heat during the winter season. A flowchart showing the included processes more specific can be found in appendix 1.

Benchmark: The benchmark is a conventional factory concrete with virgin aggregate mixed at a factory with a lower electricity consumption compared to that of the upcycle concrete. The concrete recipe for the benchmark concrete is equal to the one used for the upcycle concrete to achieve a comparable result.

RESULT: 5-8 % CO_2 reduction: Comparing the upcycle concrete as built with benchmark of conventional concrete, a saving of around 20 kg CO_2-eq has been achieved corresponding to a saving of 5-8 %. This represents a relatively small change per m^3, but looking at the amount of concrete used in buildings it can make a huge difference. Savings stem mainly from reduction of waste and corresponds to results from a lifecycle assesment of circular solutions done by SBi.

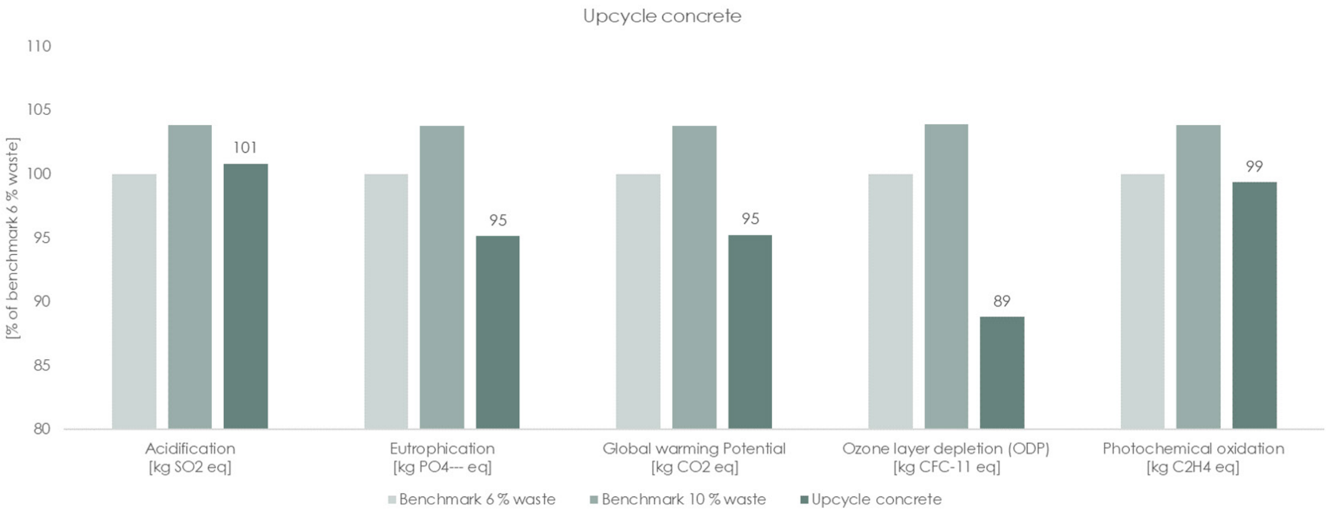
Optimised scenario: The optimised scenario of upcycle concrete is based on 1) the mobile mixing plant no longer using diesel generator but being powered through the Danish electricity grid and 2) a reduced waste percentage due to increased experience. These optimisations enable a CO_2 reduction of 8-11 % compared to benchmark.

Cement and waste: The analysis shows that the cement content by far has the highest impact in the production of concrete corresponding to 89 % of the CO_2 emissions of the upcycle concrete. To really reduce the environmental impact of concrete it is imperative to consider adoption of cement innovations that reduce the CO_2 of the cement component of the concrete. However, we are also facing a need for new solutions for concrete aggregate combined with a big existing waste problem which is why the upcycled concrete aggregate is an important step towards improving the impact of concrete production.

1 Ellen Macarthur Foundation, 2015
"Potential for Denmark as a circular economy" from Ellen MacArthur Foundation, 2015, it is estimated that 10-15 % of new building materials are wasted. This estimate is based on conducted interviews.

UPCYCLE CONCRETE

LCA - ACROSS IMPACT CATEGORIES



Impact category	Product		
	Benchmark 6 % waste	Benchmark 10 % waste	Upcycle concrete
Acidification [kg SO2 eq]	0,65	0,68	0,66
Eutrophication [kg PO4--- eq]	0,18	0,19	0,17
Global warming Potential [kg CO2 eq]	327,48	339,93	311,94
Ozone layer depletion (ODP) [kg CFC-11 eq]	1,52E-05	1,58E-05	1,35E-05
Photochemical oxidation [kg C2H4 eq]	0,027	0,028	0,027

ACROSS IMPACT CATEGORIES

The diagram and table above show the environmental impacts that occur in the production of 1 m^3 upcycle concrete from mobile mixing plants and at 1 m^3 equivalent conventional concrete with respectively 6-10 % waste (upcycled has 2 % due to local casting).

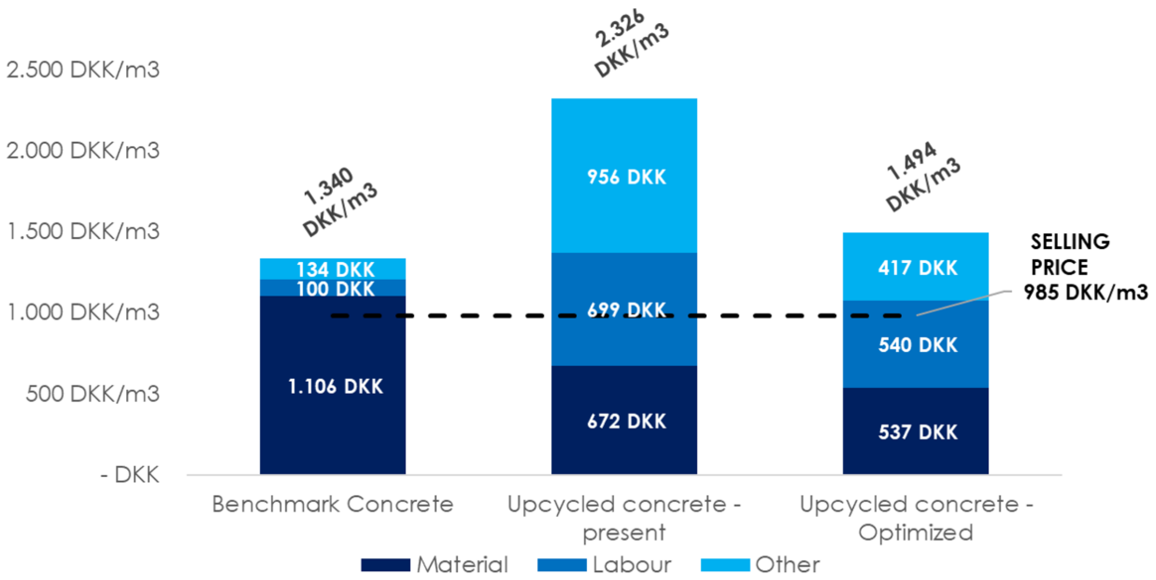
From this it can be seen that upcycle concrete performs better than conventional concrete in all impact categories.

DIRECT AND DERIVATIVE IMPACTS

In the LCA of concrete we find both direct and derivative impacts. The direct impact from upcycling stems from the savings in replacing virgin aggregate with upcycled materials, though this impact is low in amount of CO_2 relative to the high negative impact of using cement.

The derivative effect comes from minimizing waste due to on site production as industrial production was not possible at the time. This derivative impact comes out mainly positive due to reduction of waste, though we also find that using a diesel generator in the production (as it was not posible to use the Danish electricity grid) should not be repeated if possible.

LCC RESULTS - PRODUCT LEVEL



LCC UPCYCLE CONCRETE

The graph above shows the expenses for producing concrete across benchmark, upcycle concrete and optimised concrete. The results shown express the cost structure of the different alternatives across the following parameters: material, labour and other costs. The benchmark is the same as presented in the LCA of upcycle concrete.

Benchmark: The benchmark chosen is from the supplier UNICON CEMENTIR, the functional concrete UNI-WALL® (DMAX 16 MM, SLUMPFLOW 620 MM) compressive strength of C35. The prices reflected are based on MOE experience price in m^3 and do not include pumping costs as this process does not differ from upcycle concrete; by excluding them, the LCC results unbiasedly show the differences in the two production processes. In addition, a waste percentage of 10% has been added to the unit price in order to make the analysis aligned with LCA.

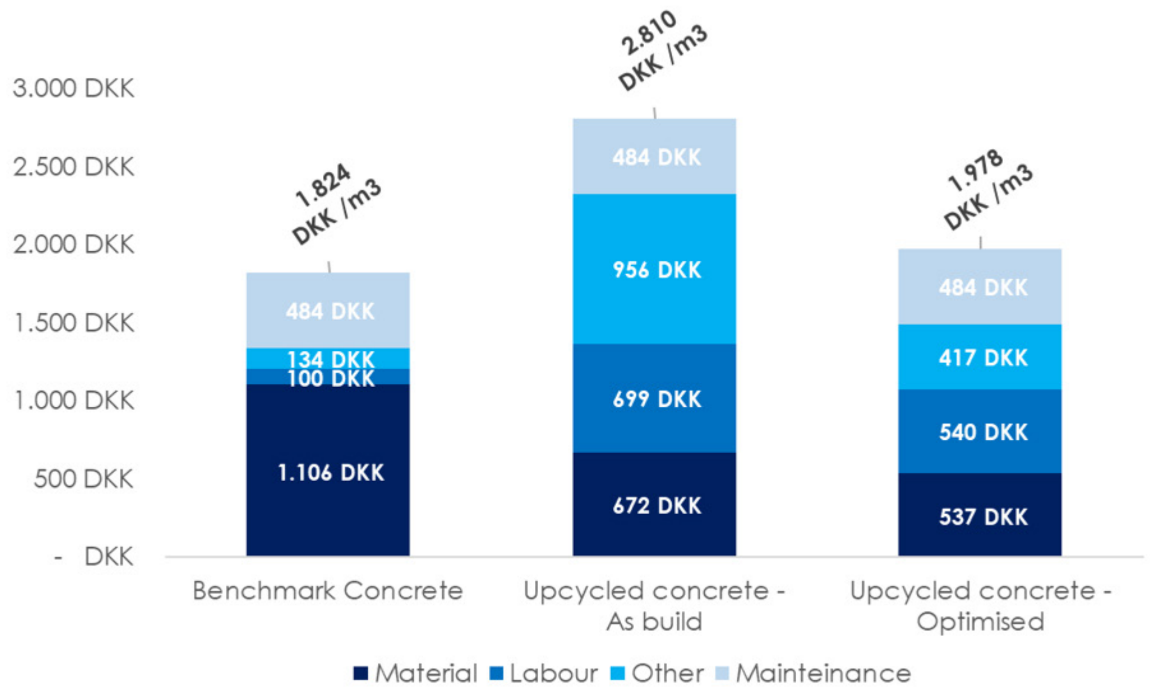
Upcycle concrete: The present cost structure of upcycle concrete reflects all production costs, excluding R&D and 90% of project management costs; they are considered to be investment in innovation, and thus ought not to be part of the analysis. Furthermore, pumping costs have been excluded following the same rationale described in the previous paragraph. Finally, an additional 2% of waste has been added to the unit price in order to make the results aligned with the LCA analysis.

Optimised scenario: The future cost structure is forecasted on the assumptions of a larger production (2000 m3), reduced idle time and a better planning of fixed cost, primarily rentals. In short, these are the benefits of economies of scale. If these premises hold, upcycle concrete is more competitive to benchmark's selling price.

Result: The benchmark concrete outperforms the present upcycle concrete. This is largely due to the low amount of concrete delivered in this project directly competing with big concrete factories with the advantage of streamlined production processes and economies of scale. In concrete products there is a very high level of fixed costs why amount has a big impact on the price per unit. This is shown in the optimised upcycle concrete where the biggest change lies in the amount produced (from 837 to 2000 m^3). Furthermore, expenses for upcycle concrete are based on a first-time-production leaving room for many smaller optimisations in production processes.

UPCYCLE CONCRETE

LCC RESULTS - PRODUCT LEVEL



Selling price: Looking at the result compared to the selling price on the former page there is a clear difference. Here it is important to state that the selling price was based on an agreement of delivering 2000 m^3 concrete, which in the development process was scaled down to 837m^3 concrete delivered. Due to this change an extra payment was made later in the process evening out the difference.

Cost structure analysis: The cost structure notably differs between the benchmark, the upcycled concrete as-build and the optimised upcycle concrete. In benchmark we find a very heavy expense to the purchase of materials while benchmark is more efficient on labour and other costs. On the other hand, circular production of concrete has a large share of "other costs", mostly reflecting costs for the rental of equipment.

As the expenses for upcycle concrete are based on first-time-production there is a clear potential in optimizing the expenses for labour costs and thus become more competitive on price. Among others, this is a big difference between the upcycling concrete delivered and the optimised upcycle concrete.

The differences in expenses do not only show interesting potentials for optimisation. They also reflect a more sustainable business model spending less on the acquisition of natural resources and more on labour, hereby investing in people instead of materials.

Maintenance: In the graph above is presented the total costs of a product including maintenance. Maintenance and replacement costs are dependent on the type of material. In short, it is the net present value of the yearly maintenance costs, estimated as a percentage of the acquisition price. Replacement costs are not included, as the calculation period is shorter than the concrete's life span.

As the materials are exactly the same across benchmark and upcycle concrete the maintenance is also forecasted to be the same.

UPCYCLE CONCRETE

SUMMARY OF IMPACT

RESOURCE OPTIMISATION

In addition to the CO_2 and financial effect, the use of recycling aggregate contributes to saving 904 tonnes of waste from downcycling and / or landfill - just for this project at Upcycle Studios. This also means that the same amount of virgine gravel has been saved as aggregate, which is a key resource impact, knowing that we will run out of access to gravel in Denmark by 2056.

UPCYCLE CONCRETE
RESULTS FOR UPCYCLE STUDIOS

	AS BUILD	POTENTIAL IF BUILD PER OPTIMISED SCENARIOS*
CO_2	25 tonnes CO_2-eq/rowhouse 8 % saving	31 tonnes CO_2-eq/rowhouse 11 % saving
$	-86,239 DKK/rowhouse 74 % more expensive	-13,469 DKK/rowhouse 12 % saving
	904 tonnes waste in total	904 tonnes waste in total

* Best case

OFFCUT DOUGLAS FACADE

PRODUCT DESCRIPTION

The offcut douglas facade consists of upcycle wood that as been treated with linseed oil in order to protect the wood and provide the desired aesthetics. Linseed oil protects the wood from the sun's radiation and its fungicide protects the wood from rot and fungus. The linseed oil penetrates the wood and, after curing, creates a strong thermoplastic membrane that minimises the absorption of moisture.

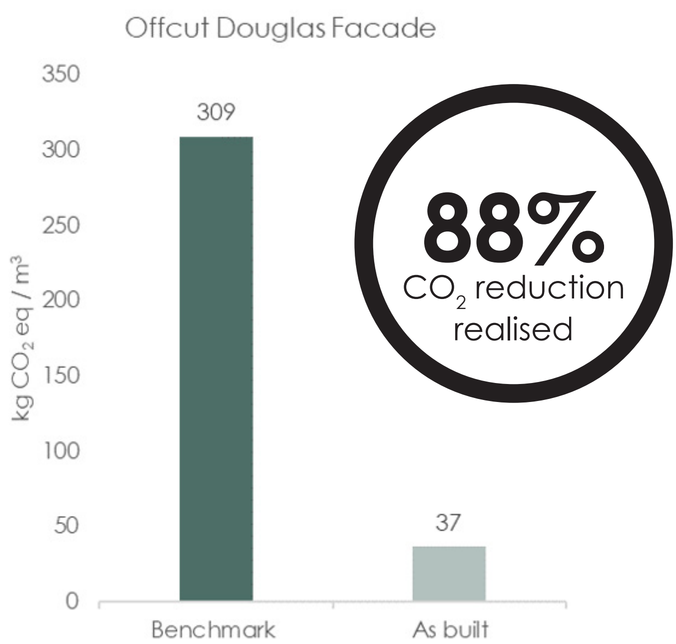
Material source: The wood is discarded wood from Dinesen Floors high quality production.

Declared unit: 1 m^3 weather resistant wood facade.

Included processes: The processes included are the handling, profiling, and surface treatment of the wood as well as production waste.

Benchmark: The benchmark is thermotreated spruce and pine (from Moelven EPD) with a surface treatment of paint.

Result: 88 % CO_2 reduction: When comparing the upcycle offcut wood facade with benchmark, a CO_2 saving of 88 % is found. This is mainly due to the fact that a waste wood material, that is used in the upcycle product, does not contribute with negative environmental impacts in the beginning phases concerning processing of the wood from full life trees to wooden materials.

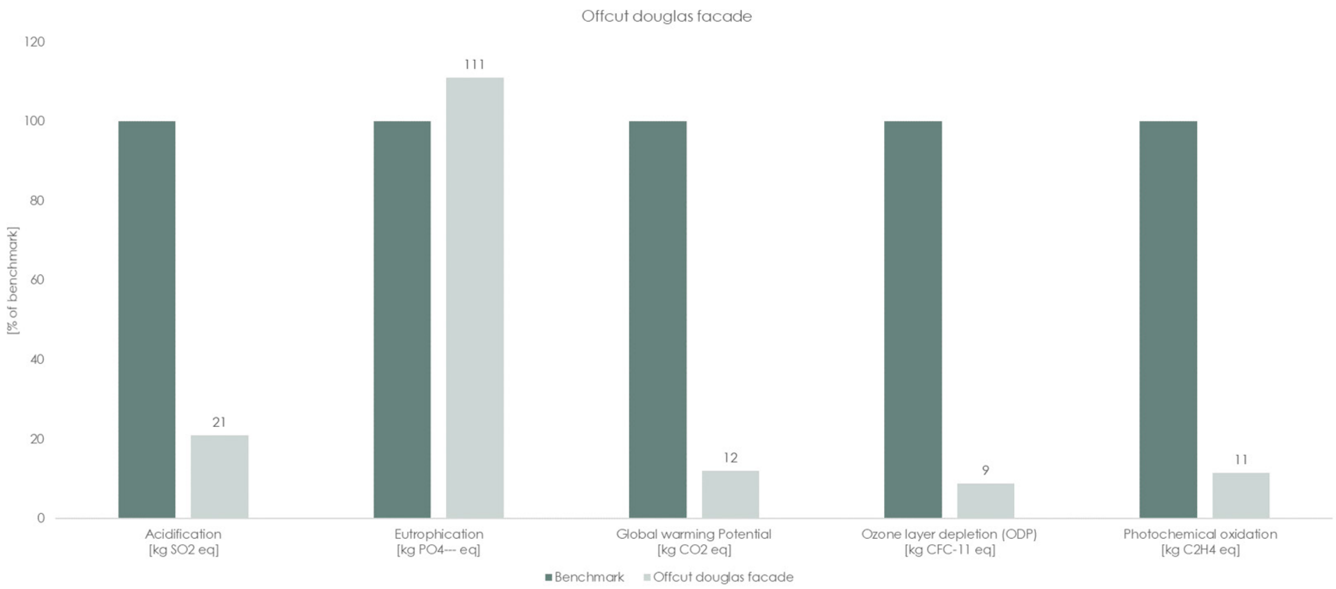


OFFCUT DOUGLAS FACADE

ACROSS IMPACT CATEGORIES

The table and graphic below show the environmental impacts that occur in the production of 1 m² offcut douglas facade in Upcycle Studio and 1 m² corresponding wooden facade. From this it can be seen that the offcut douglas facade performs better across most impact categories - and most heavily in Global Warming Potential as it is not necessary to produce new wood for the upcycle product.

Impact category	Product	
	Benchmark	Offcut douglas facade
Acidification [kg SO2 eq]	1,47	0,31
Eutrophication [kg PO4--- eq]	0,19	0,21
Global warming Potential [kg CO2 eq]	309,06	37,00
Ozone layer depletion (ODP) [kg CFC-11 eq]	4,55E-05	3,99E-06
Photochemical oxidation [kg C2H4 eq]	0,13	0,02



OFFCUT DOUGLAS WALL CLADDING

PRODUCT DESCRIPTION

The offcut douglas wall cladding is upcycle flooring wood used as interior wall cladding. The wood is painted with linseed oil in order to obtain the desired aesthetic expression. Douglas is a soft species of wood that is recognizable for its distinct annual growth rings as well as the tree's heartwood which differs in color from the sapwood.

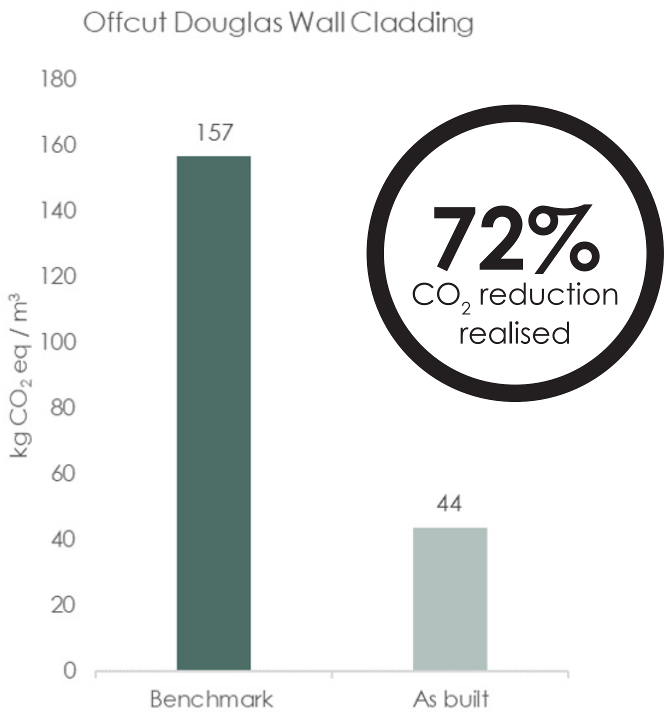
Material source: The wood is discarded wood from Dinesen Floors high quality production.

Declared unit: 1 m^3 surface treated soft wood wall cladding.

Included processes: The processes included are the handling, profiling, and surface treatment of the wood as well as production waste.

Benchmark: The benchmark is solid pine wood panel for internal use, surface treated with wood paint (from Moelven EPD).

Result: 72 % CO_2 reduction: When comparing the offcut douglas wall cladding with benchmark, a CO_2 reduction of 72% is found. This is mainly due to the fact that a waste wood material, that is used in the upcycle product, does not contribute with negative environmental impacts in the beginning phases concerning processing of the wood from full life trees to wooden materials.

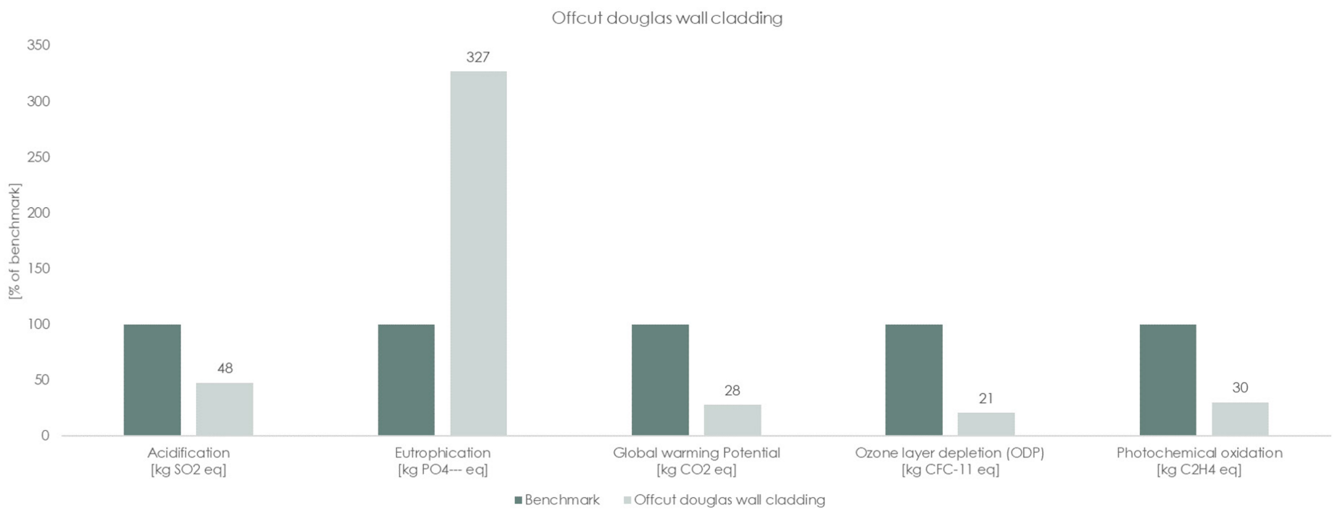


OFFCUT DOUGLAS WALL CLADDING

ACROSS IMPACT CATEGORIES

The table and graphic below show the environmental impacts that occur in the production of 1 m[2] offcut douglas wall cladding in Upcycle Studio and 1 m[2] corresponding wooden wall cladding. From this it can be seen that the offcut douglas wall cladding performs better in all impact categories apart from eutrophication compared to benchmark.

Impact category	Product	
	Benchmark	Offcut douglas wall cladding
Acidification [kg SO2 eq]	0,82	0,39
Eutrophication [kg PO4--- eq]	0,09	0,28
Global warming Potential [kg CO2 eq]	156,92	44,00
Ozone layer depletion (ODP) [kg CFC-11 eq]	1,93E-05	4,01E-06
Photochemical oxidation [kg C2H4 eq]	0,06	0,02



OFFCUT DOUGLAS FLOOR

PRODUCT DESCRIPTION

The offcut douglas floor is upcycle wood planks used for interior flooring. The wood is painted with linseed oil in order to obtain the desired aesthetic expression. Douglas is a soft species of wood that is recognisable for its distinct annual growth rings as well as the tree's heartwood which differs in color from the sapwood.

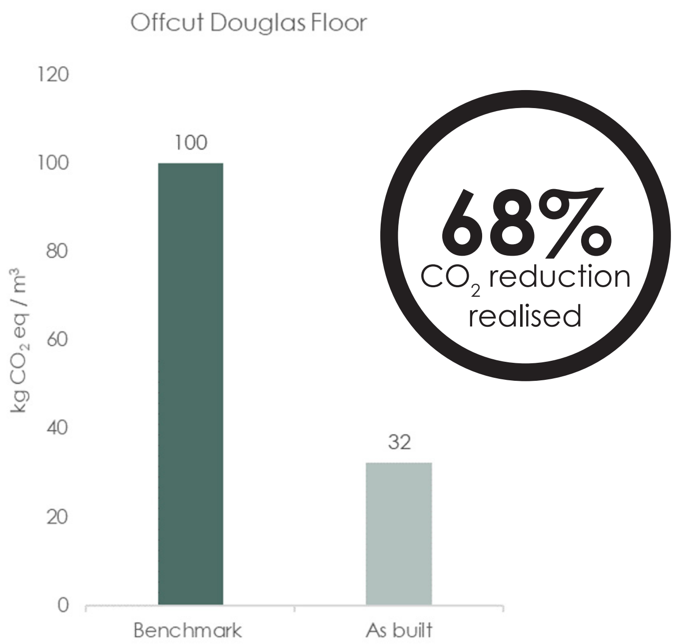
Material source: The wood is discarded wood from Dinesen Floors high quality production.

Declared unit: 1 m^3 surface treated soft wood floor.

Included processes: The processes included are the handling, profiling, and surface treatment of the wood as well as production waste.

Benchmark: The benchmark is solid pine flooring surface treated with hard wax oil (from Moelven EPD).

RESULT: 68 % CO_2 reduction: When comparing the offcut douglas floor with benchmark, a CO_2 reduction of 68% is found. This is mainly due to the fact that a waste wood material, that is used in the upcycle product, does not contribute with negative environmental impacts in the beginning phases concerning processing of the wood from full life trees to wooden materials.

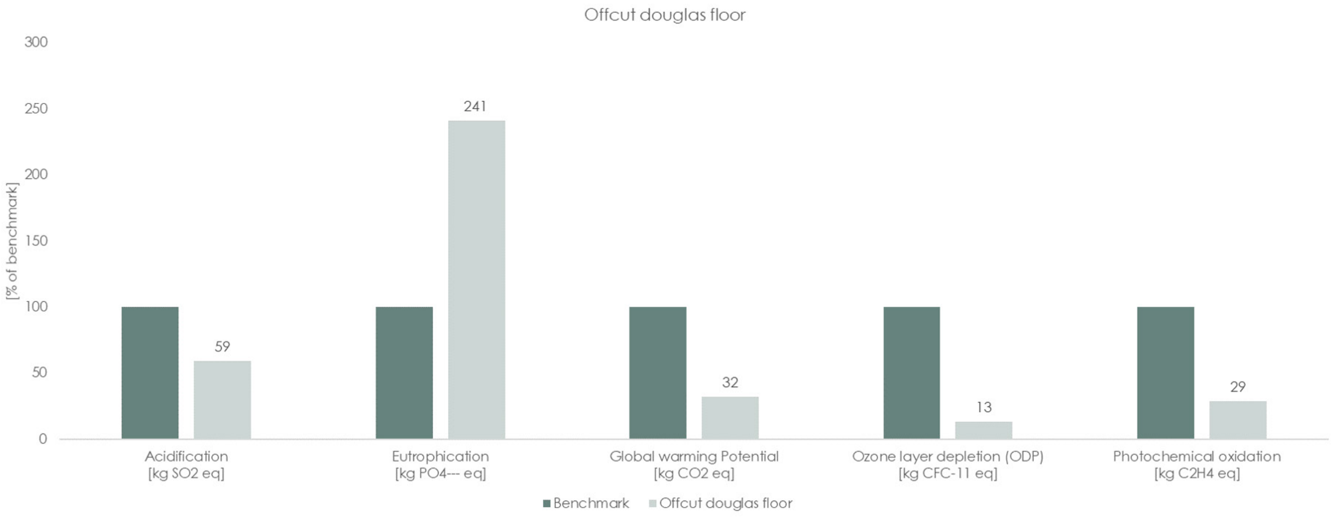


OFFCUT DOUGLAS FLOOR

ACROSS IMPACT CATEGORIES

The table and graphic below show the environmental impacts that occur in the production of 1 m[2] offcut douglas floor in Upcycle Studio and 1 m[2] corresponding wooden product. From this it can be seen that the offcut douglas floor perform better than benchmark in all impact categories apart from eutrophication.

Impact category	Product	
	Benchmark	Offcut douglas floor
Acidification [kg SO2 eq]	0,54	0,32
Eutrophication [kg PO4--- eq]	0,10	0,23
Global warming Potential [kg CO2 eq]	100,00	32,00
Ozone layer depletion (ODP) [kg CFC-11 eq]	1,63E-05	2,16E-06
Photochemical oxidation [kg C2H4 eq]	0,05	0,02



OFFCUT OAK FLOOR

PRODUCT DESCRIPTION

The offcut oak floor is upcycle wood planks used interior flooring. The wood is painted with linseed oil in order to obtain the desired aesthetic expression. Oak is a hard species of wood that is recognizable for its limited color variation, creating an aesthetically simple look.

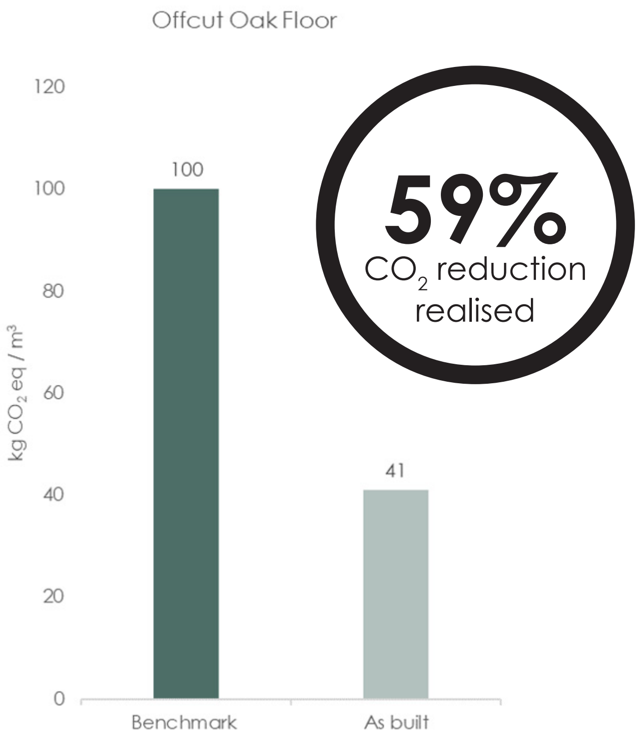
Material source: The wood is discarded wood from Dinesen Floors high quality production.

Declared unit: 1 m^3 surface treated hard wood floor.

Included processes: The processes included are the handling, profiling, and surface treatment of the wood as well as production waste.

Benchmark: The benchmark is solid pine flooring surface treated with hard wax oil (from Moelven EPD).

RESULT: 59% CO_2 reduction: When comparing the offcut oak floor with benchmark, a 59% CO_2 reduction is found. This is due to the fact that the upcycled wood is a waste material thereby not giving an impact for the growing, harvesting and production of the virgin wood material.

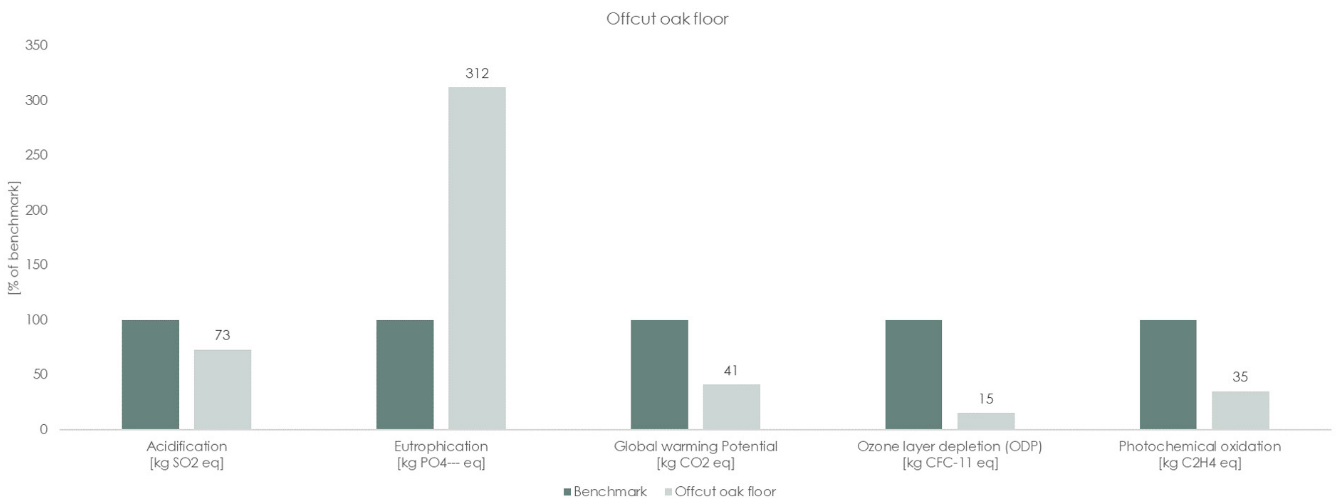


OFFCUT OAK FLOOR

ACROSS IMPACT CATEGORIES

The table and graphic below show the environmental impacts that occur in the production of 1 m^2 offcut oak floor in Resource Rows and 1 m^2 corresponding wooden product. From this it can be seen that the offcut oak floor performs better than benchmark in every impact category apart from eutrophication.

Impact category	Product	
	Benchmark	Offcut oak floor
Acidification [kg SO2 eq]	0,54	0,39
Eutrophication [kg PO4--- eq]	0,10	0,30
Global warming Potential [kg CO2 eq]	100,00	41,00
Ozone layer depletion (ODP) [kg CFC-11 eq]	1,63E-05	2,47E-06
Photochemical oxidation [kg C2H4 eq]	0,05	0,02



UPCYCLE TERRACE

PRODUCT DESCRIPTION

The upcycle terrace consists of upcycle wood that has been cut into new planks and impregnated with linseed oil. Impregnating with linseed oil protects the wood from the sun's radiation and its fungicide protects the wood from rot and fungus. The linseed oil penetrates the wood and, after curing, creates a strong thermoplastic membrane that minimises the absorption of moisture.

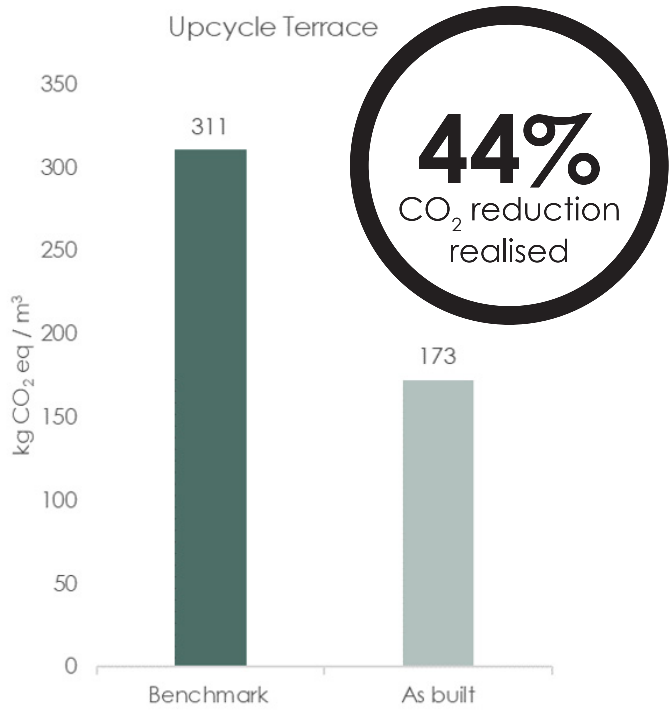
Material source: The wood used for the Resource Rows are discarded wooden sleepers from the Copenhagen Metro.

Declared unit: 1 m^3 weather resistant terrace wood.

Included processes: The processes included are handling, cutting, and impregnating the wood planks as well as waste.

Benchmark: The benchmark is thermotreated spruce and pine (from Moelven EPD) with a surface treatment.

Result: 44% CO_2 reduction: When comparing the upcycled terrace with benchmark, a CO_2 reduction of 44% is realised. This is mainly due to the fact that a waste wood material, that is used in the upcycle product, does not contribute with negative environmental impacts in the beginning phases concerning processing of the wood from full life trees to wooden materials.

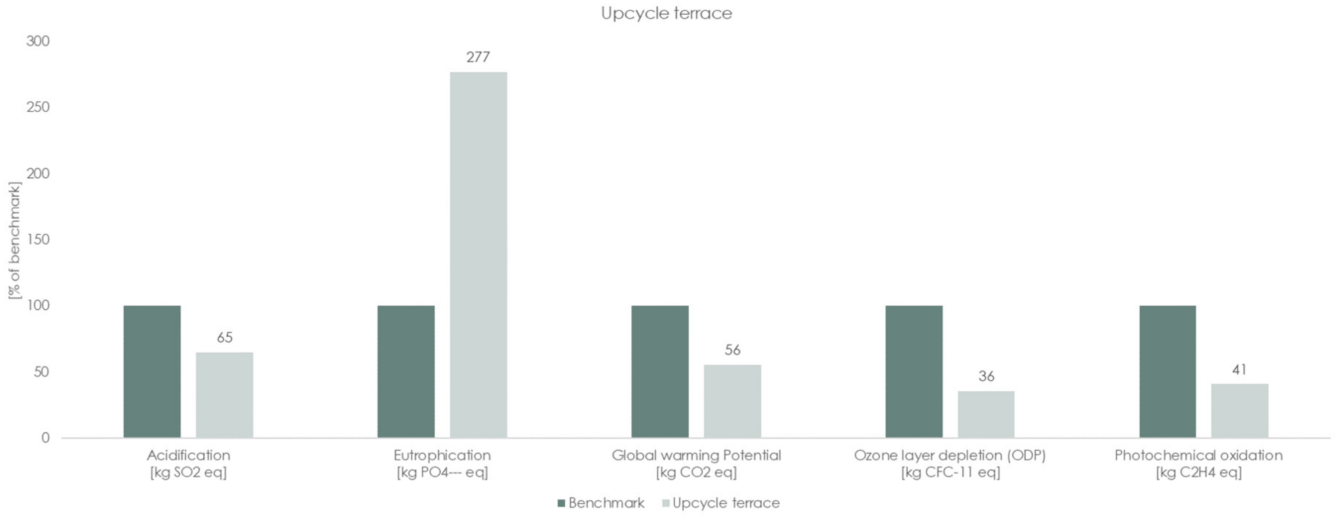


UPCYCLE TERRACE

ACROSS IMPACT CATEGORIES

The table and graphic below show the environmental impacts that occur in the production of 1 m² upcycle terrace facade in Upcycle Studio and 1 m² corresponding wooden facade. From this it can be seen that the upcycle terrace performs better across all impact categories apart from eutrophication.

Impact category	Product	
	Benchmark	Upcycle terrace
Acidification [kg SO2 eq]	1,48	0,96
Eutrophication [kg PO4--- eq]	0,19	0,53
Global warming Potential [kg CO2 eq]	310,63	173,00
Ozone layer depletion (ODP) [kg CFC-11 eq]	4,55E-05	1,63E-05
Photochemical oxidation [kg C2H4 eq]	0,13	0,06



UPCYCLE BURNED FACADE

PRODUCT DESCRIPTION

The upcycle burned wood facade consists of reused wood. Instead of impregnating the wood, the surface has been burned and treated with linseed oil. By burning the upper millimeters of the wood, the sugar inside the tree will also be burned meaning that harmful microorganisms cannot live in the wood. Additionally, water evaporates from the wood and the surfaces closes so that no water can enter. This is a sustainable method making the wood highly weather resistant and providing a beautiful surface.

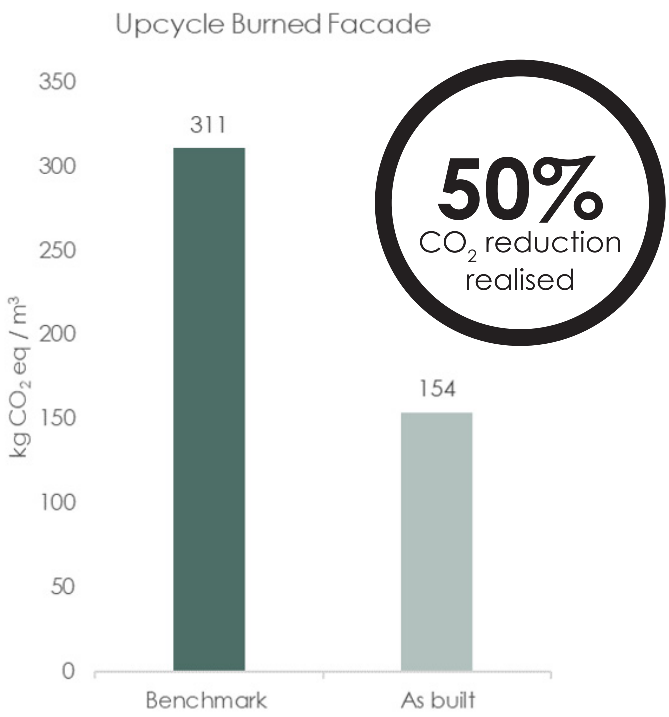
Material source: The wood used for the Resource Rows are discarded wooden sleepers from the Copenhagen Metro.

Declared unit: 1 m^3 surface treated wood facade.

Included processes: The processes included are handling, cutting, burning, surface treating the planks, and waste. Gas for and emissions from burning the planks are also included.

Benchmark: The benchmark is thermotreated spruce and pine (from Moelven EPD) surface treated with wood paint.

Result: 50% CO_2 reduction: When comparing the burned facade of upcycled wood with virgin thermotreated wood, the CO_2 emissions are lowered by 50%. This is mainly due to the fact that a waste wood material, that is used in the upcycle product, does not contribute with negative environmental impacts in the beginning phases concerning processing of the wood from full life trees to wooden materials.

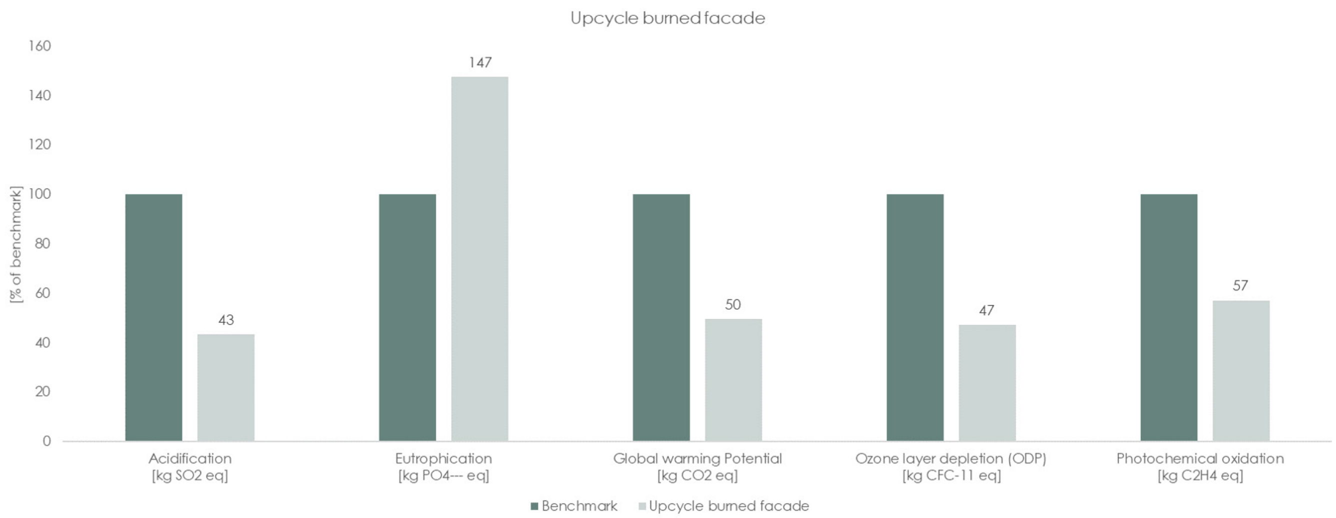


UPCYCLE BURNED FACADE

ACROSS IMPACT CATEGORIES

The table and graphic below show the environmental impacts that occur in the production of 1 m² upcycle burned wood facade in Resource Rows and 1 m² corresponding wooden facade. From this it can be seen that the upcycle burned wood facade performs better across all impact categories (apart from eutrophication) - and most heavy in Global Warming Potential.

Impact category	Product	
	Benchmark	Upcycle burned facade
Acidification [kg SO2 eq]	1,48	0,64
Eutrophication [kg PO4--- eq]	0,19	0,28
Global warming Potential [kg CO2 eq]	310,63	154,00
Ozone layer depletion (ODP) [kg CFC-11 eq]	4,55E-05	2,14E-05
Photochemical oxidation [kg C2H4 eq]	0,13	0,08



UPCYCLE ROOF TOP HOUSE

PRODUCT DESCRIPTION

The upcycle roof top house at the Resource Rows are made of different types of reused wood as well as reused glazing. The roof top house has only facade materials on three sides as it is placed against a fire resistant wall on one side it is mounted. Furthermore, there is no flooring.

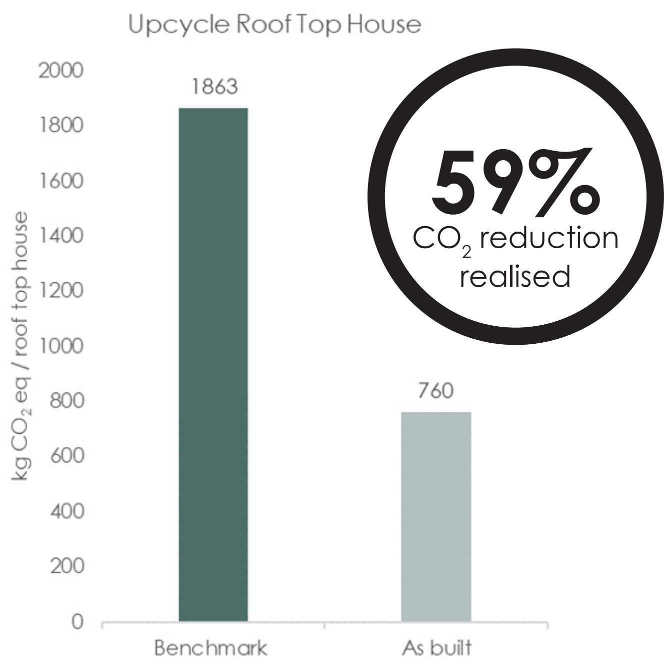
Material source: Discarded wood from the Danish gluelam factory Vinderup Træindustri and the Norwegian modified wood producer, Kebony, as well as double glazing from an energy renovation of a building in Copenhagen.

Declared unit: 1 roof top house of 10 m^2 with windows, access through a door, and no floor. Waste of wood and roofing membrane is also included.

Included processes: The processes included are transport and preparation of reused materials, production of all virgin materials, and manufacturing of the roof top house.

Benchmark: A 1:1 roof top house made of comparable virgin wood. Both wood products have been replaced with thermotreated spruce and pine. The windows are made of one layered glazing and wood frame.

59% CO_2 reduction: When comparing the upcycle roof top house with benchmark, 59% CO_2 reduction is obtained. This is mainly due to the fact that a waste wood material, that is used in the upcycle product, does not contribute with negative environmental impacts in the beginning phases concerning processing of the wood from full life trees to wooden materials.

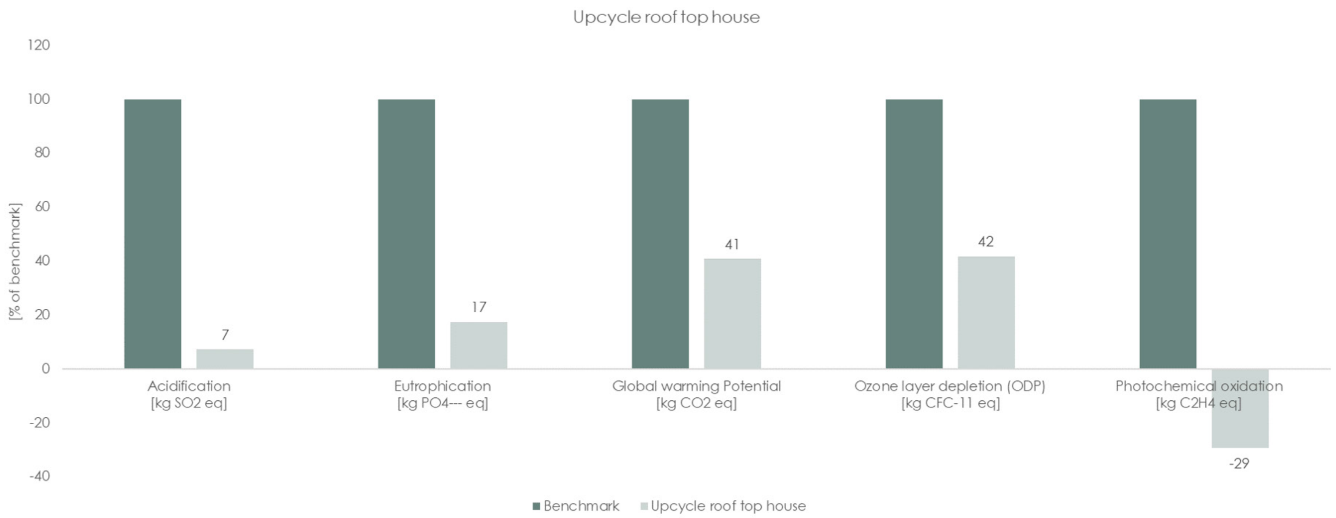


UPCYCLE ROOF TOP HOUSE

ACROSS IMPACT CATEGORIES

The table and graphic below show the environmental impacts that occur in the production of 1 m² upcycle roof top house at Resource Rows and 1 m² corresponding wooden product. From this it can be seen that the upcycle roof top houses perform better in all impact catagories.

Impact category	Product	
	Benchmark	Upcycle roof top house
Acidification [kg SO2 eq]	12,019	0,871
Eutrophication [kg PO4--- eq]	1,484	0,258
Global warming Potential [kg CO2 eq]	1863,349	760,000
Ozone layer depletion (ODP) [kg CFC-11 eq]	2,06E-04	8,60E-05
Photochemical oxidation [kg C2H4 eq]	-0,177	0,052

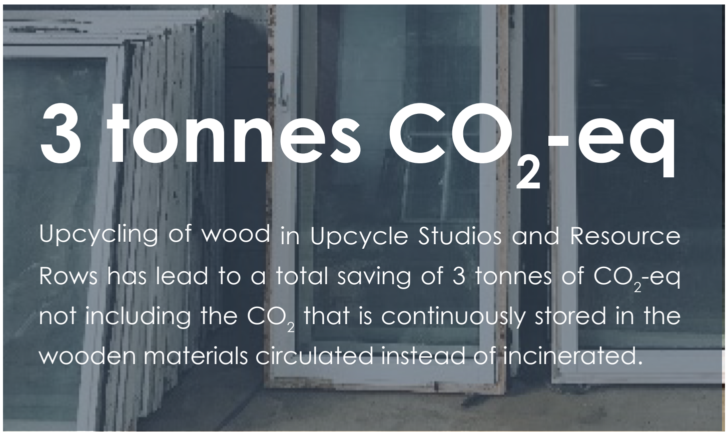


UPCYCLE WOOD

SUMMARY OF IMPACT

RESOURCE OPTIMISATION

In addition to the CO_2 savings achieved by upcycling the window panes, a saving of resources has also been achieved. The upcycling of wooden products have resulted in a saving of 7 tonnes of waste that has been upcycled instead of being downcycled, incinerated or landfilled. This minimises the need to produce new, virgine panes that pose a significant environmental impact.



UPCYCLED WOOD
FOR UPCYCLE STUDIOS & RESOURCE ROWS

AS BUILD*

CO_2 — 3 tonnes CO_2-eq

7 tonnes waste

* Includes interior and exterior wood products


LENDAGER GROUP

REFLECTION

HOW DOES CIRCULAR BUILDING MATERIALS PERFORM?

UPCYCLING MATTERS
Across the analysed materials, it is seen that upcycling matters. It does make a difference to use upcycle materials instead of virgin materials! This is both in regards to climate change, resource scarcity, and partly financials having potentials to be directly competitive in optimised scenarios.

Based on an assessment of the four upcycle materials; concrete, windows, bricks and wood, we can conclude that significant environmental value has been created in all four material categories. Despite that it is the first time windows and bricks have been circulated with this method and the first time that concrete is based on 100% recycled aggregate, we have now demonstrated clear positive effect of upcycle materials across resource consumption and CO_2 emissions.

The products included in Upcycle Studios and the Resource Rows are all first time productions. This means, that we have obtained an impressive impact based on little former experience.

WASTE MINIMISING
There is also a significant positive environmental impact in the minimisation of waste and the saving of virgin resources. In the development of the four products we have saved 2,223 tonnes of waste from the two case builds alone. A saving that will be rising in a scenario of scaling.

THE POSITIVE ADD-ON'S OF UPCYCLING
Clarifying that circulation of materials has a positive CO_2 effect is positive, but not surprising. What is also interesting in these analyses is how we have several positive impacts that are not directly embedded in the specific circulated materials, but related to the processes and consequences of the circulation. These include:

- Being able to use wooden frames instead of aluminium frames for the windows due to the double-layered framing strengthening the upcycle window.
- The opportunity to source concrete aggregate locally instead of transporting it long distances.
- The treatment of the wood material where there has been made very sustainable choices due to the focus on circular economy and clean materials.

PRICES WITH POTENTIAL
In the LCC analysis we have found that though products were more expensive than benchmark they all have the potential for direct competitive optimised versions which will not only lead to better prices, but also to an even higher impact across waste and CO_2 emissions (as the price optimisation partly is achieved through an increase in recycled materials).

Reasons for the relatively higher product prices include:

- Precautionary principles taken to ensure the quality and performance of the upcycle materials due to first-time-production. This includes increased strength requirements for concrete, thickness of concrete back wall in brick element and retrofitting of recycle glazing in windows.
- Lack of economies of scale, thus relatively high fixed costs, imply a high cost per unit.
- Due to the first production line for windows and bricks, and second production line for concrete, it will be possible to increase efficiency that can reduce costs for development, harvesting, transport, production and assembly costs.

All reasons that can be handled in future productions making the upcycle products more price competitive with high performance on design and aesthetics, while further improving the environmental impact.

PRODUCTS ACROSS CO_2, WASTE AND PRICE
For a review of impact across parameters, see next page.

BRICK

Looking at the brick analysis, the percentage potential of lowering environmental impacts is larger at material level than at product level. This difference is caused by the need of adding either steel or concrete behind the cut brick elements in order to reuse them as a facade. The brick facade is not directly competitive on price and will only be so if harvest and production methods are very optimised. That being said, the brick facade brings a completely new aesthetic providing a branding and aesthetic value to the final building project.

Window

The upcycle windows have the largest percentage improvement of CO_2 across the four materials. Here CO_2 savings of 380 kg CO_2 eq / m^2 have been achieved. That's a total CO_2 saving of 87% compared to benchmark - a saving that can be made even better in optimised scenarios with a higher recycling rate. Windows are also the material performing best on price with +13 % in comparison to a standard curtain wall benchmark and a potential to reach 40-50 % improvement on price in the optimised scenario.

CONCRETE

Though the impact of upcycle concrete is lower than on eg. upcycle bricks looking at the percentage of CO_2 savings per m^3, the impact in large scale is still bigger. In construction today concrete is still the most used material meaning that an improvement of 5-8 % of CO_2 per m^3 can and will be a significant impact if the solution is scaled across construction sites. This also enables a more profitable business case, as the fixed costs of concrete production are very high, and we therefore need volume to make it a scalabe solution. Future scenarios, where the aggregate cannot be sourced locally, will lead to a further increase in CO_2-savings.

WOOD

The upcycle wooden products include everything from interior such as wall cladding and flooring as well as exterior products including terrasse flooring, roof top houses and wooden facade materials. Across LCA analyses of wooden products, we see a positive performance of upcycle materials with 44-82 % reduced CO_2 savings compared to benchmarks. These savings have been reached due to eliminating the need of the production phases as you have when using virgin wooden materials. LCC calculations have not been conducted on wooden products ,why we cannot say how they performed in terms of price.

CHAPTER 3
SUSTAINABLE BUILDINGS

SUSTAINABLE BUILDINGS

INTRODUCTION

LCA, LCC AND ENERGY

Building on the prior chapter's review of the impact of the specific upcycle materials and products, this chapter will seek to elaborate on how the impact of upcycle solutions is reflected in the overall construction of an average row house in Upcycle Studios and Resource Rows respectively.

The impact analysis is conducted based on the following parameters:

- LCA on building level
- LCC on building level
- 12 different benchmarks
- Energy optimisations

All impact parameters are analysed across the two buildings Upcycle Studios and the Resource Rows. LCA and LCC on building level is conducted on a single, average row house of Upcycle Studios og Resource Rows respectively.

In the different analyses we will dive into the overall effect of different sustainability efforts supplemented by a deep dive into the effect of upcycle efforts across parameters of CO_2, financials and waste.

12 DIFFERENT BENCHMARKS

In the LCA and LCC analyses the results are benchmarked to the same row house in Upcycle Studios og Resource Rows - but without upcycling products.

To understand how Upcycle Studios and Resource Rows perform compared to other row house products, we have included a comparative analysis with 12 LCA calculations of row houses conducted by SBi (see p 98).

UPCYCLE STUDIOS

UPCYCLE STUDIOS - BUILDING LEVEL

LCA AND LCC

THE CONCEPT

Upcycle Studios was the first fully circular residential development, using upcycled solutions ranging from the concrete structure to the upcycle floors, wall cladding, facade, and windows.

In the design of Upcycle Studios there was a great emphasis on upcycling, resource efficiency, and minimizing carbon footprint. At the same time, Upcycle Studios facilitates sharing economy through an embodied basic idea of access instead of ownership creating a shared community between residents.

The building is designed for a high degree of flexibility to ensure the best possible use of the homes at all hours of the day and in different phases of life. The units can be used as a combined housing and workshop for creative freelancers or self-employed entrepreneurs, but also as one dwelling for large families or divided into two separate apartments.

UPCYCLE STUDIOS

Adress:

Robert Jacobsens Vej,

2300 København S

Construction year: 2015-2018

Size: 3340 m^2

Housing: 20 row houses

Project partners:

- Developer: NREP A/S
- Contractor: Arkitektgruppen
- Architect: Lendager ARC
- Upcycle material supplier: Lendager UP
- Consulting engineer: MOE

Total cost: EUR 13.9 millon

The project was economically constructed as a conventional row house project, where sustainability actions could not increase the total budget for the development. This general budgetary constraint has lead to many iterative processes with suppliers and partners that initially had different views and constraints with regards to material upcycling and sustainability.

THE IMPACT

The following chapter will show the overall impact of Upcycle Studios on a building level across carbon footprint and financials. An overview of how many products that are upcycled as well as how the buildings perform across LCA and LCC will be presented here. The LCA will be a deep dive on CO_2 and an overview on how the building performs across all impact categories, while the LCC will investigate the spilt in costs across building elements and between conventional and upcycle products.

Focus on sustainability includes:

MATERIALS

Building waste today represent a huge untapped resource which was exploited in the construction of Upcycle Studios. This was done through upcycling of windows, wood, and concrete.

ENERGY

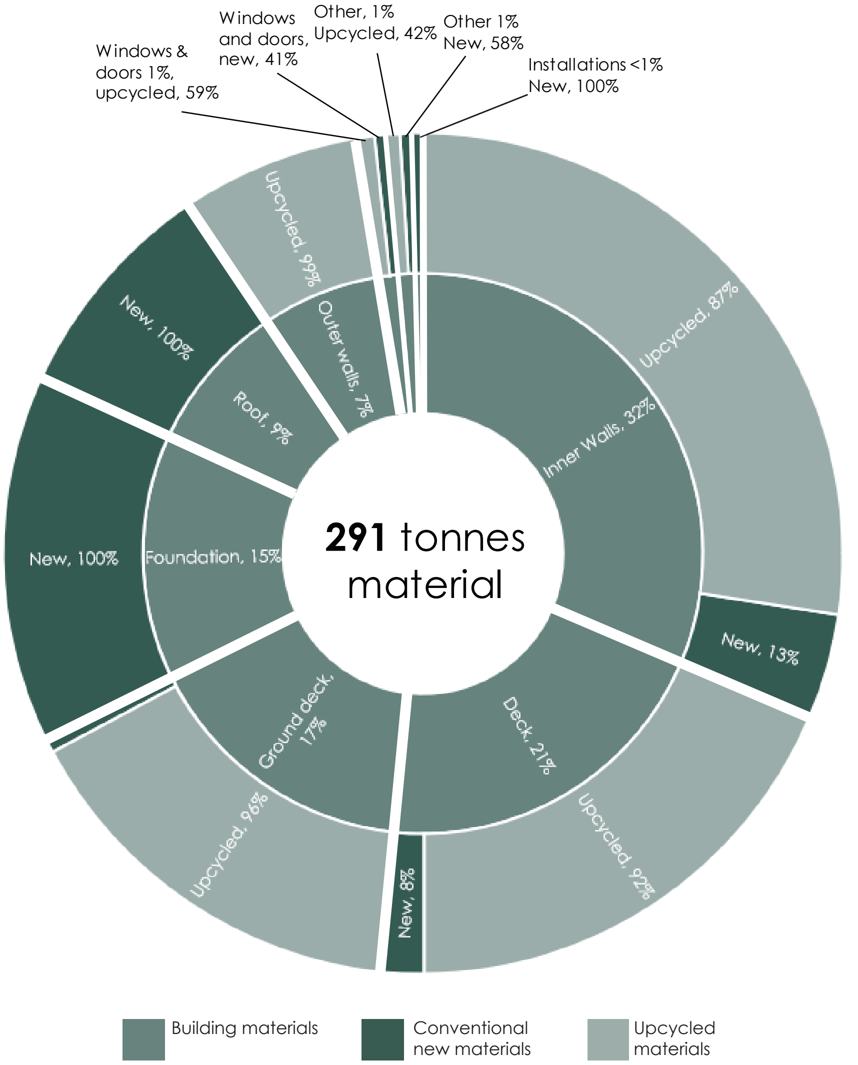
Through the design of the building envelope and use of efficient ventilation, heat recycling, and solar technologies, it is possible to lower the energy consumption for the operation of each home as well as saving CO_2 when using the buildings.

SOCIAL

Communities are developed around the concept of sharing resources providing economic and social benefits for all parties.

UPCYCLE STUDIOS - BUILDING LEVEL

LCA - MATERIAL AMOUNT



DISTRIBUTION BETWEEN UPCYCLE AND NEW MATERIALS

Our current relation to the world's resources is paradoxical. We are continuously exploiting new resources from the Earth, while discarding large amounts of materials that could be reused. Fortunately, we can change the way we do things.

The graph above illustrates the distribution of materials in the building - 291 tonnes representing the total weight of one average row house in Upcycle Studios. The inner annulus shows the distribution across building parts and components, and the outer annulus shows the distribution between new and upcycle materials for each of the building parts.

Out of the 291 tonnes of materials, approximately 202 tonnes or 69% represent upcycle materials, most of which are visible materials. This is a very significant amount considering that all types of materials including foundation, insulation and installations are included here. Not only does it mean that we have eliminated 202 tonnes of waste in the construction of Upcycle Studios. It also means that we have avoided the extraction, production and transportation of the same amount of virgin materials.

The graph reflects the conscious choice of focusing upcycle materials where they are visible in the outer walls, inner walls, and windows. Though upcycle materials also take up a significant part of ground deck and decks, future projects might consider a further effort in using upcycle materials in the more invisible parts and components as e.g. insulation. In the graph above it seems like windows do not take up a big part of upcycle materials. This is only due to window's low density compared to other materials. Had the graph reflected a distribution in m^2 the picture would have been a bit different.

BUILDING PARTS AND COMPONENTS

Foundation:

- Foundation

Ground slab:

- Ground slab

Outer walls:

- Upcycled windowpanel
- Basement outerwall
- Stern capsule
- Upcycled brick
- Street row house
- Murkrone row house

Inner walls:

- Glass shielding
- Residential wall
- Bath wall
- Apartment boundary walls

Deck:

- Concrete Deck
- Suspended ceiling
- Wooden floor on joists
- Concrete hollow deck

Roof:

- Roof
- Upcycled terrasse
- Upcycled roof greenhouse

Windows and doors

Installations:

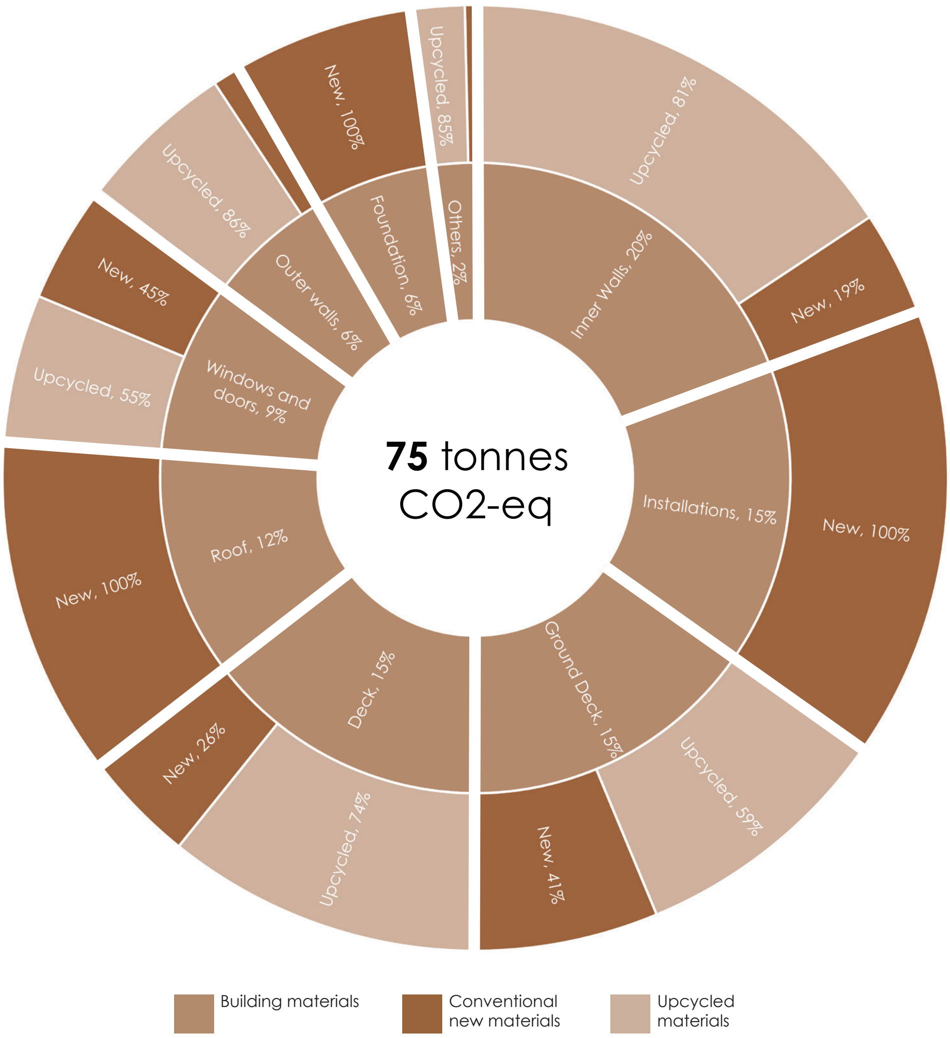
- Sanitation
- Heat
- Ventilation
- Electricity

Others:

- Stairs
- Pillars

UPCYCLE STUDIOS - BUILDING LEVEL

LCA - EMISSIONS OF CO_2-EQ



DISTRIBUTION OF CO_2-EQ

The built environment is one of the most polluting industries due to the high resource consumption and large CO_2 footprint. The built environment is responsible for 40% of the global CO_2 emission. By circulating the materials in the existing buildings, we can reduce CO_2 emissions, minimise the amount of waste generated and decrease the use of virgin materials.

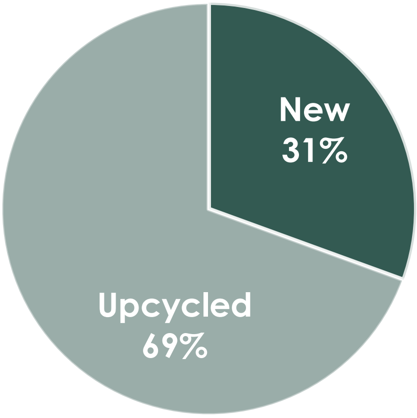
There are considerable differences in the amount of CO_2 embedded in different construction materials. Classical sinners include concrete, windows and bricks as they are CO_2 heavy in the production phase.

The graph above shows the distribution of CO_2-eq from new and upcycle materials - 75 tonnes CO_2-eq representing the total amount of CO2 emitted from one average row house in Upcycle Studios. The inner annulus shows the distribution across the building parts and components, and the outer annulus shows the distribution between new and upcycle materials for each of the building part. A total of 35 tonnes CO_2-eq, or 48% is from upcycle materials, while the main amount of CO_2 emissions stems from conventional materials (52 %). This shows that even though we have a bigger amount of upcycle materials, still the highest amount of CO_2 emission comes from conventional materials speaking the case for circulation.

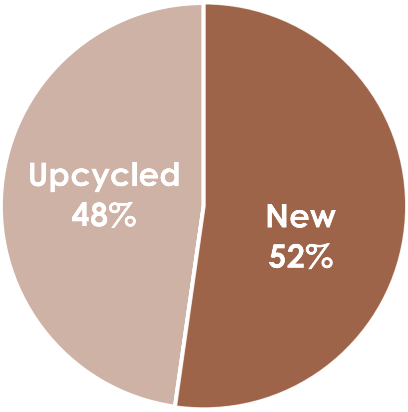
Going a layer deeper we see how the amount of CO_2 emitted from upcycle products mostly come from the concrete elements. This is partly due to the fact that concrete elements "only" has a upcycle percentage of 45 % with several CO_2 heavy virgin materials, including cement. Furthermore, the relatively high level of CO_2 from the concrete is also based on several precautionary principles in the production demanding a higher strength than actually needed. These precautionary principles have been taken to ensure that the upcycle materials live up to safety standards. This is done even if the materials have been tested, and are perform according to standard. As circular construction becomes more common, this will change in the future.

LIFE CYCLE ASSESMENT

Material distribution by weight



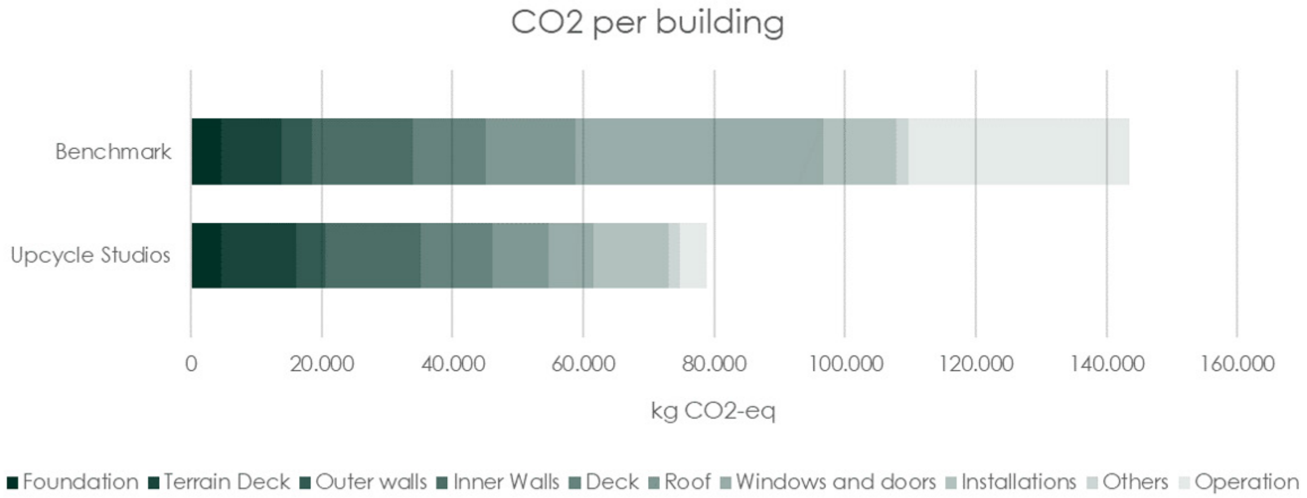
CO2-eq distribution



CO2-eq distribution

UPCYCLE STUDIOS - BUILDING LEVEL

LCA- BENCHMARK ANALYSIS



COMPARING UPCYCLE STUDIOS TO BENCHMARK

Life Cycle Assessment (LCA) considers both the embodied CO_2 as well as the CO_2-impact of operations across the life of the building. When comparing the amount of CO_2-eq for Upcycle Studios to the benchmark the results shows that Upcycle Studios has saved in total 65 tonnes of CO2-eq. The graph above illustrates how we move from over 140,000 kg CO_2-eq in benchmark to just beneath 80,000 kg CO_2-eq in Upcycle Studios.

This leads to a 32 % reduction in materials and a total saving of 45 % including operations.

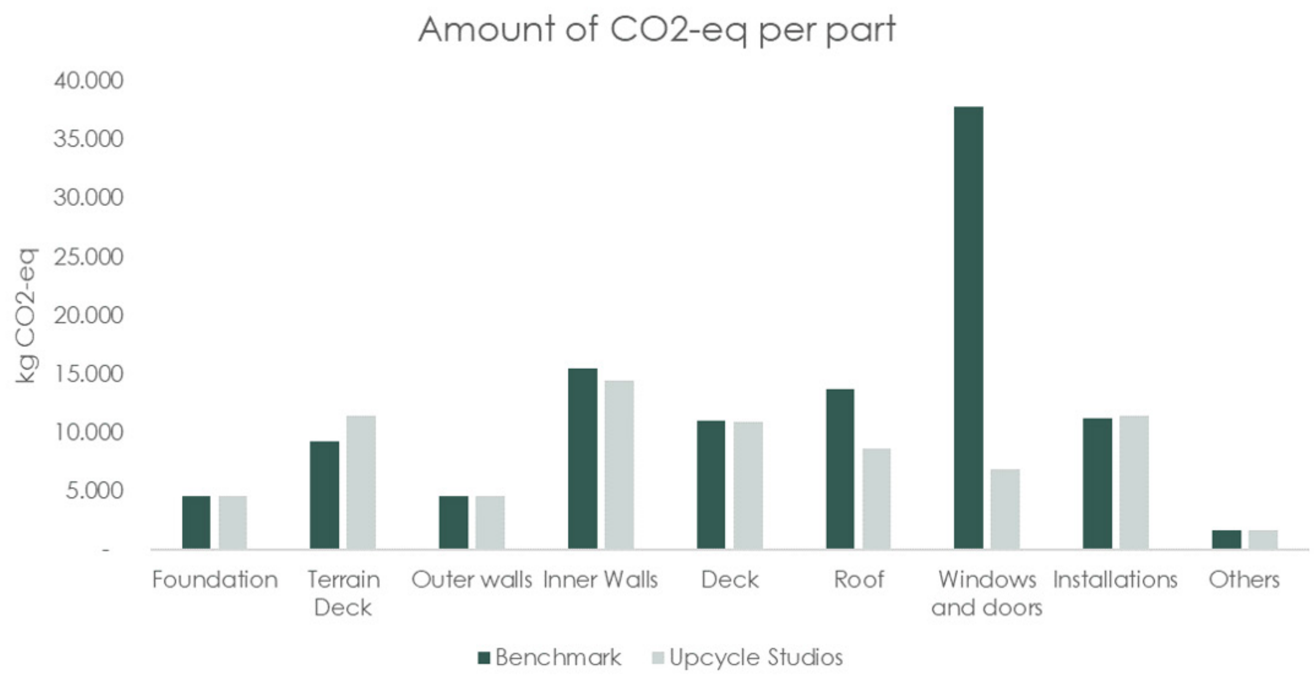
In the top graph on the next page it is shown where the CO_2 emissions come from across building parts, components and operations compared to benchmark.

Here we find two central impact categories including operations and windows. You will find a deep dive of operations in section below. The high positive impact within the category of windows and doors stems from upcycle windows as we have reached a 87 % CO2 saving here compared to a curtain wall. If we choose to compare the windows to regular alu/wood windows we see a smaller, but still high impact of 45 %

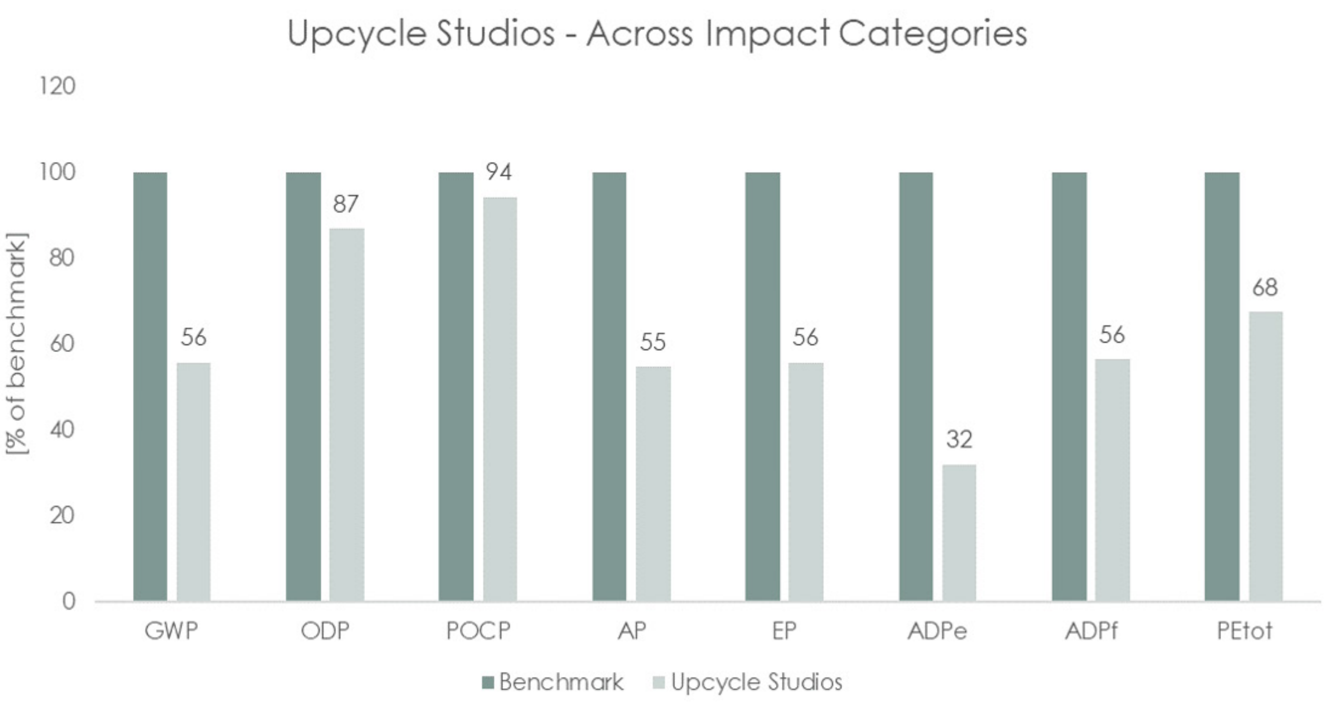
The central impact categories are supplemented by several other smaller improvements across outer walls, decks and inner walls.

ACROSS IMPACT CATEGORIES

When comparing Upcycle Studios to the benchmark Upcycle Studios has a lower impact across all impact categories. See bottom graph on next page.



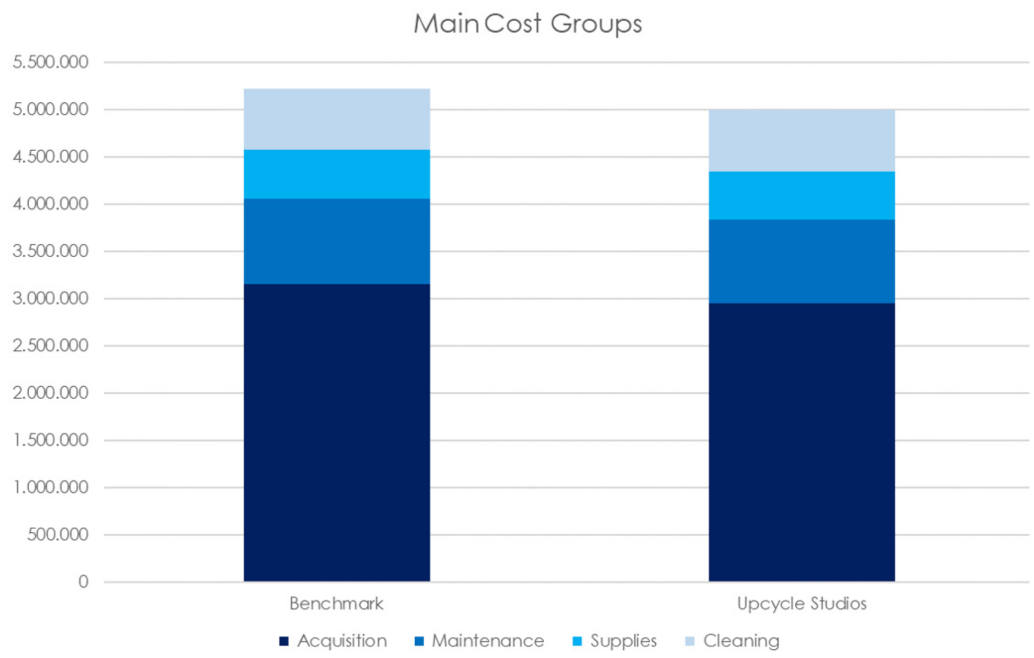
Amount of CO2-eq per part
kg CO2-eq
40.000
35.000
30.000
25.000
20.000
15.000
10.000
5.000
-
Foundation
Terrain Deck
Outer walls
Inner Walls
Deck
Roof
Windows and doors
Installations
Others
Benchmark
Upcycle Studios



Upcycle Studios - Across Impact Categories
[% of benchmark]
120
100
80
60
40
20
0
56
87
94
55
56
32
56
68
GWP
ODP
POCP
AP
EP
ADPe
ADPf
PEtot
Benchmark
Upcycle Studios

UPCYCLE STUDIOS - BUILDING LEVEL

LCC- OVERALL COST DISTRIBUTION



LCC ON BUILDING LEVEL

To be able to scale an impactful solution, it needs to be able to compete on price or at least fit into an overall budget for construction and maintenance. On the following pages we will dive into an analysis of life cycle costings on building level to clarify the competitiveness of one average Upcycle Studios row house.

DIVISION OF COSTS

The bar chart above reflects all life cycle costs for one Upcycle Studios row house and its benchmark. It gathers all cost categories, ranging from acquisition (construction/materials), maintenance, supply of water and electricity, as well as cleaning costs.

The largest differences arise in the acquisition and maintenance groups. This is due to the price difference in the materials, adding to DKK 203,000, as well as the different maintenance needs given the specifics of the products, adding an additional DKK 22,137. Supply and maintenance are assumed to be the same.

PLOT AND ADVISORY COSTS

In the green diagram the distribution of expenses for advisory is visualised.

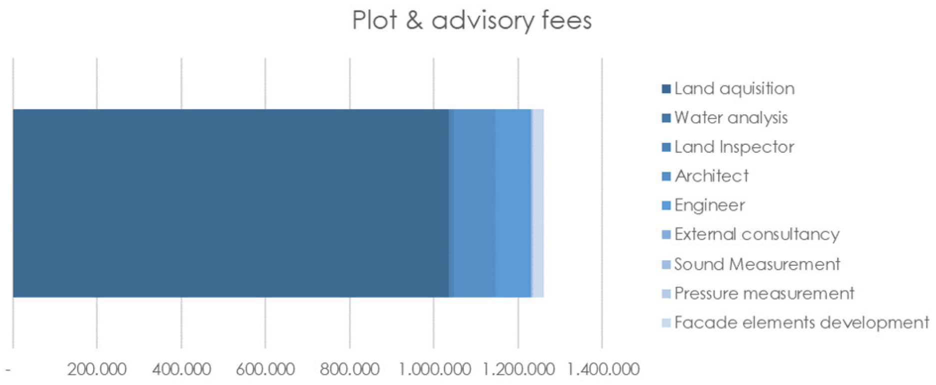
KEY FIGURES

Upcycle Studios:

- Acquisition per building costs: DKK 2,956,167
- Net present value of total life cycle costs (including maintenance, supply and cleaning): DKK 5,001,500
- Net present value/m^2/year: DKK 1,405 / m^2 / year is achieved for Upcycle Studios

Benchmark:

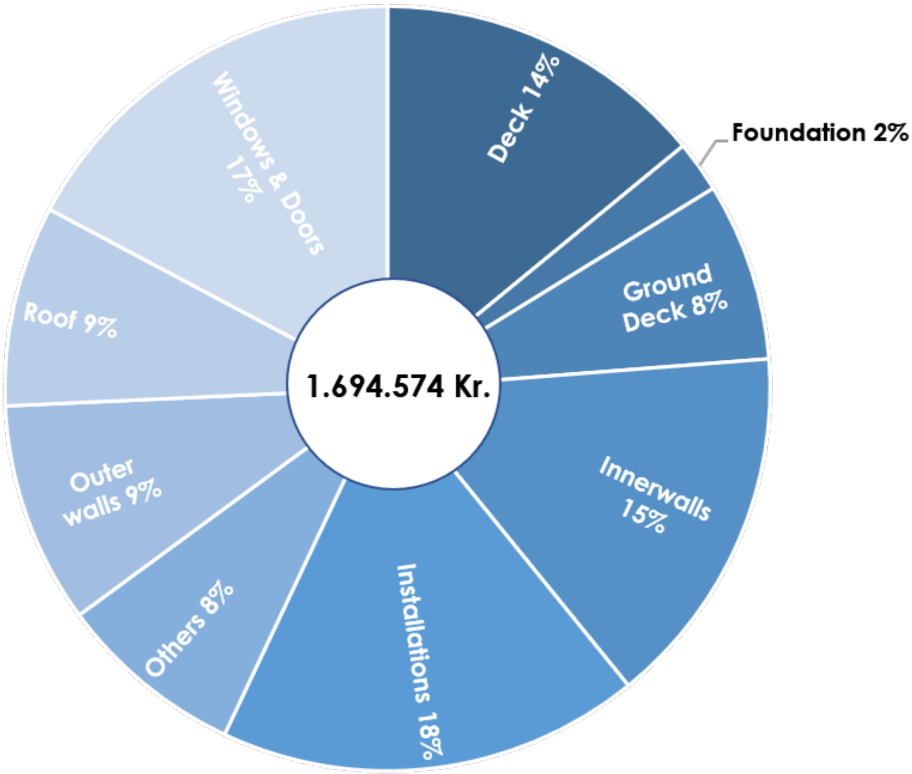
- Acquisition per building costs: DKK 3,159,167
- Net present value of total life cycle costs (including maintenance, supply and cleaning): DKK 5,226,637
- Net present value per m^2 per year: DKK 1,467 / m^2 / year is achieved for benchmark



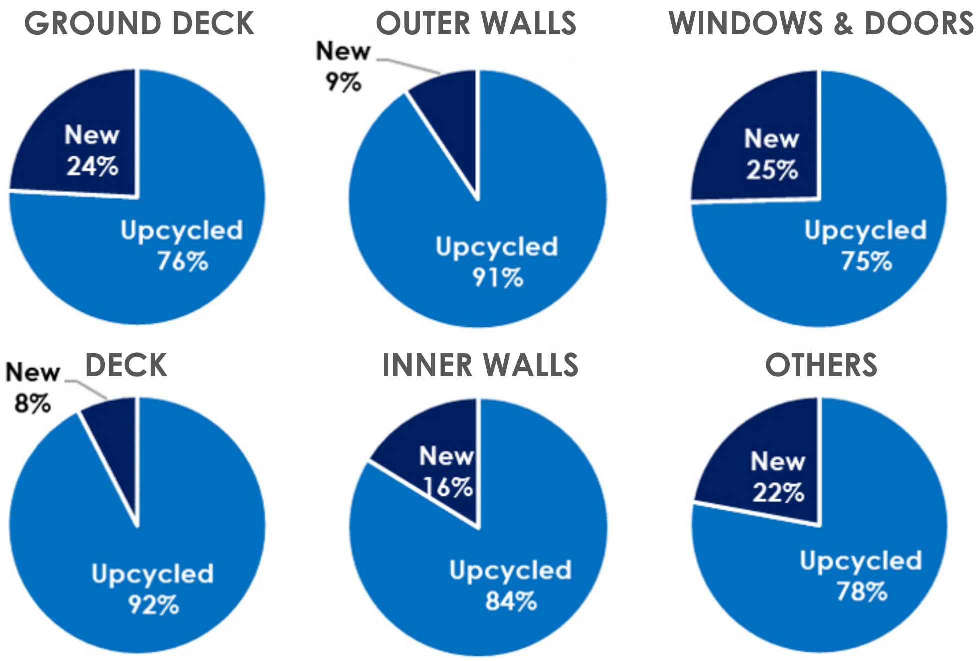
	Benchmark		Upcycle Studios	
	DKK	**%**	**DKK**	**%**
Acquisition	**3.158.586**	**60%**	**2.956.167**	**57%**
Land & advisory	1.261.593	24%	1.261.593	24%
Building basis	182.435	3%	164.531	3%
Primary building parts	941.687	18%	770.109	15%
Complementary building parts	325.991	6%	329.639	6%
Surface building parts	142.590	3%	127.941	2%
Installations	168.453	3%	168.453	3%
Electrical & mechanical systems	135.837	3%	133.901	3%
Maintenance	**901.599**	**17%**	**879.614**	**17%**
Building basis	23.734	0%	21.405	0%
Primary building parts	254.631	5%	205.389	4%
Complementary building parts	189.853	4%	229.096	4%
Surface building parts	98.777	2%	90.638	2%
Installations	260.732	5%	260.732	5%
Electrical & mechanical systems	73.872	1%	72.354	1%
Supplies	**514.453**	**10%**	**514.453**	**10%**
Water	436.266	8%	436.266	8%
Electricity	78.187	1%	78.187	1%
Cleaning	**651.266**	**12%**	**651.266**	**12%**
Terrain	3.724	0%	3.724	0%
Buildings, exterior	79.620	2%	79.620	2%
Indoor areas and spaces	567.922	11%	567.922	11%

UPCYCLE STUDIOS - BUILDING LEVEL

LCC - DIVISION OF COSTS



Material cost distribution



GROUND DECK AND FOUNDATION:

- Upcycle concrete ground deck
- Upcycle foundation

OUTER WALLS:

- Concrete outer walls
- Upcycle wooden staircase (roof)
- Mineral wool insulation
- Concrete fence-walls

INNER WALLS:

- Upcycle concrete partition walls
- Upcycle wooden wall
- Upcycle inner wall wooden surface (Dinesen)
- Concrete shaft walls
- Concrete blocks

DECK:

- Upycle concrete floor slab
- Mineral wool insulation
- Upcycle Dinesen wooden floor

ROOF:

- Skylights
- Concrete roof
- Mineral wool insulation
- Alu and plywood cover
- Concrete tiles
- Roofing boards

WINDOWS AND DOORS:

- Upcycle windows
- Upcycle wooden door
- Wooden door

INSTALLATIONS:

- Sanitation
- Heat
- Ventilation
- Electic

OTHERS:

- Upcycle wooden staircase (interior)
- Supporting structures (concrete and steel columns)
- Steel handrails
- Wood railings

DISTRIBUTION OF MATERIAL COSTS

The overall figures for Upcycle Studios show that the construction is competitive on price on an overall level. In the following we dive deeper into how the costs are distributed across virgin and upcyle materials to better understand the size of investment related to the size of impact.

The big piechart to the top left shows the distribution of costs across all material categories registered in Upcycle Studios.

Upcycle Studios has been built primarily with concrete, and this becomes evident when we add all concrete elements together: Deck, foundation, ground deck, outer walls, and a part of inner walls, adding up to 58% of total material expenditure. It must be stated, that some other than concrete are included in them. The other building material that has been widely used is glass. Windows and doors amount to 17% of material expense, the largest cost category after installations.

Diving into the costs across upcycle and conventional materials the small piecharts to the left show the split across building parts and components where at least 75 % of each category is upcycled. This shows a relative high investment in upcycle materials in the six categories presented. The other categories in the big piechart do not include expenses for upcycling, why these are not highlighted. Across categories 54 % of all costs have been spent on upcycle products and 46 % on other types of expenses. As 69 % of the total weight of materials and only 44 % of the CO_2 emissions is based on upcycle products the relation between material amount, CO_2 performance/value and price is reasonable.

UPCYCLE STUDIOS - BUILDING LEVEL

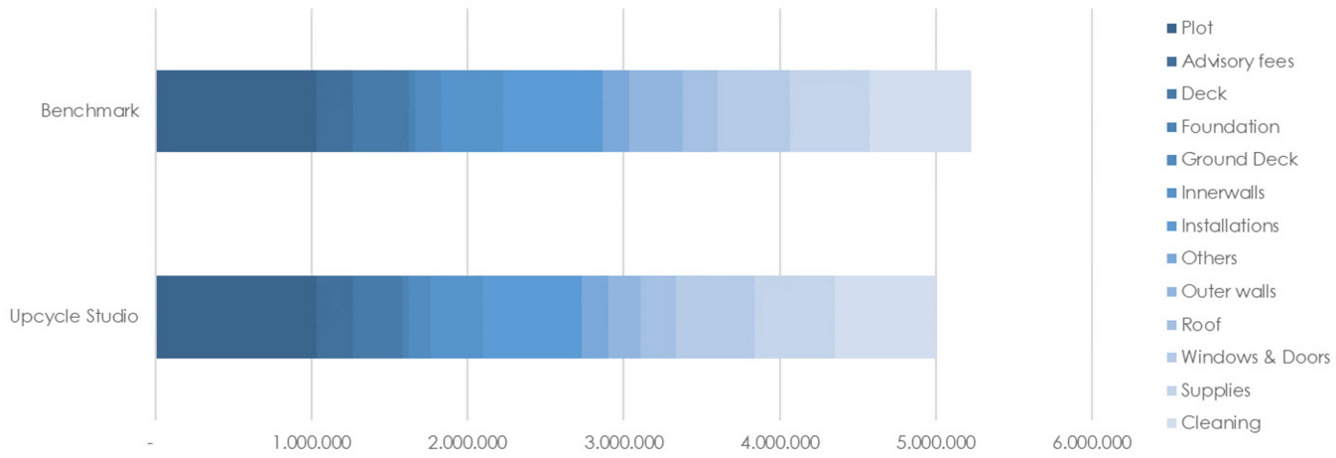
LCC - BENCHMARK ANALYSIS

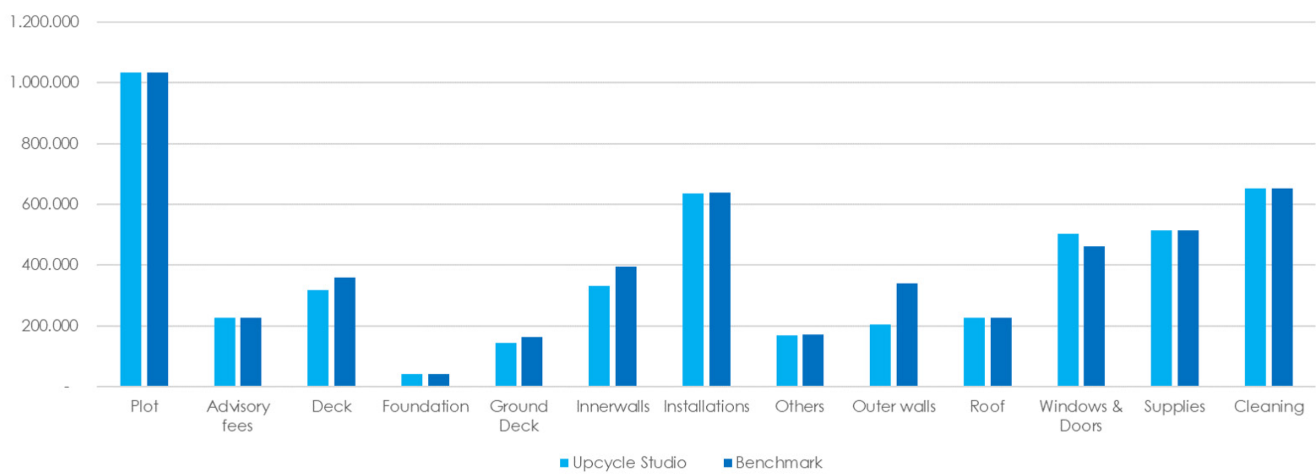
BENCHMARK ANALYSIS

One thing is how the costs are distributed in one project. Another thing is how it performs compared to benchmark. As in LCA, here the benchmark is Upcycle Studios, but without the use of upcycle products.

Differing from the LCC on product level it is very important to notice that the prices on upcycle products included here are based on selling price - and therefore do not necessarily reflect the upcycle products' financial reality as shows in LCC on product level (concrete, windows and bricks). This choice is partially due to that we do not have LCC on product level for all upcycle products and that the purpose of the building level LCC is to reflect the costs to the developer.

In the bottom bar-chart you see how building level LCC of all categories with upcycle products compare to benchmark. The categories that are exactly the same as benchmark do not include any costs for upcycle products.

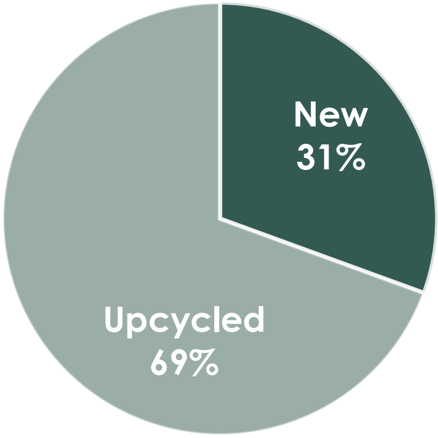




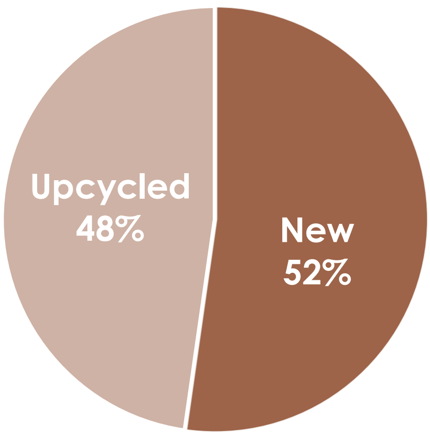
UPCYCLE STUDIOS - BUILDING LEVEL

RESULTS ACROSS CO_2, WASTE AND PRICE

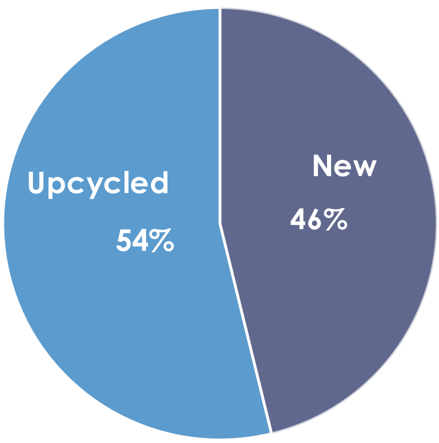
Material distribution by weight



CO2-eq distribution



Cost distribution



UPCYCLE STUDIOS

65 tonnes CO_2 -eq
45 % saving

914 tonnes waste in total

488 kg CO_2 -eq per year
53 % saving

THE RESOURCE ROWS

THE RESOURCE ROWS - BUILDING LEVEL

INTRODUCTION

THE CONCEPT
With the Resource Rows project, NREP strived to challenge and investigate what a thorough understanding of resources can bring about in terms of value and quality for new constructions.

Resource Rows is a residential project comprising 29 row houses and 63 apartments in Ørestaden. Resource efficiency and optimisation formed the underlying concept of the project.

The project was underwritten based on a conventional row house and apartment project meaning that all sustainability efforts had to fit in a conventional budget frame in order to be implemented in the final project.

THE IMPACT
The following chapter will show the overall impact of a row house in The Resource Rows across carbon footprint and financials. An overview of how many products are upcycled as well as how the buildings perform across LCA and LCC will be presented here. The LCA will be a deep dive on CO_2 and an overview on how the building performs across all impact categories.

The Resource Rows focuses on the following impacts:

THE RESOURCE ROWS

Adress:
Else Alfelts Vej,
2300 København S
Construction year: 2017-2019
Size: 9148 m^2
Housing:
- 63 apartments
- 29 row houses

Project partners:
- Developer: NREP A/S
- Contractor: Arkitektgruppen
- Architect: Lendager ARC
- Upcycle material supplier: Lendager UP
- Consulting engineer: MOE

Total cost: EUR 38.3 millions

SOCIAL
The sharing economy proves that it is practical to allow resources that are otherwise used only occasionally to be shared by people other than the owner. This provides an economic incentive to all parties involved and it brings neighbours together.

BIO
The integration of green infrastructure acts as a common thread throughout the settlement, with large biodiversity green areas.

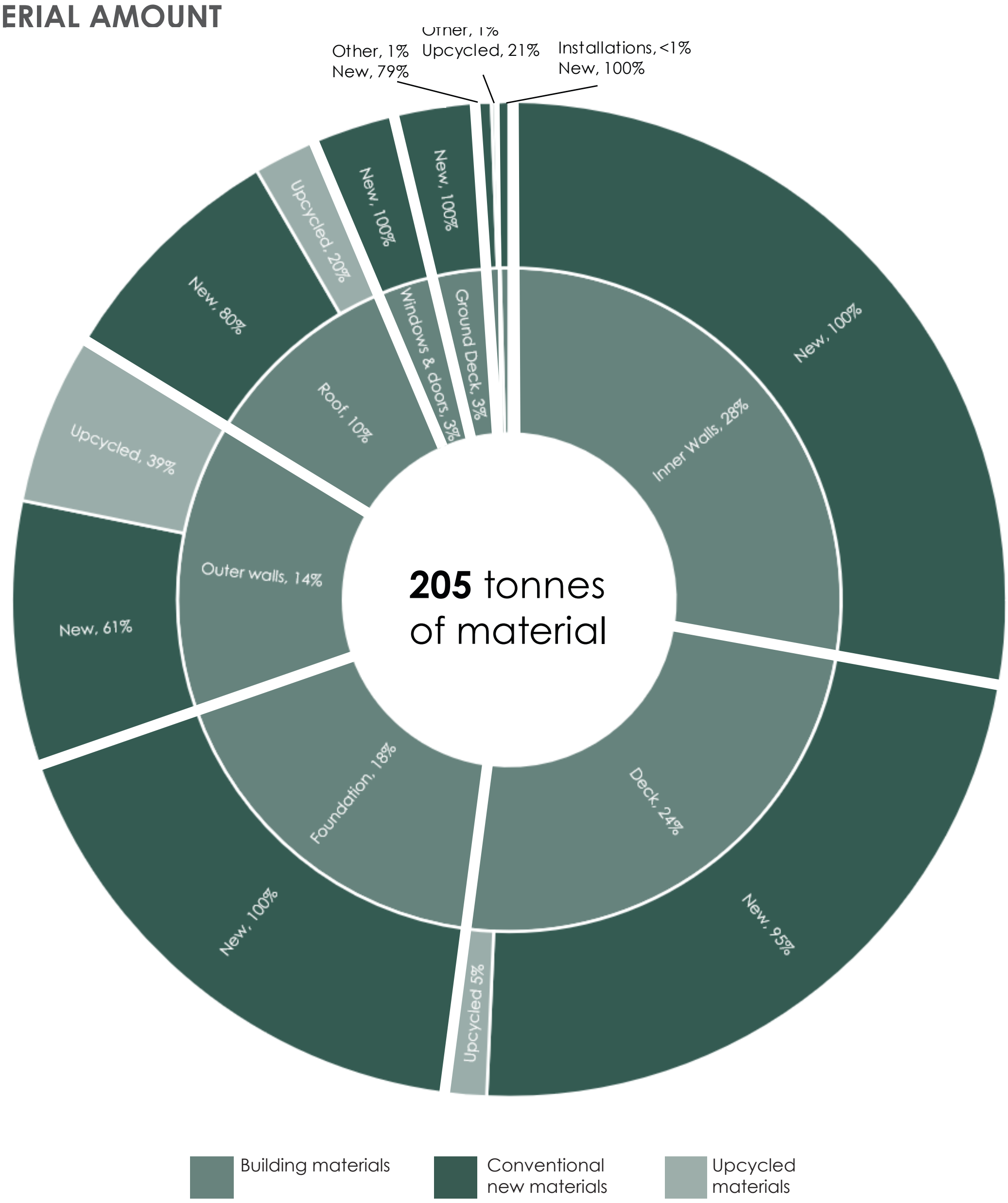
WATER
Reuse of water is an important part of the Resource Rows' identity. For non-portable uses, outdoor waster is replaced with rainwater that is collected from solar cells and other unused surfaces.

ENERGY
Design of the building envelope and use of efficient ventilation, heat recycling, and solar cells. This resulting in economic savings on utility costs for the residents as well as CO_2 savings on the building use.

MATERIALS
Building waste today represents a huge untapped resource, which was exploited in the construction of the Resource Rows. By reusing the walls from abandoned dwellings as new facadeelements, CO_2 and use of virgin materials was minimised while getting a new building with history and character from day one.

THE RESOURCE ROWS - BUILDING LEVEL

LCA - MATERIAL AMOUNT



DISTRIBUTION BETWEEN UPCYCLE AND NEW MATERIALS

The Resource Rows is built from a combination of new and upcycled materials. The graph above illustrates the distribution of materials in the building - 205 tonnes representing the total weight of one average row house in Resource Rows. The inner annulus shows the distribution across the building parts and components, and the outer annulus shows the distribution between new and upcycle material for each of the building parts.

In the Resource Rows there has been a focus on using visible upcycle materials such as the upcycle brick facade, the offcut wooden facades, offcut wooden floors, offcut wooden terrace, upcycle roof top houses and more wooden products listed in chapter 2. Ensuring the visibility of upcycle products is done to inform about circular economy and show that it is not only possible to do, but also aesthetically pleasing.

Out of the 205 tonnes of materials, approximately 18 tonnes or 9% are upcycled materials. The volume of upcycle materials seem much lower than in Upcycle Studios due to the amounts calculated in tonnes which makes the many upcycle wooden materials disappear in more dense conventional materials such as concrete, that is not upcycled in Resource Rows.

The design of Resource Rows has focused on more natural materials speaking to the softer side of community building - especially on the roof, where there has been made great efforts in using upcycle wooden materials along with a directly reused bridge connecting different parts of the city block.

BUILDING PARTS AND COMPONENTS

Foundation:

- Slab foundation

Ground deck:

- Ground deck basement

Outer walls:

- Upcycled windowpanel
- Basement outerwall
- Stern capsule
- Upcycled brick
- Street row house
- Murkrone row house

Inner walls:

- Glass shielding
- Residential wall
- Bath wall
- Apartment boundary walls

Deck:

- Concrete Deck
- Suspended ceiling
- Wooden floor on joists
- Concrete hollow deck

Roof:

- Roof
- Upcycled terrasse

Windows and doors

Installations:

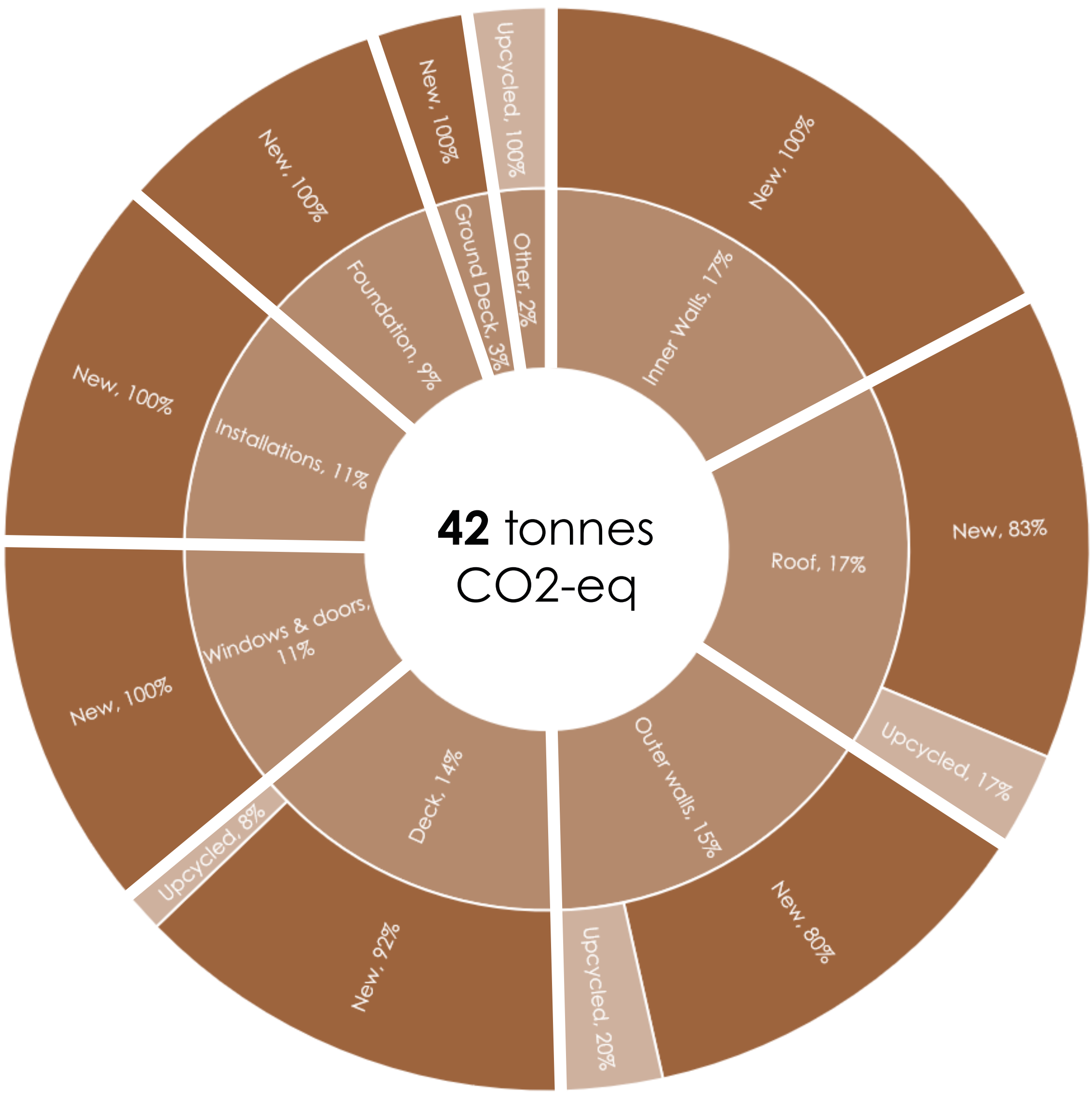
- Sanitation
- Heat
- Ventilation
- Electricity

Others:

- Stairs
- Upcycle roof top house

THE RESOURCE ROWS - BUILDING LEVEL

LCA - CO_2-EQ EMISSIONS



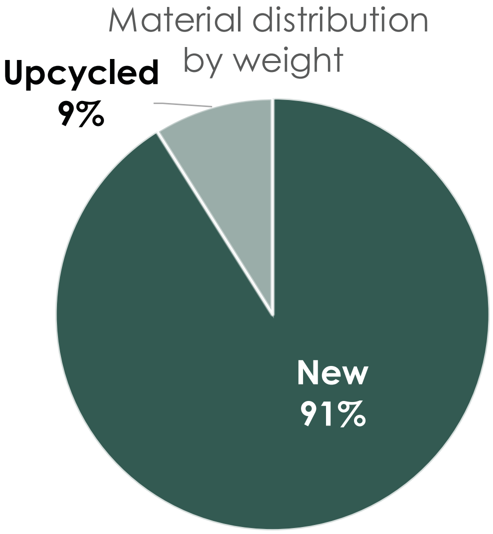
DISTRIBUTION OF CO_2-EQ

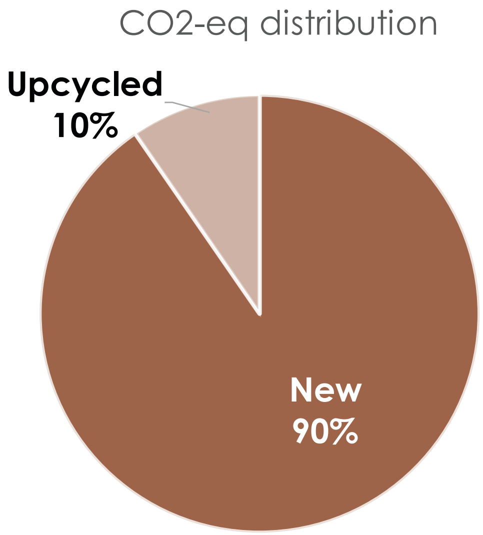
The graph above shows the distribution of CO_2-eq from new and upcycle materials - 42 tonnes CO_2-eq representing the total amount of CO_2 emitted from one average row house in Resource Rows. The inner annulus shows the distribution across the building parts and components, and the outer annulus shows the distribution between new and upcycle material for each of the building parts.

The outer walls consists of 39% upcycle materials, while only contributing with 20% of the CO_2-eq for the outer walls. This is an example of how circulating materials makes it possible to lower the amount of CO_2 emissions from construction projects.

The ratio between the amount of material and CO_2-eq for the roof indicates that the upcycle materials in the roof contribute more. This could be due to precautionary principles when a larger amount of material is used, to ensure that the upcycle materials live up to safety standards. This is done even if the materials have been tested, and are seemingly strong enough. As circular construction becomes more common, this will change in the future.

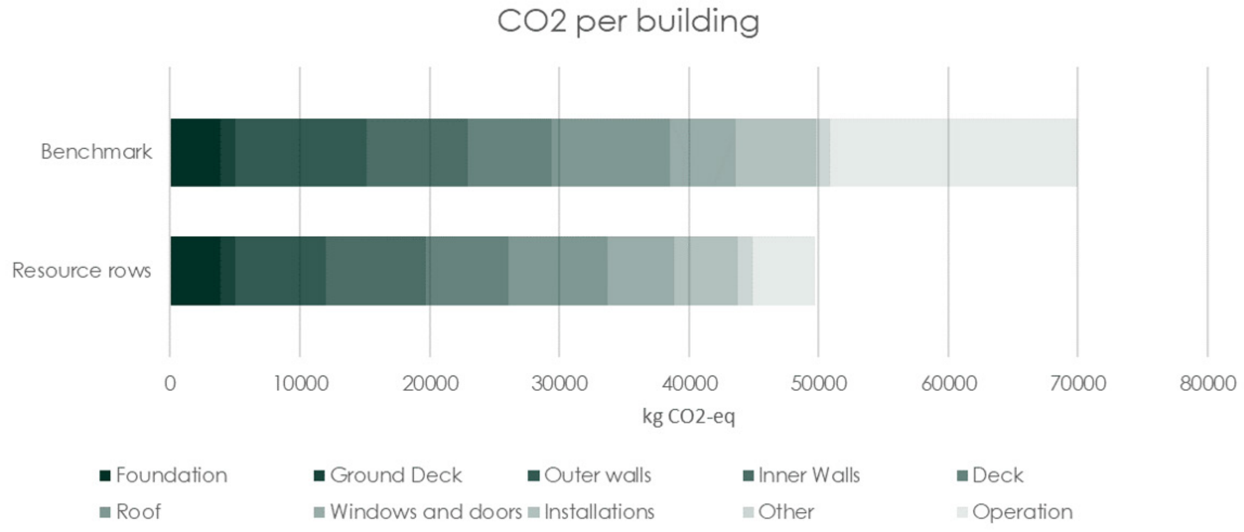
LCA - TOTAL RESULTS ON MATERIALS





THE RESOURCE ROWS - BUILDING LEVEL

LCA - BENCHMARK ANALYSIS



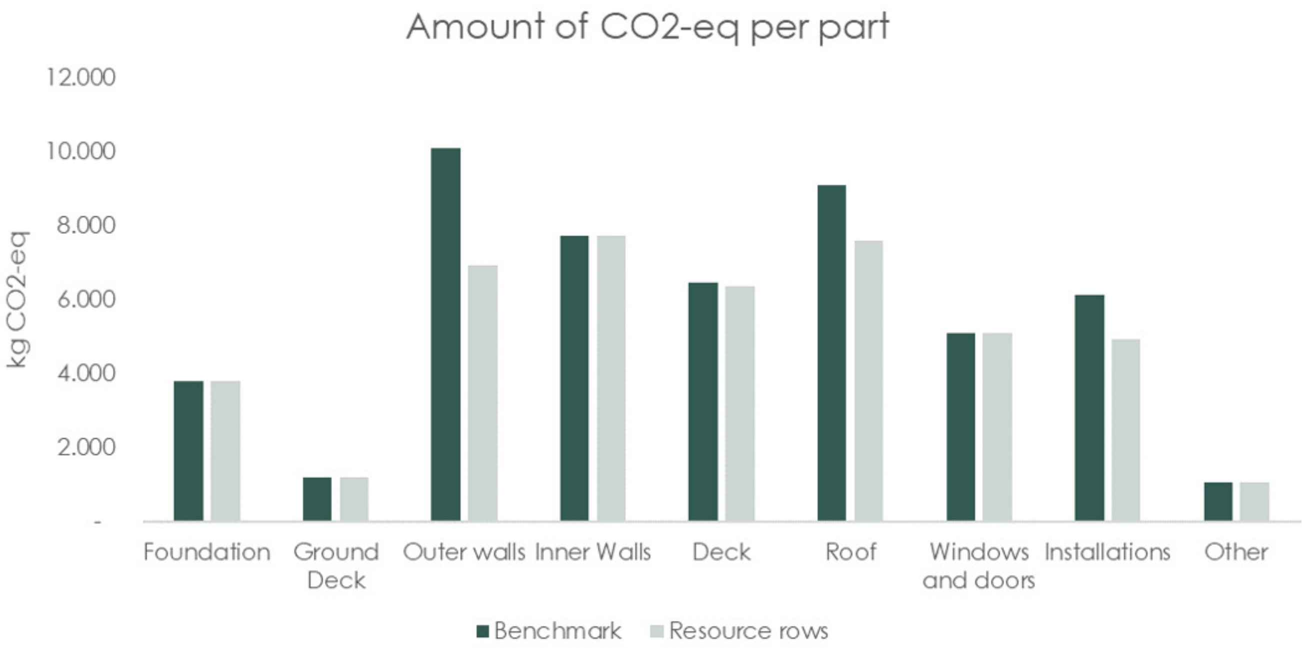
LCA BENCHMARK ANALYSIS

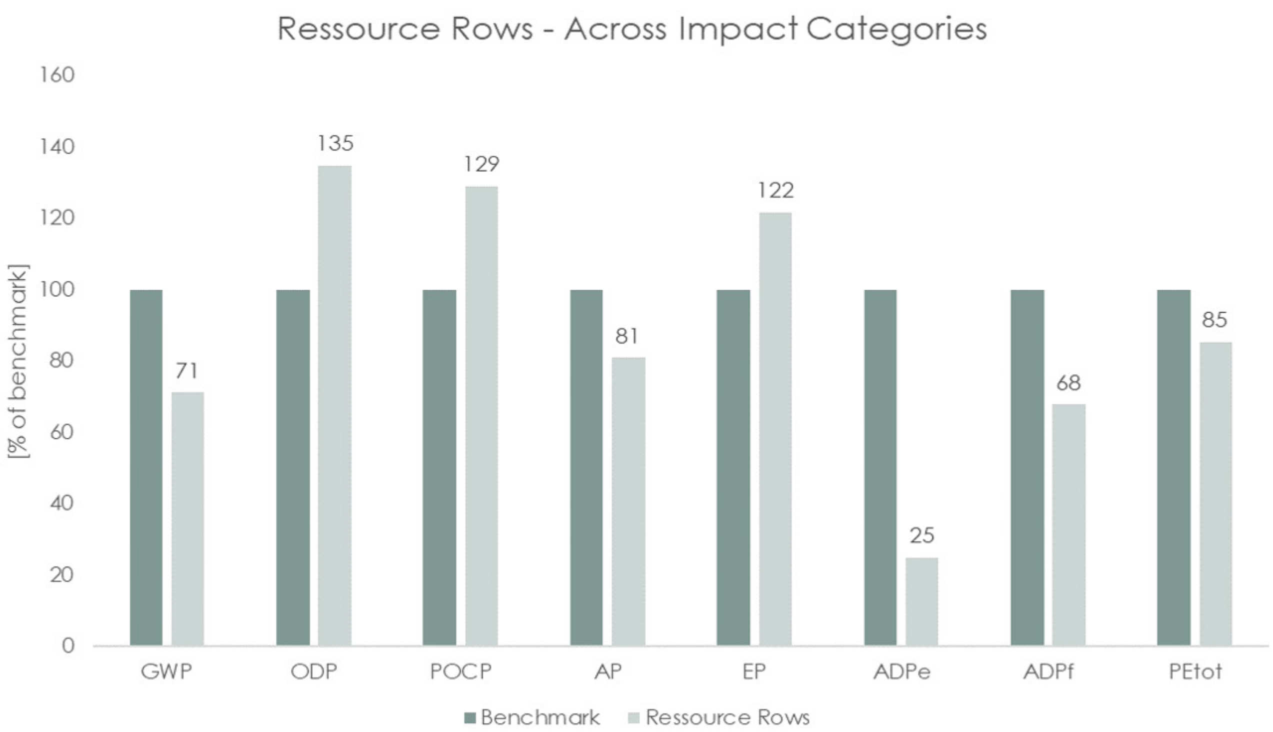
Life Cycle Assessment (LCA) considers both the embodied CO_2 as well as the CO_2 impact of operations across the life of the building. Compared to benchmark, Resource Rows has saved in total 20 tonnes CO_{2eq}, or 29%. The graph above illustrates how we move from a 12 % reduction in materials to a total saving of 29 % including operations.

The upper graph on the next page illustrate where the savings occur, indicating that we have achieved savings across the categories of outer walls, roof and installations supplemented by a small impact on decks (the wooden indoor floors).

ACROSS IMPACT CATEGORIES

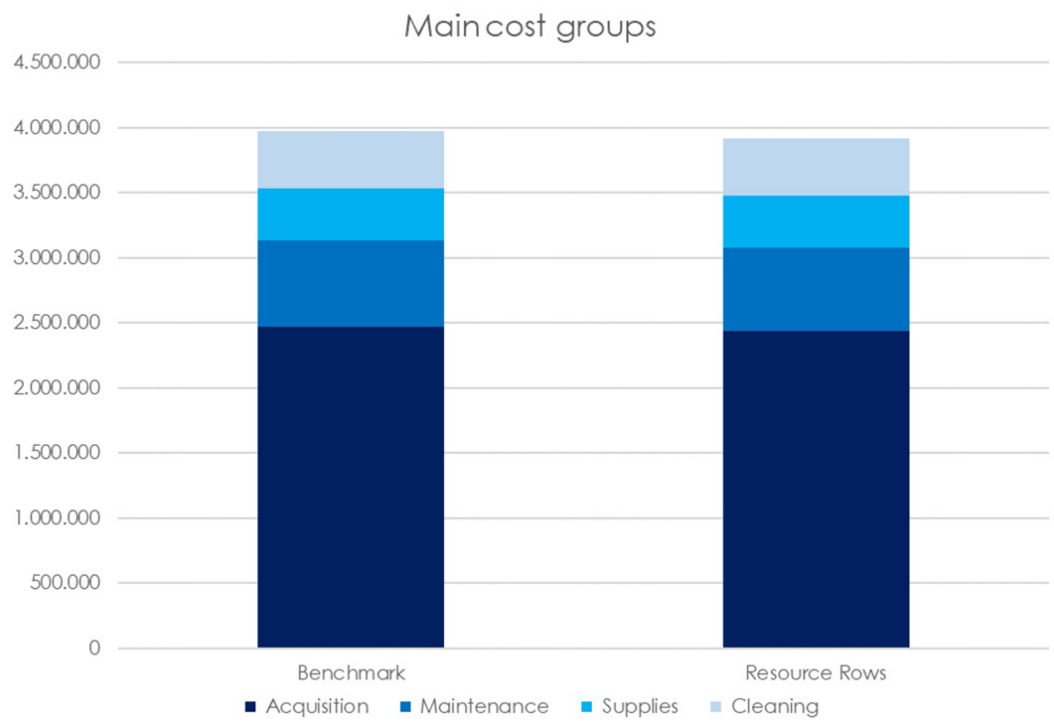
When comparing the Resource Rows to benchmark, the Resource Rows have lower impacts in most categories compared to the benchmark, except in ODP, POCP and EP.


Amount of CO2-eq per part
12.000
10.000
8.000
6.000
4.000
2.000
-
kg CO2-eq
Foundation
Ground Deck
Outer walls
Inner Walls
Deck
Roof
Windows and doors
Installations
Other
Benchmark
Resource rows


Ressource Rows - Across Impact Categories
160
140
120
100
80
60
40
20
0
[% of benchmark]
71
135
129
81
122
25
68
85
GWP
ODP
POCP
AP
EP
ADPe
ADPf
PEtot
Benchmark
Ressource Rows

RESOURCE ROWS - BUILDING LEVEL

LCC - OVERALL COST DISTRIBUTION



LCC ON BUILDING LEVEL

To be able to scale an impactful solution, it needs to be able to compete on price or at least fit into an overall budget for construction and maintenance. On the following pages we will dive into an analysis of life cycle costings on building level to clarify the competitiveness of one average Resource Rows row house.

DIVISION OF COSTS

The bar chart above reflects all life cycle costs for one Resource Rows row house and its benchmark. It gathers all cost categories, ranging from acquisition (construction/materials), maintenance, supply of water and electricity, as well as cleaning costs.

The largest differences arise in the acquisition and maintenance groups. This is due to the price difference in the materials, adding to DKK 36,162, as well as the different maintenance, adding an additional DKK 19,687. The difference in maintenance is particularly high due to the choice of a benchmark for the upcycle brick walls. Supply and maintenance are assumed to be the same.

PLOT AND ADVISORY COSTS

In the green diagram the distribution of expenses for advisory is visualised.

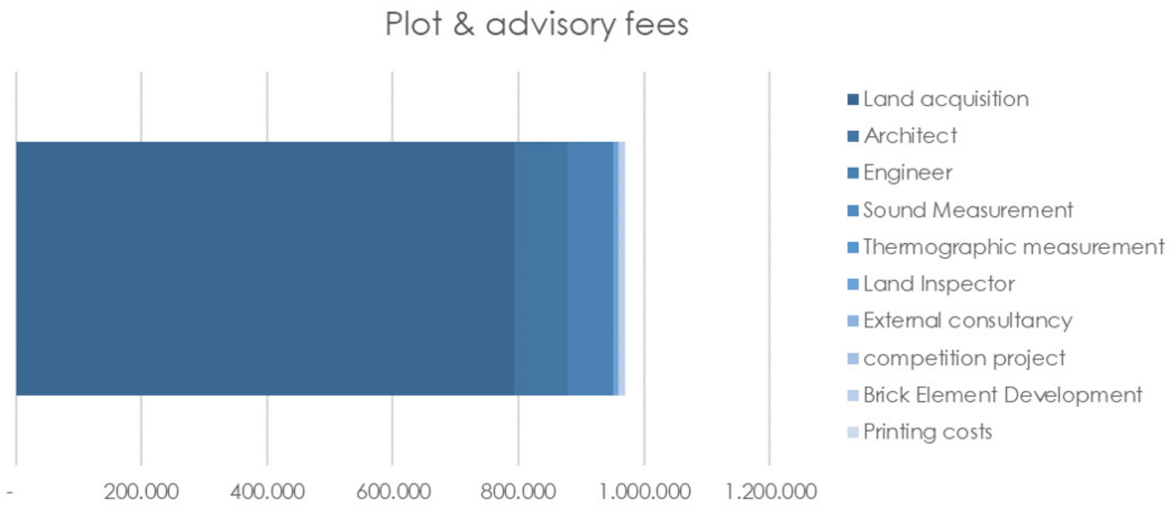
KEY FIGURES

Resource Rows:

- Acquisition costs per row house: DKK 2,435,954.
- Net present value of total life cycle costs (including maintenance, supply and cleaning): DKK 3,921,784.
- Net present value/m^2/year: DKK 1,432 / m^2 / year is achieved for Resource Rows.

Benchmark:

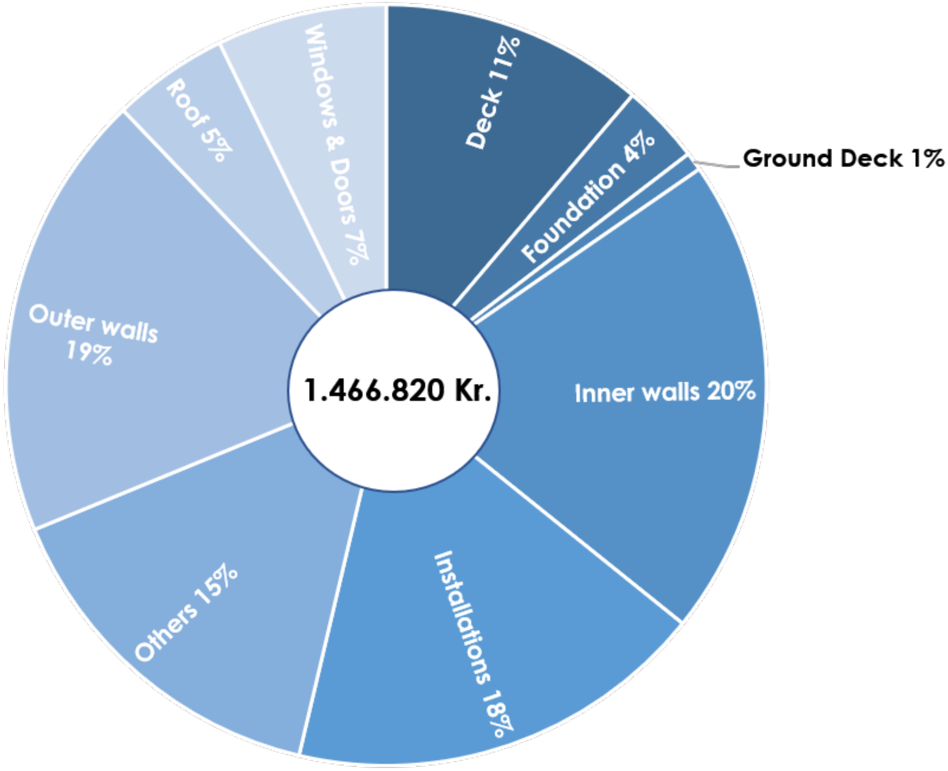
- Acquisition costs per row house: DKK 2,472,116.
- Net present value of total life cycle costs (including maintenance, supply and cleaning): DKK 3,977,633.
- Net present value per m^2 per year: DKK 1,453 / m^2 / year is achieved for Resource Row's Benchmark.



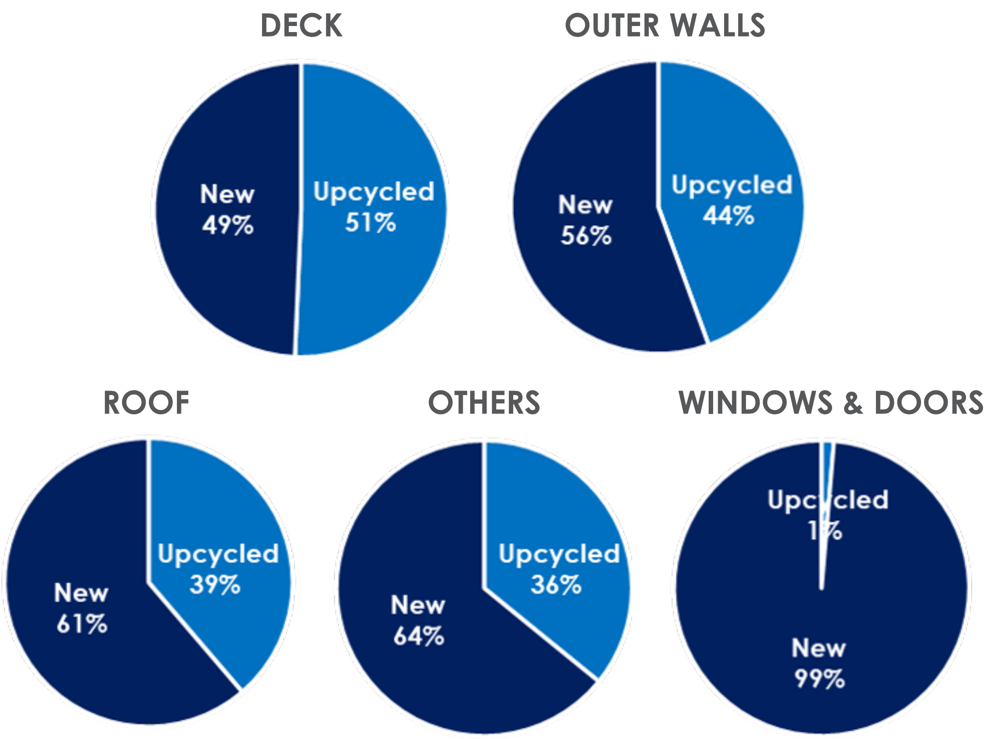
	Benchmark		Resource Rows	
	DKK	%	DKK	%
Acquisition	**2.472.116**	**62%**	**2.435.954**	**62%**
Land & advisory	969.134	24%	969.134	25%
Building basis	61.260	2%	61.260	2%
Primary building parts	652.188	16%	707.832	18%
Complementary building parts	280.659	7%	218.850	6%
Surface building parts	238.442	6%	216.189	6%
Installations	155.470	4%	155.470	4%
Electrical & mechanical systems	114.963	3%	107.219	3%
Maintenance	**661.123**	**17%**	**641.436**	**16%**
Building basis	8.269	0%	8.269	0%
Primary building parts	185.921	5%	199.185	5%
Complementary building parts	115.602	3%	94.513	2%
Surface building parts	161.254	4%	155.464	4%
Installations	146.634	4%	146.634	4%
Electrical & mechanical systems	43.442	1%	37.370	1%
Supplies	**404.074**	**10%**	**404.074**	**10%**
Water	325.010	8%	325.010	8%
Electricity	79.064	2%	79.064	2%
Cleaning	**440.320**	**11%**	**440.320**	**11%**
Terrain	6.765	0%	6.765	0%
Buildings, exterior	41.621	1%	41.621	1%
Indoor areas and spaces	391.934	10%	391.934	10%

THE RESOURCE ROWS - BUILDING LEVEL

LCC- DIVISION OF COSTS



Material cost distribution



FOUNDATION:

- Concrete slab foundation

GROUND DECK:

- Concrete ground deck
- Insulation

OUTER WALLS:

- Upcycle brick wall elements
- Concrete retaining walls
- Aluminium wall elements
- Paint products

INNER WALLS:

- Various concrete wall types
- Paint products

DECK:

- Upcycle wooden floor
- Concrete floor slab
- Paint products

ROOF:

- Upcycle wooden roof boards
- Roof insulation
- Plaster ceiling surfaces
- Roofing felt

WINDOWS AND DOORS:

- Upcycle facade wood elements
- Doors (alu, messing and wood)
- Windows (alu and meesing)

INSTALLATIONS:

- Sanitation
- Heat
- Ventilation
- Electric

OTHERS:

- Upcycle Roof top house
- Steel staircase

DISTRIBUTION OF MATERIAL COSTS

The overall figures for Upcycle Studios show that the construction is competitive on price on an overall level. In the following we dive deeper into how the costs are distributed across virgin and upcycle materials to better understand the size of investment related to the size of impact.

The big pie-chart on the prior page shows the distribution of costs across all material categories registered in the Resource Rows.

Outer walls is the largest cost group with upcycle materials, accounting for the upcycle brick elements. Furthermore, we find a lot of wooden products in the rest of the cost groups. Their overall economic impact is lesser compared to other more financially demanding material categories.

Diving into the costs across upcycle and conventional materials the small pie-charts to the bottom left shows the split across building parts and components visualising a higher level of expenses related to conventional materials than upcycle materials. This is positive based on the amount of materials upcycle stated above. The other categories in the big pie-chart do not include expenses for upcycling, why these are not highlighted. Across categories 20 % of all costs have been spent on upcycle products and 80 % on other types of expenses. As 9 % of the total weight of materials and 10 % of the CO_2 emissions is based on upcycle products the relation between material amount, CO_2 performance/value and price seems reasonable, though a bit higher than for Upcycle Studios. This can be reasoned in the high focus on upcycle wood in Resource Rows that are not as CO_2 heavy as e.g. winows.

THE RESOURCE ROWS - BUILDING LEVEL

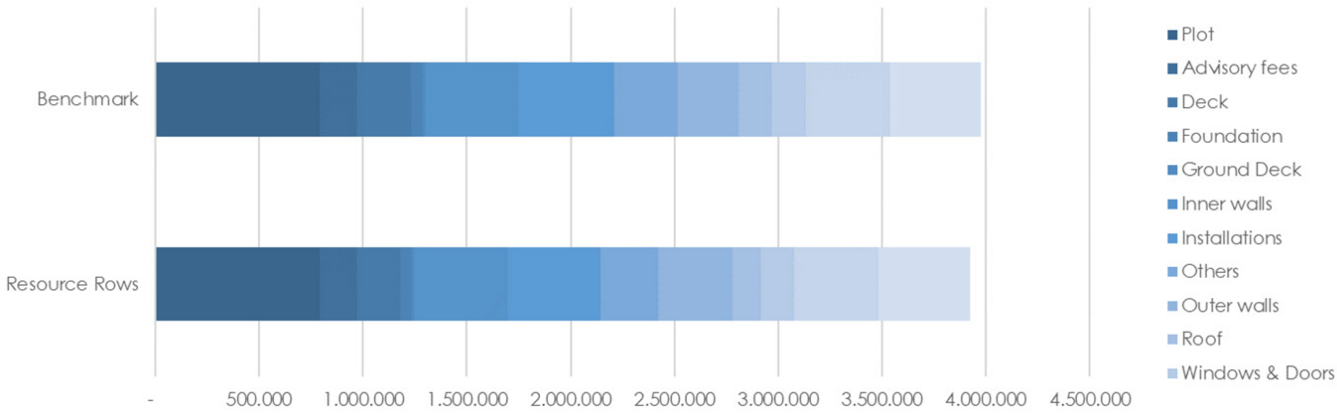
LCC- BENCHMARK ANALYSIS

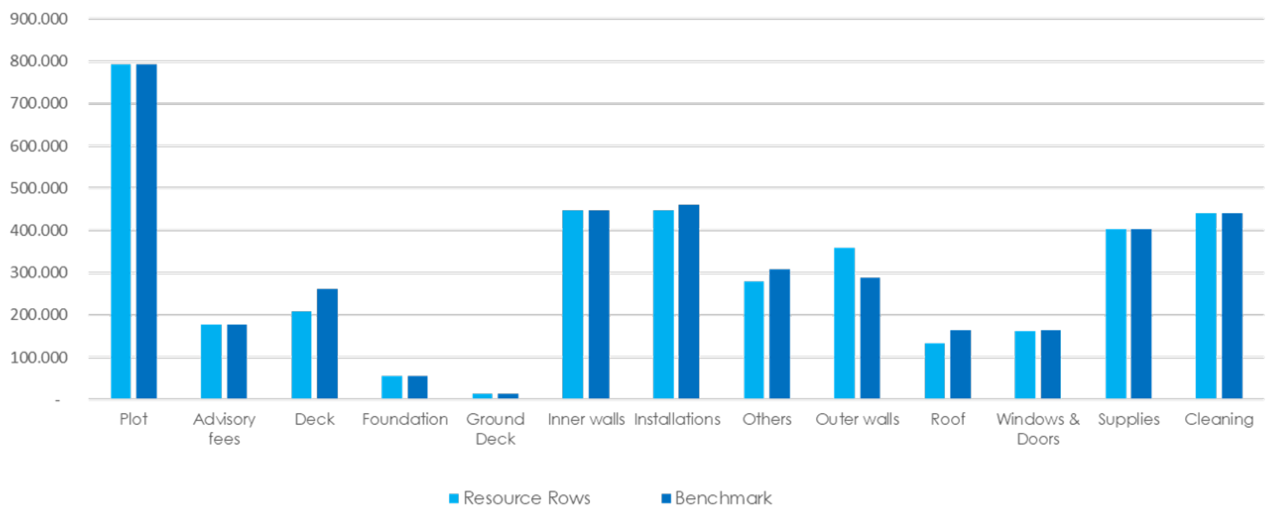
BENCHMARK ANALYSIS

One thing is how the costs are distribution in one project. Another thing is how it performs compared to benchmark. As in LCA, here the benchmark is a Resource Rows row house, but without the use of upcycle products.

Differing from the LCC on product level it is very important to notice that the prices on upcycle products included here are based on selling price - and therefore do not necessarily reflect the upcycle products' financial reality as shown in LCC on product level (concrete, windows and bricks). This choice is partially based on the need as we do not have LCC on product level for all upcycle products. At the same time the purpose of LCC on building level is to reflect the costs held by the developer, why expenses for delivering the upcycle products are not relevant here - though interesting of cause to see and understand the potential differences.

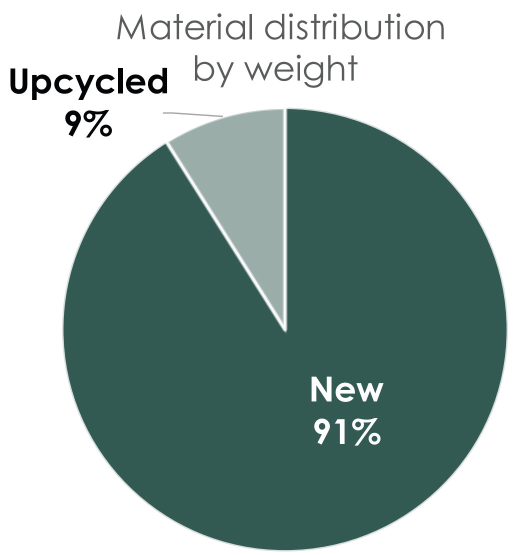
The two diagrams below show a result very close to benchmark both at an overall level (upper diagram) and across expense categories (lower diagram). In the bottom bar-chart you see how all categories with upcycle products include less costs compared to benchmark except windows, doors and outer walls (due to the choice of benchmark). The categories that are exactly the same as benchmark do not include any costs for upcycle products.

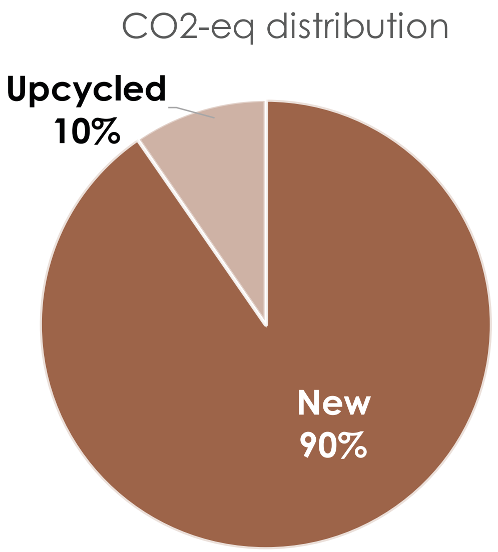


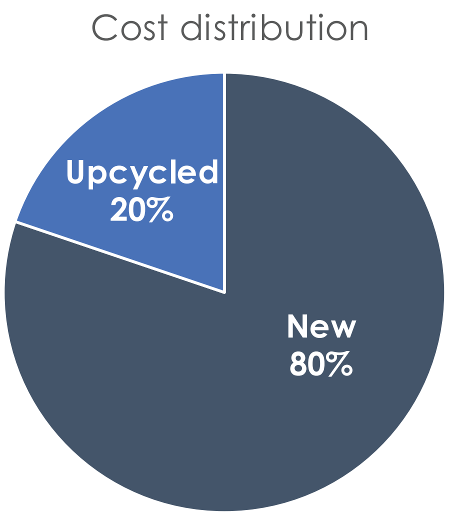


THE RESOURCE ROWS - BUILDING LEVEL

RESULTS ACROSS CO_2, WASTE AND PRICE







RESOURCE ROWS

20 tonnes CO_2 -eq
29 % saving

463 tonnes waste in total

270 kg CO_2 -eq per year
39 % saving

12 DIFFERENT BENCHMARKS

VOLUNTARY SUSTAINABILITY VALUATION

BUILDING LEVEL

A NEW SUSTAINABILITY CLASS FOR BUILDINGS

The Danish Government has presented a new standard for sustainability valuation in the construction sector based on recommendations from the Climate Partnership in the build & construction sector. Amongst others, it is suggested that Carbon Footprint assessments are made mandatory for the voluntary sustainability classification and build regulation. This classification will continuously be sharpened as the market develops. In the Climate Partnership recommendations they included recommendations for making it mandatory for all buildings to have a maximum total GWP of 12 kg CO_2-eq /m^2/year and a voluntary sustainability standard to perform below a GWP of 8.5 kg CO_2-eq /m^2/year.

Recently, SBi has conducted life cycle assessments of 60 sustainable houses of which 12 row houses are included. To get a more varied result and a broader perspective on the sustainable impacts of the Resource Rows and Upcycle Studios these buildings are benchmarked towards the 12 row houses, which can be seen in the table below.

BUILDINGS AHEAD OF THEIR TIME

The table below shows that Upcycle Studios and the Resource Rows are placed in top three performing row houses compared to the 12 row house calculations published by SBi.

Furthermore, it shows how both Upcycle Studios and the Resource Rows perform better than the potential coming voluntary sustainability standard of 8.5 kg CO_2-eq/m^2/year.

Both building projects were planned and initiated long before standards were published and despite not deliberately working towards these standards both buildings are meeting the requirement.

Rowhouse Number	GWP total kg CO_2-eq/m²/year	GWP materials kg CO_2-eq/m²/year	GWP operation kg CO_2-eq/m²/year	Ranking
R06	6.58	4.42	2.16	1
RES	**6.64**	**5.99**	**0.65**	**2**
UPS	**8.08**	**7.67**	**0.41**	**3**
R01	8.39	8.17	0.22	4
R10	8.5	5.9	2.6	5
R07	8.57	5.8	2.77	6
R09	8.67	6.13	2.55	7
R11	9.63	6.85	2.78	8
R08	9.99	7.39	2.6	9
R02	10.2	7.44	2.78	10
R12	10.5	5.87	4.58	11
R03	10.6	8.11	2.48	12
R04	14.2	10.8	3.36	13
R05	14.5	10.8	3.7	14

ENERGY IMPROVING INITIATIVES

ENERGY IMPROVING INITIATIVES

BACKGROUND DATA

ENERGY IMPROVING INITIATIVES

In the following, we will map the impact of energy improving initiatives in connection to Upcycle Studio and the Resource Rows. The significance is investigated by comparing energy calculations of current buildings and if they were built as "standard" buildings. This section is written by MOE and based on their calculations.

Three scenarios are examined for each of the two buildings:

1. "As-built": The actual construction as it is built today
2. "As-built: The actual construction where solar cells are adapted to comply with BK2020 requirements only" BK2020
3. "Reference": The building adapted so that building components conform to the "standard / common" practice for compliance with BK2020 requirements.

PREREQUISITES

To map the significance of incorporated energy measures in respectively Upcycle Studios and The Resource Rows, the two energy calculations have been adapted to match how one would build a traditional town house. In the case of building parts/components where common practice has been applied in UPC or RES, the same values are used in the two calculations. Only the row houses for The Resource Rows were included in the analysis.

The diagrams below show the changes made in the respective energy frames. Calculations have been conducted in accordance with Building Regulations 2015 incl. associated energy calculation program Be15.

Upcycle Studios		**As-built**	**Referencebyggeri**
Klimaskærm	Vinduer, alm.	Gns. 0,76 W/m²K Upcycle vinduer 2+2 lag	Gns. 0,85 W/m²K Standard vinduer 3 lags
	Vinduer, dobbelthøje	Gns. 0,71 W/m²K Upcycle vinduer 2+2 lag	Gns. 1,20 W/m²K Curtain wall (alu)
	Ydervægge, inkl. kuldebroer og linjetab	Gns. 0,16 W/m²K	Gns. 0,18 W/m²K
Varmeanlæg	Forsyning	Varmepumper med buffertanke	Varmeveksler, indirekte fjernvarme
	Frem- og returløbstemperatur [°C]	45/35	60/30
	Varmefordelingsanlæg, ublandet vand, længde	0 m	180 m
Varmekapacitet		140 Wh/K m² Tung bygning, flere tunge dele fx blottede betonvægge	100 Wh/K m² Middel let bygning, Enkelte tunge dele fx porebetonvægge
Tæthed ved trykprøvning på 50 Pa		Ekstra tæt: 0,5 l/s m²	Alm. tæthed: 1,0 l/s m²

Ressourcerækkerne		**As-built**	**Referencebyggeri**
Klimaskærm	Vinduer, alm.	Gns. 0,82 W/m²K Standard vinduer 3 lags (projektspecifik)	Gns. 0,85 W/m²K Standard vinduer 3 lags
	Ydervægge inkl. kuldebroer og linjetab	Gns. 0,15 W/m²K	Gns. 0,18 W/m²K
Varmeanlæg	Forsyning	Varmepumper med buffertanke	Varmeveksler, indirekte fjernvarme
	Frem- og returløbstemperatur [°C]	45/35	60/30
	Varmefordelingsanlæg, ublandet vand, længde	0 m	120 m
Tæthed ved trykprøvning på 50 Pa		Ekstra tæt: 0,55 l/s m²	Alm. tæthed: 1,00 l/s m²

ENERGY IMPROVING INITIATIVES

ENERGY RESULTS

ENERGY CALCULATION

The top table on next page shows the energy requirements for the customized standard buildings, as well as the importance of the individual energy measures. The calculated energy demand is stated as primary energy i.e. a primary energy factor of 0.6 for district heating and a primary energy factor of 1.8 for electricity (cf. BR15, BK2020).

The graphs below show the construction scenario's energy frame result (primary energy demand) as well as the proportion covered by electricity produced by solar cells.

Both Upcycle Studio and The Resource Rows (row houses) are listed to comply with the BK2020, which was necessary to introduce heat pumps into the row houses.

The graphs show that the required solar cell area to comply with BK2020 for Upcycle Studio has been reduced from 14 m² per housing unit in standard construction to 7 m2 per housing unit with the energy measures used. That is, the need for solar cells has halved.

For the Resource Rows it is seen that there is a need for 5 m² of solar cells per housing unit in standard construction, while it is possible to comply with BK2020 requirements with only 0.5 m² per housing unit with the energy measures used.

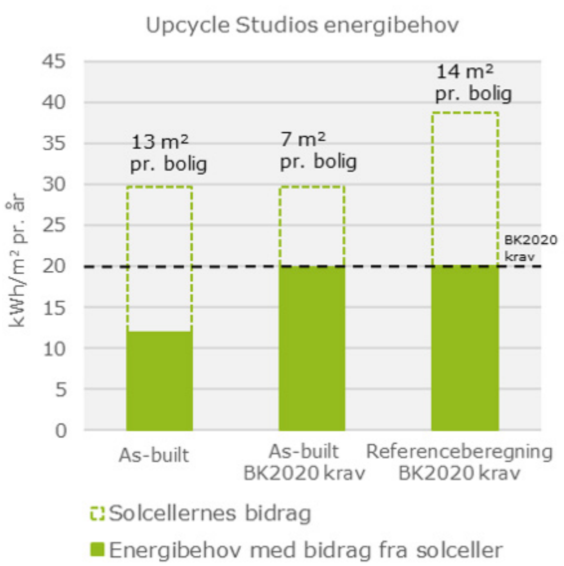
NETTO ENERGY CONSUMPTION

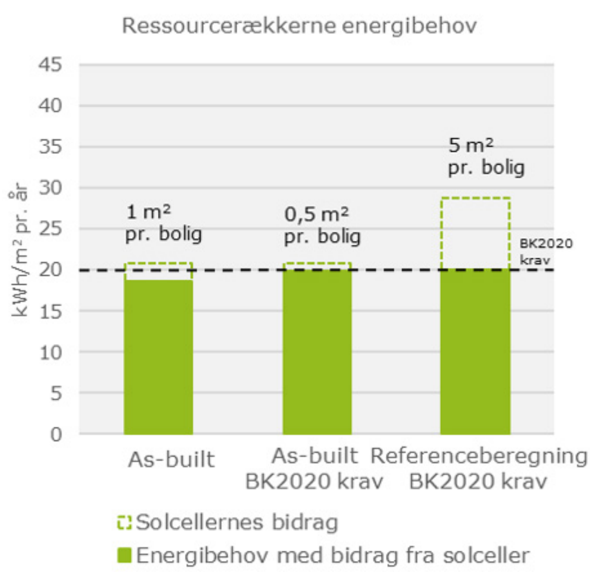
The bottom table on next page shows the buildings' contribution to energy needs without primary energy factors (ie net energy consumption = the theoretical real consumption in the house). In BR15, BK2020, the energy factors used are 0.6 for district heating and 1.8 for electricity. That is, the primary energy consumption in Upcycle Studio from the previous section is converted to a theoretical measure of energy consumption in operation by 11.9 / 1.8 = 6.6 kWh / m² per year.

Both Upcycle Studio and the Resource Rows are made with heat pumps (which produce heat via electricity), which is why only energy consumption for electricity is stated here.

Net electricity consumption is electricity for building operations minus electricity produced by solar cells. For the reference buildings, more electricity is produced with solar cells than is in-cluded in the energy calculation in order to comply with the energy frame requirement, which explains the negative contribution from this.

It should be noted that the enlightened energy for building operation, i.e. energy for pumps, ventilation systems, heat, etc., in fact also include an energy consumption for, for example, lighting and electrical appliances.





		Upcycle Studios kWh/m² pr. år	Ressourcerækkerne
Referencebyggeri energibehov (uden solceller)		38,7	28,8
Tiltag:			
Klimaskærm	Vinduer alm.	-0,7	-0,2
	Vinduer dobbelthøje	-3,1	N/A
	Ydervægge	-0,5	-1,2
Varmeanlæg		-3,1	-5,9
Varmekapacitet		-0,3	N/A
Tæthed		-1,3	-0,7
As-built energibehov (uden solceller)		**29,7**	**20,8**
Reduktion i Energibehov ift. reference		-9	-8
BK2020 krav jf. BR15 [kWh/m² år]		20,0	20,0
As-built energibehov (inkl. solceller)		**11,9** (13 m² solceller pr. bolig)	**18,6** (1 m² solceller pr. bolig)
Reduktion i Energibehov ift. reference		-26,8	-10,2

Upcycle Studios	**As-built**	**As-built BK2020 krav**	**Referencebygning**
El til bygningsdrift [kWh/m² pr. år]	16,5	16,5	3,7
El produceret af solceller [kWh/m² pr. år]	9,9	5,4	10,0
Netto El forbrug, (bygningsdrift minus produceret) [kWh/m² pr. år]	6,6	11,1	-6,3
Varme [kWh/m² pr. år]	0	0	53,5

Ressourcerækkerne	**As-built**	**As-built BK2020 krav**	**Referencebygning**
El til bygningsdrift [kWh/m² pr. år]	11,6	11,6	3,9
El produceret af solceller [kWh/m² pr. år]	1,2	0,5	4,9
Netto El forbrug, (bygningsdrift – produceret) [kWh/m² pr. år]	10,4	11,1	-1,0
Varme [kWh/m² pr. år]	0	0	36,2

ENERGY IMPROVING INITIATIVES

ENERGY RESULTS

CO_2 EMISSION FROM BUILDING OPERATION

Based on calculated net energy consumption, the buildings' CO_2 emissions from construction operations are determined for the three scenarios. The calculations are based on LCA emission factors for the year 2020 from LCAbyg:

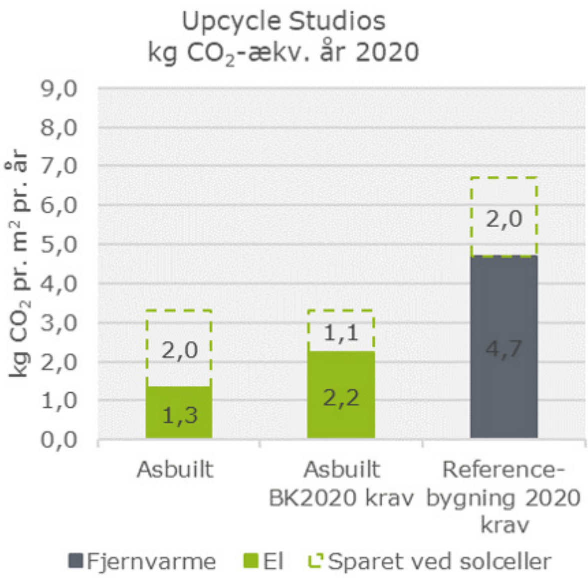
- Electricity: 0.201 kg CO_2 eq / kWh
- District heating: 0.112 kg CO_2 eq / kWh

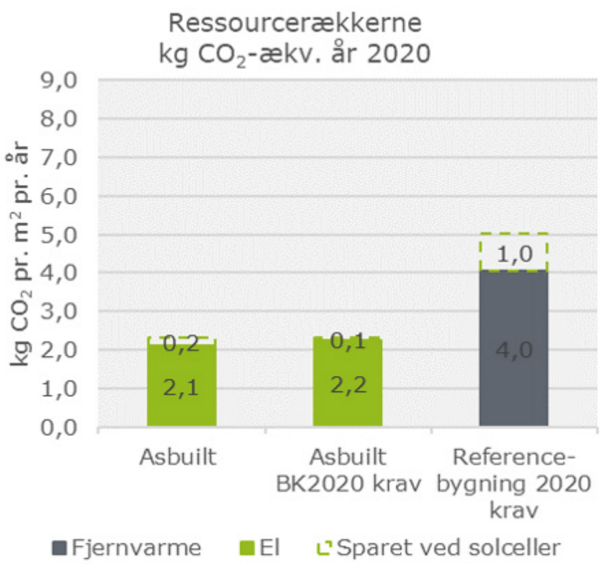
The results are summarized in the diagrams here.

For Upcycle Studio, CO_2 emissions from building operations are seen to be 4.7 kg CO_2 eq pr. m² pr. year for the reference building. By incorporating the previously listed energy measures (improved climate display, heat pump, density, etc.), the CO_2 emissions during building operation are seen to be 2.2 kg CO_2 eq pr. m² per year. This is a 53 % reduction.

For Upcycle Studio, more solar cells have been established than necessary for compliance with the BR15 BK2020. When this solar cell production is offset, the emission is again seen to halve. That means, in the year 2020, Upcycle Studios will emit 72 % less CO_2 than a similar reference building.

For Resource Rows, it is seen that the CO_2 emissions during building operation are 4.0 kg CO_2 eq/ m² per years for the reference building. By incorporating the previously listed energy measures (improved climate display, heat pump, density, etc.), the CO_2 emissions during building operation are 2.2 kg CO_2 eq/m² per year. This represents a reduction of 39 %.





RESULTS

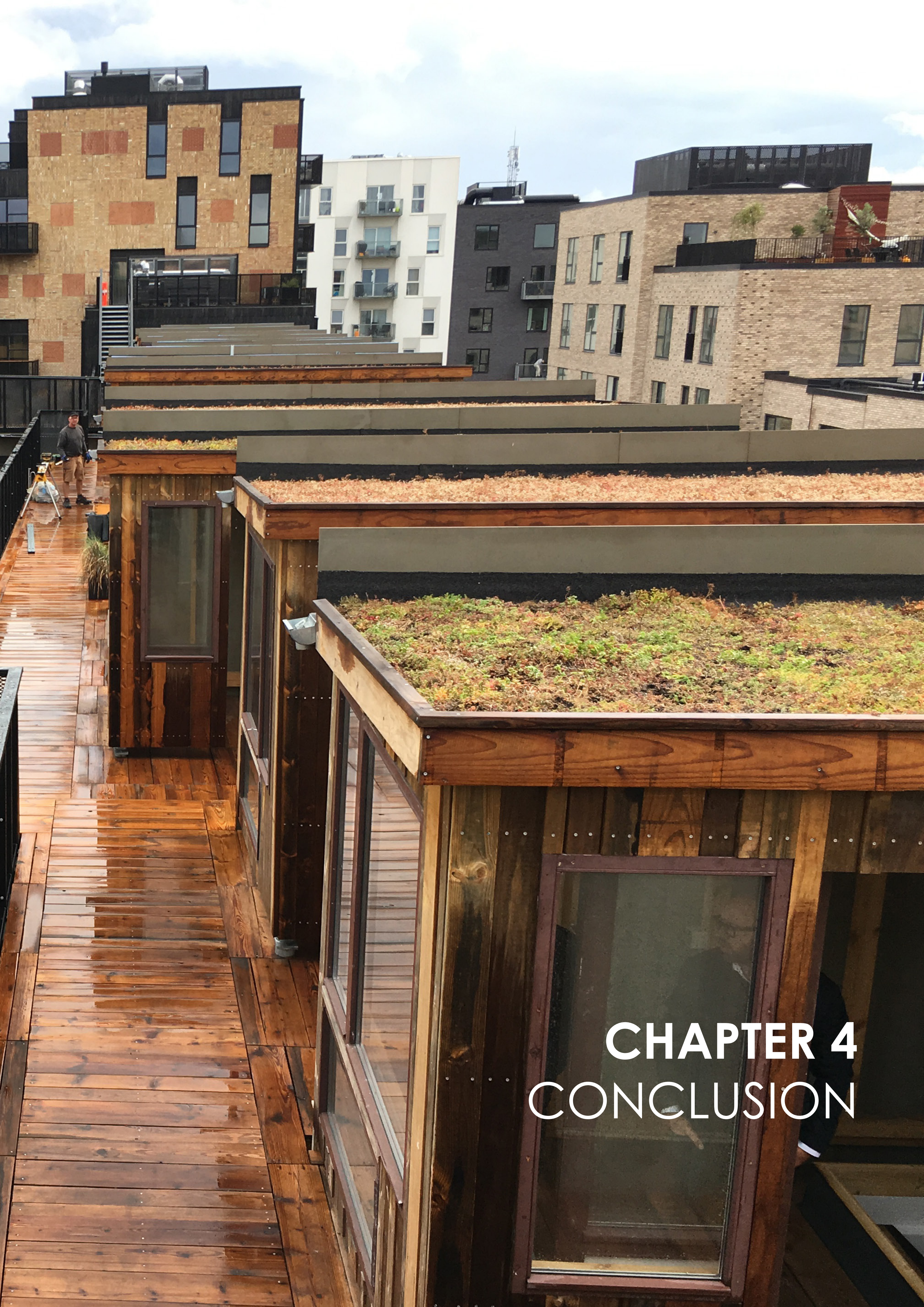
This section has presented the results of multiple energy calculations for Upcycle Studios and the Resource Rows with and without the implementation of energy-enhancing initiatives. To understand the significance of the initiatives, a benchmark building using only "standard" building methods was used as benchmark for both cases.

The analysis clarifies that implementing energy-enhancing initiatives both reduces the primary energy need and the need of using solar cells to obey the energy demand for low energy buildings stated in the building regulations. In both cases, the use of windows with a low U-value, high building airtightness, heat pumps with buffer tanks and a low temperature heating system, is compared to normal windows, normal airtightness and traditional district heating. Furthermore, the analysis investigates the effect of applying heavy and exposed structures for Upcycle Studios versus lighter building structures.

For Upcycle Studios the need of primary energy was reduced from 38.7 to 29.7 kWh/m2/year by implementing the energy-enhancing initiatives. This reduced the area of necessary solar cells from 14 to 7 m2 per dwelling.

For the Resource Rows the need of primary energy was a bit lower for the benchmark building, but it was still possible to reduce the energy consumption from 28.8 to 20.8 kWh/m^2/year by implementing the energy-enhancing initiatives. The area of necessary solar cells was reduced from 5 to 0.5 m^2 per dwelling. However, to reduce the energy consumption for building operation even more, a total of respectively 13 m^2 and 1 m^2 solar cells were implemented at Upcycle Studios and the Resource Rows. The need of primary energy hereby ended at 11.9 kWh/m^2 year for Upcycle Studios and 18.6 kWh/m^2 year for the Resource Rows.

The reduction in need of primary energy not only has a positive effect on the operational cost, but also on the environment. By implementing the energy-enhancing initiatives, the total CO_2 emission from the two buildings was also reduced. For Upcycle Studios the CO_2 emission at building operation was reduced 72 % from 4.7 to 1.3 kg CO_2eq/m^2 per year and for the Resource Rows the CO_2 emission at building operation was reduced 48 % from 4.0 to 2.1 kg CO_2eq/m^2 per year.



CHAPTER 4
CONCLUSION

CONCLUSION

MAIN FINDINGS

Summarizing the analysis presented in prior chapters of this report, it can be concluded that in spite of first-time production challenges and only replacing parts of the building components, the upcycling initiatives achieved significant environmental impacts. The project learnings indicate that the solutions could be expected to achieve even stronger results in a next iteration of projects.

EMBODIED CO_2

In Upcycle Studios, upcycling 69 % of the building mass made it possible to realise a CO_2 reduction of 32% taking only materials into account.

For the Resource Rows, 9 % of the building mass was upcycled leading to a CO_2 reduction of 12 %, again taking only materials into account. On top of the realised CO_2 reductions at Upcycle Studios and the Resource Rows, this study shows that there is potential for even higher CO_2 reductions when optimising the developed products.

ENERGY EFFICIENCY

Besides upcycling materials, effective energy initiatives have also contributed to a large reduction of CO_2 from operations. For Upcycle Studios the reduction of CO_2 from building operations was 72 % compared to benchmark, achieving 1.3 kg $CO_{2\text{-eq}}/m^2$ per year compared to 4.7 kg. For the Resource Rows the CO_2 emissions from building operations was reduced 48 % from 4.0 kg to 2.1 kg $CO_{2\text{-eq}}/m^2$ per year.

WASTE MINIMISATION

Putting waste material to use, thus optimising resource efficiency and minimising the projects' upcycling initiatives decreased the need for virgin materials. Across Upcycle Studios and the Resource Rows no less than 1,377 tonnes of waste was put into use giving the materials new life while adding value to the building projects.

THE IMPACT OF BENCHMARK

As with all other LCA and LCC calculations the choice of benchmark highly impacts the final results. For this reason we have chosen to include several benchmarks on product and building level creating transparency and insight into potential savings in future sustainable building projects.

On building level we compare Resource Rows and Upcycle Studios to 12 other life cycle analyses on row houses. Here we find a performance of 6.64 kg CO_2/m^2/year in Resource Rows and 8.08 kg CO_2/m^2/year in Upcycle Studios ranking no. 2 and 3 out of the 12 benchmarks conducted by SBi.

ECONOMIC IMPACT

While LCCs at building level were favourable compared to benchmark, looking at product level of upcycled products it is clear that some upcycling products were economically competitive in spite of first-time production challenges while others will need to be further developed or implemented with larger scale in order to achieve cost competitiveness.

Due to experience gained across the value chain, the costs for delivering optimised upcycle products can and will lower in next productions based on;

1. Less precautionary principles in terms of quality and performance,
2. Higher level of quantity lowering the effects of high fixed costs on product/$m^{2/3}$ and
3. Higher efficiency based on optimised processes cutting costs on harvesting, production and mounting.

All optimisations are based on gaining experience not only for the material supplier, but as important for the developer, contractor and advising engineer - making it easier to obtain and increase positive impacts across the value chain and in new building projects.

UPCYCLE STUDIOS

65 tonnes CO_2 -eq
45 % saving

914 tonnes waste in total

488 kg CO_2 -eq per year
53 % saving

RESOURCE ROWS

20 tonnes CO_2 -eq
29 % saving

463 tonnes waste in total

270 kg CO_2 -eq per year
39 % saving

TOTAL

85 tonnes CO_2 -eq

1377 tonnes waste in total

758 kg CO_2 -eq per year

Upcycle product or material	kg CO_2-eq/unit	% CO_2 saved	Total waste saved
Upcycle Brick Wall	49 kg CO_2-eq/m^2	38%	459 tonnes
Upcycle Windows	380 kg CO_2-eq/m^2	87%	7 tonnes
Upcycle Window Panes**	17 kg CO_2-eq/m^2	32%	-
Upcycle Concrete	28 kg CO_2-eq/m^3*	5-8 %	904 tonnes
Upcycle Concrete Aggregate**	9 kg CO_2-eq/m^3	84%	-
All Wood Products	127 kg CO_2-eq/m^3****	44-88%	7 tonnes

*Best case

** Upcycle material

*** Compared to new bricks

**** Average saving of all wood products

MORTEN BIRKVED

REFLECTION ON LCA

MORTEN BIRKVED
Professor MSO
SDU Livscyckluscenter
Institut for Kemi-, Bio- og Miljøteknologi, SDU

Overall challenges of environmental assessment of circular building materials.

Building materials developed for a future circular economy should inherently be assessed in a way where the environmental assessment considers the economic model (i.e. circular economic oriented) that these materials are intended to fit into.

Unfortunately, the situation is that building materials are evaluated using data and modeling approaches intended for a linear economic model which e.g. is reflected by the data typically used in LCAs of buildings. Building LCAs are most often based on an inventory system model called "cut-off" (i.e. when data from the Swiss database Ecoinvent are used, which is the case here). One of the main assumptions in the "cut-off" model is that used materials/components that are recycled are available environmentally “free” when recycled. This obviously means that the first user of the produced material/component bears the entire burden and, therefore, all subsequent uses are "environmentally impact free"/burden free. This basic assumption reflects, of course, a subjective angle induced in the data/system model by the data provider.

The cut-off system model is probably intended to motivate for recycling by giving materials based on recycled products an environmental advantage as well as facilitating the use of these data (as making the production system models needed for the assessments much simpler). Whether a simplified system like the cut-off model reflects the actual conditions and all relevant aspects on circular economic models for building components/materials is questionable as there probably are several other relevant perspectives on how the burden of the primary use of a material should be distributed down in the circular value chain (i.e. one could imagine that the second and perhaps third user must also carry a part of the environmental impact from the original production together with the first user).

In the assessments presented in this report, Lendager UP has used the “cut-off” inventory system model which follows current/typical practice for building related LCAs. This also makes it possible to compare the results on the environmental impacts of the building components with other assessments of building products/components/materials.

The system models for concrete, windows, and bricks presented in this report, are all set up in OpenLCA which, in contrast to e.g. LCAbyg offered by the Danish Building Research Institute (SBi), allows the assessor to create complete product system models themselves and thereby assess new/alternative building materials/components. In LCAbyg, the user has a very limited opportunity to model and introduce new materials and components. LCAbyg was therefore opted less usable as product system modeling software in this project when modelling product systems for upcycled building products.

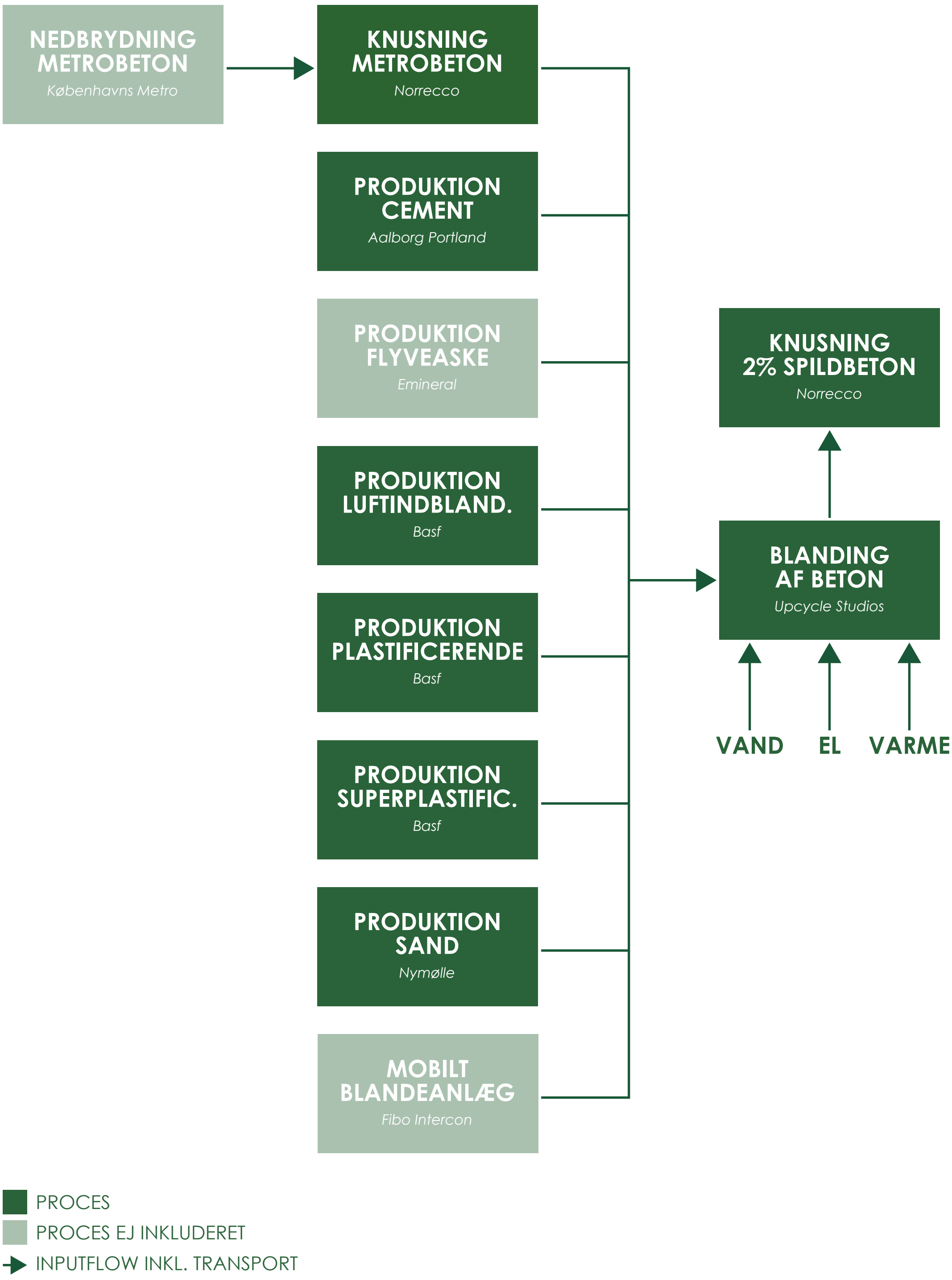
In addition, OpenLCA makes it possible to use several different system boundary models and, in contrast to LCAbyg, it hence allows for exploring other ways of distributing the environmental burden from the original production over several use cycles.

An alternative distribution (compared to the current cut-off system model) of the environmental burden from the original production has not been investigated in this project. However, it seems relevant to reevaluate which system models can catalyze the Danish construction industry's transition into circular economy by providing the most fair and accurate decision support on the environmental performance of building materials, building components and entire buildings.

APPENDIX INDEX

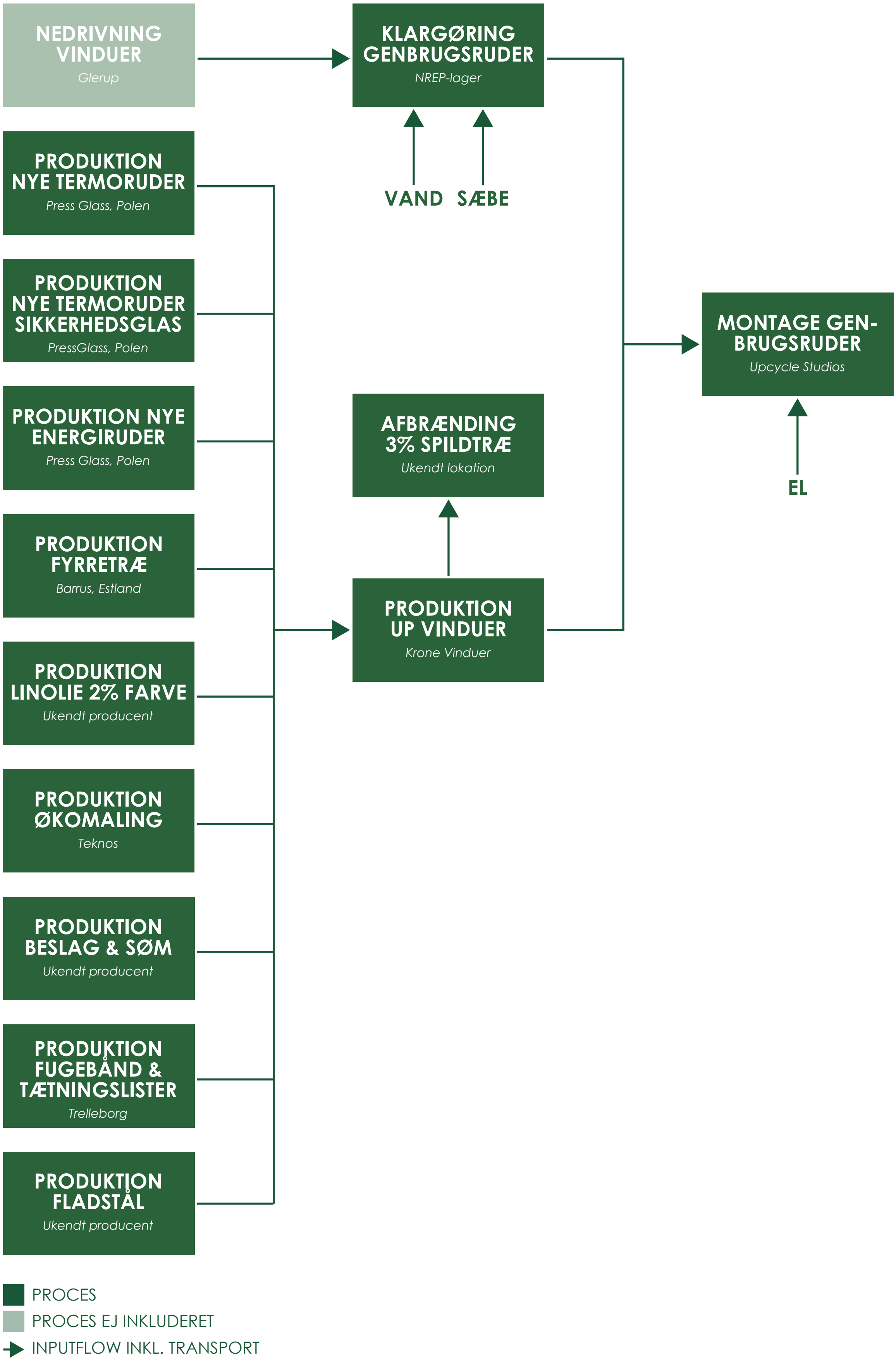
APPENDIX I

FLOW CHART OF THE INCLUDED PROCESSES IN THE LCA OF UPCYCLE CONCRETE



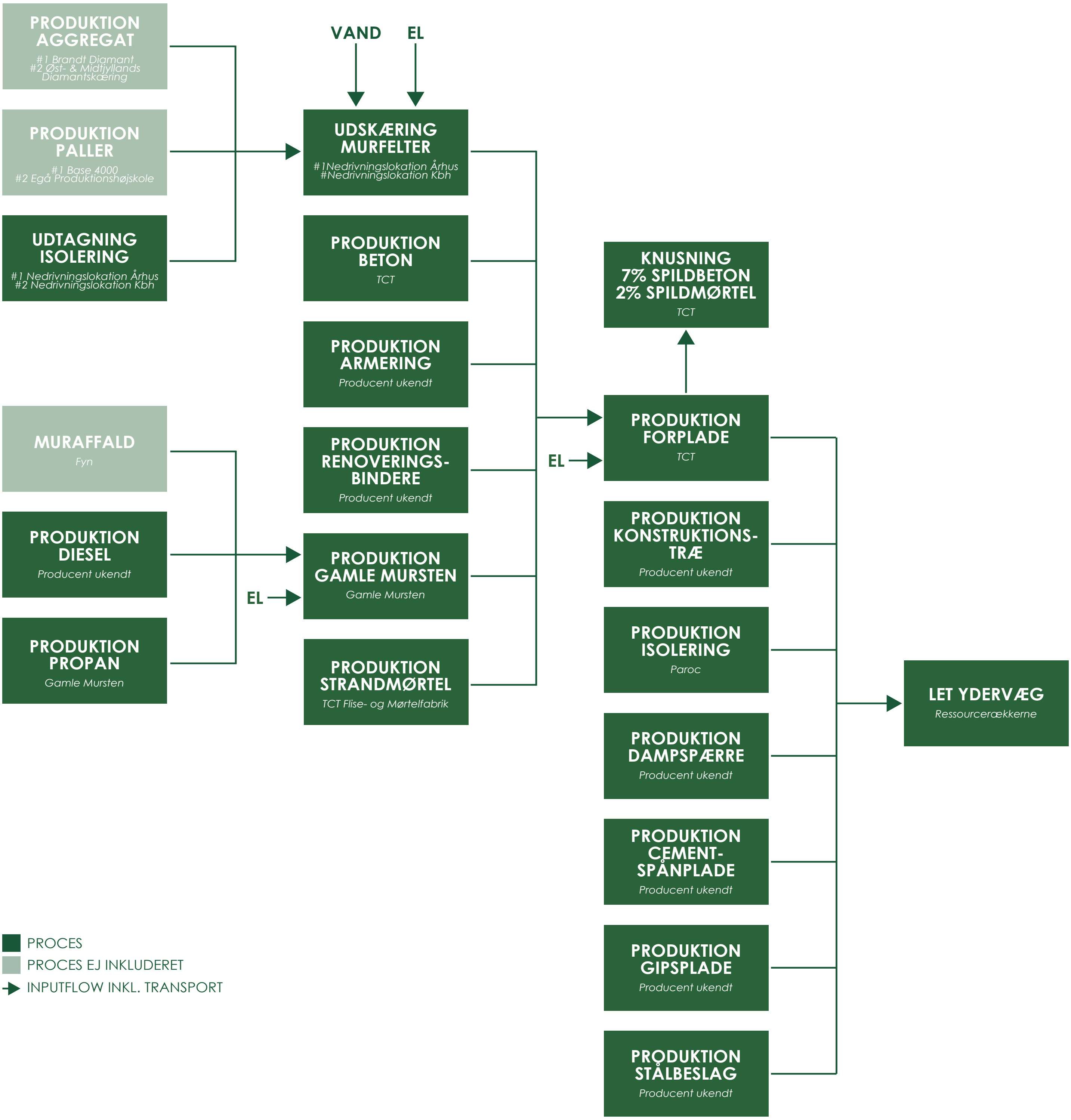
APPENDIX II

FLOW CHART OF THE INCLUDED PROCESSES IN THE LCA OF UPCYCLE WINDOWS



APPENDIX III

FLOW CHART OF THE INCLUDED PROCESSES IN THE LCA OF UPCYLCE BRICK WALL



APPENDIX IV

LCC BUILD REPORT OF UPCYCLE STUDIOS

Upcycle Studios

Denne rapport er udfærdiget i LCCbyg 2.2.52

LCC af et rækkehus i Upcycle Studios

Alternativer

Upcycle Studios	Upcycle Studios, ét rækkehus

Antagelser

Generelle beregningsforudsætninger	50 år
Kalkulationsrente	fra og med år 1: 5,00 % fra og med år 36: 5,00 % fra og med år 71: 5,00 %
Prisudvikling generelt	2,00 %
Prisudvikling for drikkevand	4,00 %
Prisudvikling for spildevand	7,00 %
Prisudvikling for energi generelt	4,00 %
Prisudvikling for fjernvarme	3,00 %
Prisudvikling for gas	1,50 %
Prisudvikling for flydende brændsel	4,00 %
Prisudvikling for fast brændsel	3,00 %
Prisudvikling for el	3,50 %
Prisudvikling for skatter og afgifter	2,00 %
Prisudvikling for forsikring	5,00 %
Prisudvikling for administration	2,00 %

Konklusion

Nøgletallene for analysen er opgjort nedenfor. Nøgletallene for analysen viser, at:

- De laveste anskaffelsesomkostninger er på ***2.956.167*** kr. for ***Upcycle Studios***
- Den laveste nutidsværdi er på ***5.001.500*** kr. for ***Upcycle Studios***
- Den laveste årlige omkostning per kvadratmeter på ***1.405*** kr/m2/år opnås for ***Upcycle Studios***
- Det foretrukne alternativ er ***Ikke valgt***.

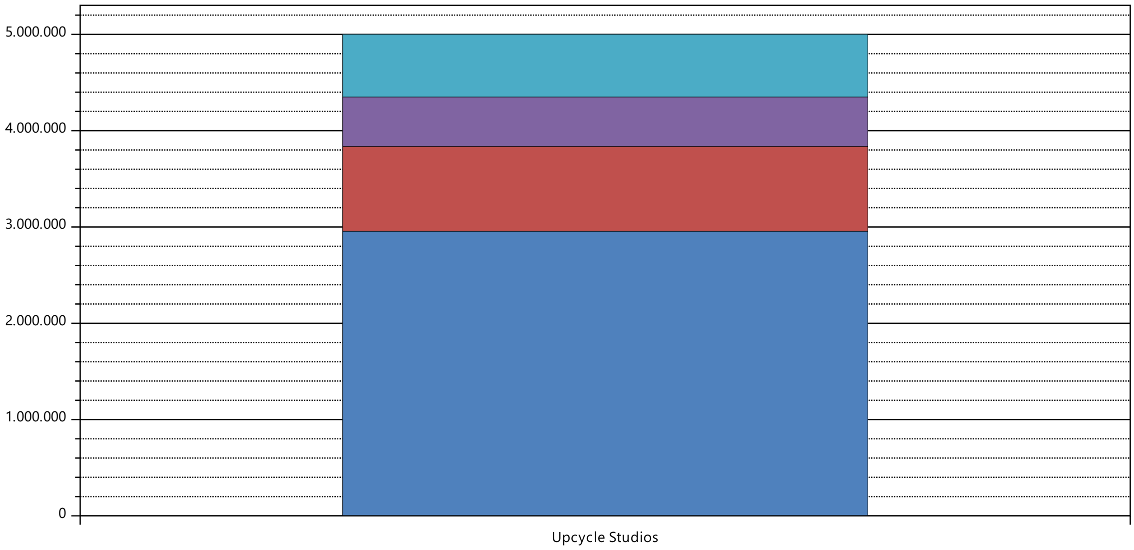
Nutidsværdi

	Upcycle Studios	**%**
Anskaffelse	2.956.167	59
Bygning (drift og vedligehold)	879.614	18
Inventar (drift og vedligehold)	0	0
Forvaltning	0	0
Forsyning	514.453	10
Renhold	651.266	13
Nutidsværdi	**5.001.500**	
Nutidsværdi per m2	**25.649**	
Årsomkostning (kr/m2/år)	**1.405**	

LCC BUILD REPORT OF UPCYCLE STUDIOS

Hovedomkostningsgrupper

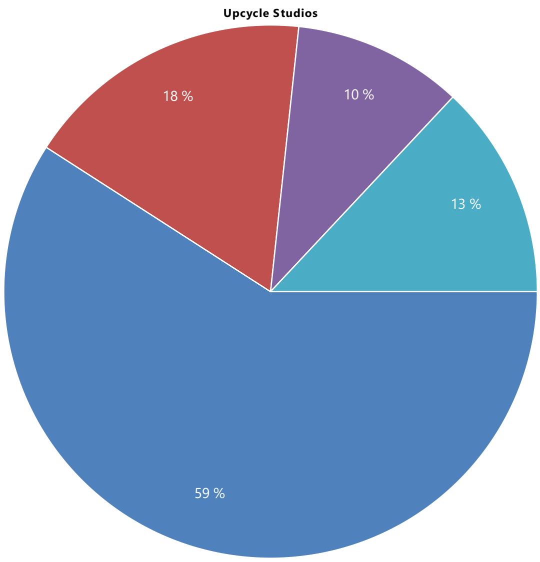
Stavdiagram med alternativers hovedomkostninger



Farvekoder Anskaffelse | Bygning (drift og vedligehold) | Inventar (drift og vedligehold) | Forvaltning | Forsyning | Renhold

Hovedomkostningsgrupper

Figurerne nedenfor viser, hvordan nutidsværdien for det eller de valgte alternativer fordeler sig på hovedomkostningsgrupper.
Cirkeldiagrammerne viser ikke eventuelle indtægter.



Farvekoder Anskaffelse | Bygning (drift og vedligehold) | Inventar (drift og vedligehold) | Forvaltning | Forsyning | Renhold

LCC BUILD REPORT OF UPCYCLE STUDIOS

Hovedomkostningsgrupper i tal

	Upcycle Studios	%
Anskaffelse	**2.956.167**	**59**
Grund, rådgivning og bygherre	1.261.593	25,22
Bygningsbasis	164.531	3,29
Primære bygningsdele	770.109	15,40
Kompletterende bygningsdele	329.639	6,59
Overfladebygningsdele	127.941	2,56
VVS-anlæg	168.453	3,37
El- og mekaniske anlæg	133.901	2,68
Inventar og udstyr	0	0,00
Bygning (drift og vedligehold)	**879.614**	**18**
Bygningsbasis	21.405	0,43
Primære bygningsdele	205.389	4,11
Kompletterende bygningsdele	229.096	4,58
Overfladebygningsdele	90.638	1,81
VVS-anlæg	260.732	5,21
El- og mekaniske anlæg	72.354	1,45
Inventar (drift og vedligehold)	**0**	**0**
Inventar og udstyr	0	0,00
Forvaltning	**0**	**0**
Forvaltning	0	0,00
Forsyning	**514.453**	**10**
Forsyning	514.453	10,29
Renhold	**651.266**	**13**
Terræn	3.724	0,07
Bygninger, udvendigt	79.620	1,59
Indendørsarealer og rum	567.922	11,36

Hovedomkostningsgrupper i tal med undergrupper

	Upcycle Studios	%
Anskaffelse	**2.956.167**	**59**
Grund, rådgivning og bygherre	1.261.593	25,22
Byggegrund	1.048.299	20,96
Rådgiverhonorarer	213.294	4,26
Bygherreomkostninger	0	0,00
Bygningsbasis	164.531	3,29
Bygningsbasis, terræn	0	0,00
Fundamenter	36.764	0,74
Terrændæk	127.767	2,55
Primære bygningsdele	770.109	15,40
Terræn	1.296	0,03
Ydervægge	157.459	3,15
Indervægge	255.354	5,11
Dæk	170.760	3,41
Trapper og ramper	104.400	2,09
Bærende konstruktioner	12.800	0,26
Altaner og altangange	0	0,00
Tage	68.040	1,36
Øvrige primære bygningsdele, bygning	0	0,00
Kompletterende bygningsdele	329.639	6,59
Terræn, komplettering	0	0,00
Ydervægge, komplettering	264.472	5,29
Indervægge, komplettering	27.500	0,55
Dæk, komplettering	0	0,00
Trapper og ramper, komplettering	0	0,00
Lofter, komplettering	0	0,00
Altaner, komplettering	16.785	0,34
Tage, komplettering	20.882	0,42
Kompletterende bygningsdele bygning, øvrige	0	0,00
Overfladebygningsdele	127.941	2,56
Belægninger, terræn	39.358	0,79

LCC BUILD REPORT OF UPCYCLE STUDIOS

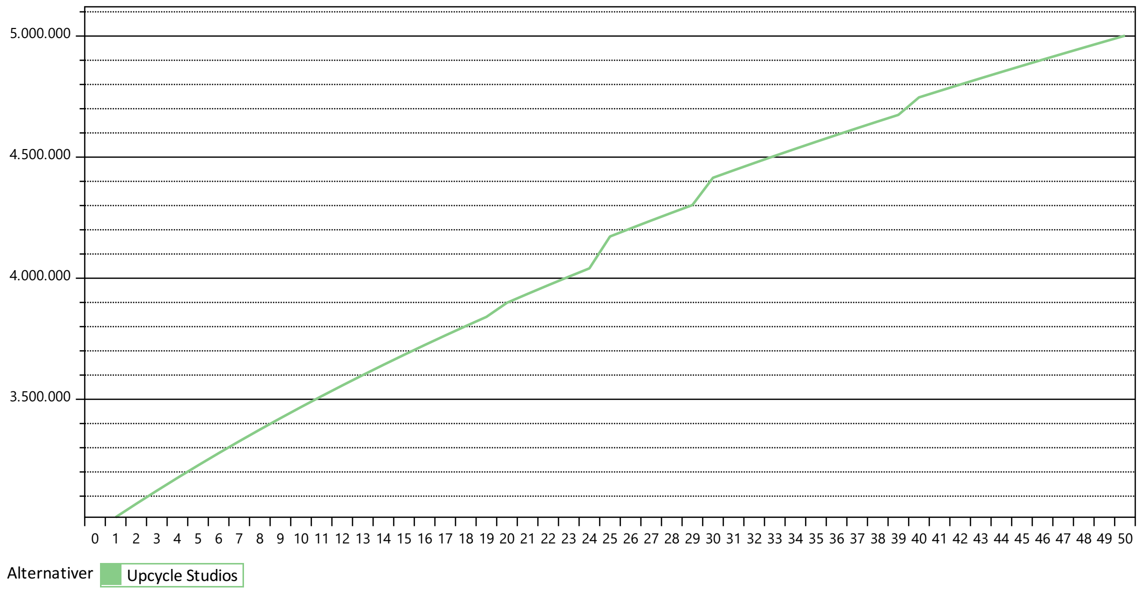
Udvendige vægoverflader	0	0,00
Indvendige vægoverflader	5.640	0,11
Dæk og gulve, overflader	67.311	1,35
Trapper og ramper, overflader	0	0,00
Lofter, overflader	0	0,00
Altaner, overflader	0	0,00
Tage, overflader	15.633	0,31
Øvrige overflader, bygning	0	0,00
VVS-anlæg	168.453	3,37
VVS-anlæg, terræn	3.722	0,07
Affald	0	0,00
Afløb og sanitet	27.039	0,54
Vand (koldt/varmt vand, behandlet vand)	5.238	0,10
Luftarter (gas, trykluft, vakuum, damp)	0	0,00
Køling	0	0,00
Varme (vand, damp, kondens, hedtolie)	81.370	1,63
Ventilationsanlæg	49.135	0,98
VVS-anlæg, bygning, øvrige	1.949	0,04
El- og mekaniske anlæg	133.901	2,68
El- og mekaniske anlæg, terræn	4.322	0,09
Højspændingsanlæg	25.168	0,50
Lavspændingsanlæg	94.185	1,88
Elektronik og svagstrøm	2.374	0,05
Transportanlæg	0	0,00
Mekaniske anlæg, øvrige	0	0,00
Elektriske anlæg, øvrige	7.852	0,16
Inventar og udstyr	0	0,00
Inventar og udstyr	0	0,00
Bygning (drift og vedligehold)	**879.614**	**18**
Bygningsbasis	21.405	0,43
Bygningsbasis, terræn	0	0,00
Fundamenter	4.783	0,10
Terrændæk	16.622	0,33
Primære bygningsdele	205.389	4,11
Terræn	337	0,01
Ydervægge	45.979	0,92
Indervægge	66.442	1,33
Dæk	44.431	0,89
Trapper og ramper	27.165	0,54
Bærende konstruktioner	3.331	0,07
Altaner og altangange	0	0,00
Tage	17.704	0,35
Øvrige primære bygningsdele, bygning	0	0,00
Kompletterende bygningsdele	229.096	4,58
Terræn, komplettering	0	0,00
Ydervægge, komplettering	203.992	4,08
Indervægge, komplettering	7.155	0,14
Dæk, komplettering	0	0,00
Trapper og ramper, komplettering	0	0,00
Lofter, komplettering	0	0,00
Altaner, komplettering	4.367	0,09
Tage, komplettering	13.581	0,27
Kompletterende bygningsdele bygning, øvrige	0	0,00
Overfladebygningsdele	90.638	1,81
Belægninger, terræn	30.792	0,62
Udvendige vægoverflader	0	0,00
Indvendige vægoverflader	3.678	0,07
Dæk og gulve, overflader	35.028	0,70
Trapper og ramper, overflader	0	0,00
Lofter, overflader	0	0,00
Altaner, overflader	0	0,00
Tage, overflader	21.140	0,42
Øvrige overflader, bygning	0	0,00
VVS-anlæg	260.732	5,21

LCC BUILD REPORT OF UPCYCLE STUDIOS

VVS-anlæg, terræn	484	0,01
Affald	0	0,00
Afløb og sanitet	29.398	0,59
Vand (koldt/varmt vand, behandlet vand)	4.259	0,09
Luftarter (gas, trykluft, vakuum, damp)	0	0,00
Køling	0	0,00
Varme (vand, damp, kondens, hedtolie)	139.130	2,78
Ventilationsanlæg	87.460	1,75
VVS-anlæg, bygning, øvrige	0	0,00
El- og mekaniske anlæg	72.354	1,45
El- og mekaniske anlæg, terræn	2.819	0,06
Højspændingsanlæg	19.734	0,39
Lavspændingsanlæg	45.643	0,91
Elektronik og svagstrøm	3.210	0,06
Transportanlæg	0	0,00
Mekaniske anlæg, øvrige	0	0,00
Elektriske anlæg, øvrige	948	0,02
Inventar (drift og vedligehold)	**0**	**0**
Inventar og udstyr	0	0,00
Inventar og udstyr	0	0,00
Forvaltning	**0**	**0**
Forvaltning	0	0,00
Skatter	0	0,00
Forsikringer	0	0,00
Administration	0	0,00
Forsyning	**514.453**	**10**
Forsyning	514.453	10,29
Vand	436.266	8,72
Varme	0	0,00
Electricitet	78.187	1,56
Renhold	**651.266**	**13**
Terræn	3.724	0,07
Udeareal	3.724	0,07
Bygninger, udvendigt	79.620	1,59
Klimaskærm	79.620	1,59
Indendørsarealer og rum	567.922	11,36
Rum	567.922	11,36

Hovedomkostningsgrupper

Figurerne nedenfor viser, hvordan nutidsværdien for det eller de valgte alternativer fordeler sig på hovedomkostningsgrupper.



side 5/5

APPENDIX V

LCC BUILD REPORT OF UPCYCLE STUDIOS BENCHMARK

Upcycle Studios

Denne rapport er udfærdiget i LCCbyg 2.2.52

LCC af et rækkehus i Upcycle Studios

Alternativer

Upcycle Studios	Upcycle Studios, ét rækkehus

Antagelser

Generelle beregningsforudsætninger	50 år
Kalkulationsrente	fra og med år 1: 5,00 % fra og med år 36: 5,00 % fra og med år 71: 5,00 %
Prisudvikling generelt	2,00 %
Prisudvikling for drikkevand	4,00 %
Prisudvikling for spildevand	7,00 %
Prisudvikling for energi generelt	4,00 %
Prisudvikling for fjernvarme	3,00 %
Prisudvikling for gas	1,50 %
Prisudvikling for flydende brændsel	4,00 %
Prisudvikling for fast brændsel	3,00 %
Prisudvikling for el	3,50 %
Prisudvikling for skatter og afgifter	2,00 %
Prisudvikling for forsikring	5,00 %
Prisudvikling for administration	2,00 %

Konklusion

Nøgletallene for analysen er opgjort nedenfor. Nøgletallene for analysen viser, at:

- De laveste anskaffelsesomkostninger er på ***3.159.167*** kr. for ***Upcycle Studios***
- Den laveste nutidsværdi er på ***5.226.637*** kr. for ***Upcycle Studios***
- Den laveste årlige omkostning per kvadratmeter på ***1.467*** kr/m2/år opnås for ***Upcycle Studios***
- Det foretrukne alternativ er ***Ikke valgt***.

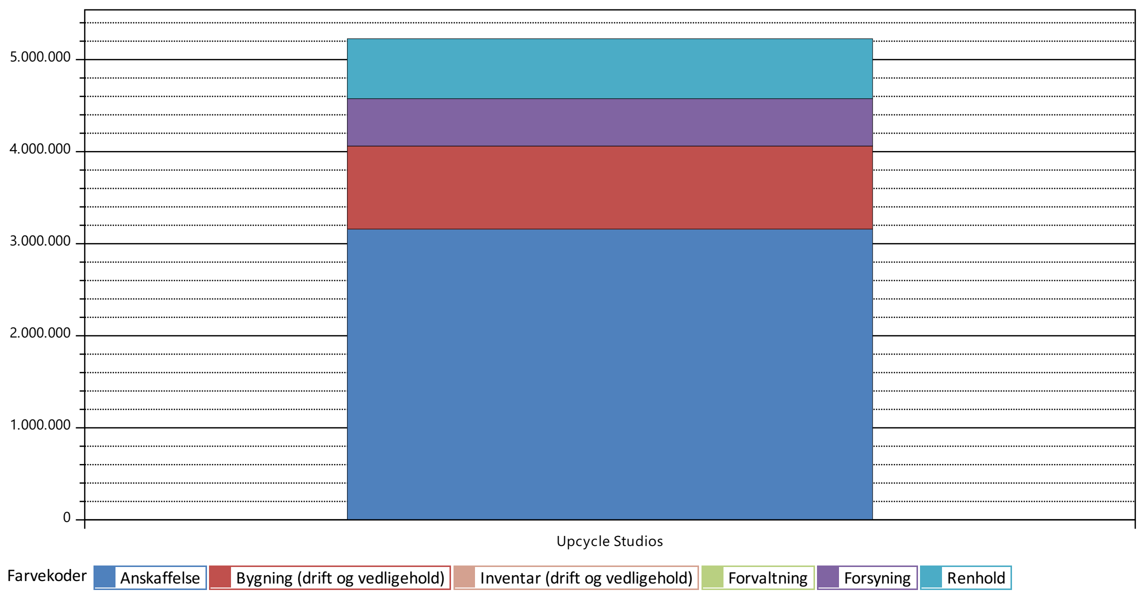
Nutidsværdi

	Upcycle Studios	**%**
Anskaffelse	3.159.167	60
Bygning (drift og vedligehold)	901.750	17
Inventar (drift og vedligehold)	0	0
Forvaltning	0	0
Forsyning	514.453	10
Renhold	651.266	12
Nutidsværdi	**5.226.637**	
Nutidsværdi per m2	**26.787**	
Årsomkostning (kr/m2/år)	**1.467**	

LCC BUILD REPORT OF UPCYCLE STUDIOS BENCHMARK

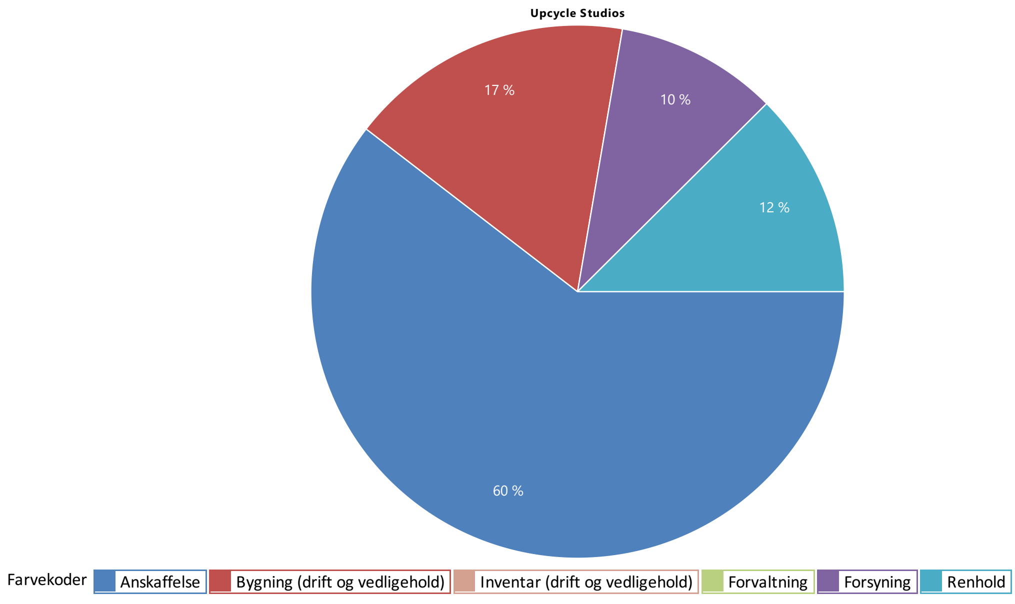
Hovedomkostningsgrupper

Stavdiagram med alternativers hovedomkostninger



Hovedomkostningsgrupper

Figurerne nedenfor viser, hvordan nutidsværdien for det eller de valgte alternativer fordeler sig på hovedomkostningsgrupper.
Cirkeldiagrammerne viser ikke eventuelle indtægter.



LCC BUILD REPORT OF UPCYCLE STUDIOS BENCHMARK

Hovedomkostningsgrupper i tal

	Upcycle Studios	%
Anskaffelse	**3.159.167**	**60**
Grund, rådgivning og bygherre	1.261.593	24,14
Bygningsbasis	182.435	3,49
Primære bygningsdele	941.687	18,02
Kompletterende bygningsdele	326.572	6,25
Overfladebygningsdele	142.590	2,73
VVS-anlæg	168.453	3,22
El- og mekaniske anlæg	135.837	2,60
Inventar og udstyr	0	0,00
Bygning (drift og vedligehold)	**901.750**	**17**
Bygningsbasis	23.734	0,45
Primære bygningsdele	254.631	4,87
Kompletterende bygningsdele	190.004	3,64
Overfladebygningsdele	98.777	1,89
VVS-anlæg	260.732	4,99
El- og mekaniske anlæg	73.872	1,41
Inventar (drift og vedligehold)	**0**	**0**
Inventar og udstyr	0	0,00
Forvaltning	**0**	**0**
Forvaltning	0	0,00
Forsyning	**514.453**	**10**
Forsyning	514.453	9,84
Renhold	**651.266**	**12**
Terræn	3.724	0,07
Bygninger, udvendigt	79.620	1,52
Indendørsarealer og rum	567.922	10,87

Hovedomkostningsgrupper i tal med undergrupper

	Upcycle Studios	%
Anskaffelse	**3.159.167**	**60**
Grund, rådgivning og bygherre	1.261.593	24,14
Byggegrund	1.048.300	20,06
Rådgiverhonorarer	213.293	4,08
Bygherreomkostninger	0	0,00
Bygningsbasis	182.435	3,49
Bygningsbasis, terræn	0	0,00
Fundamenter	36.764	0,70
Terrændæk	145.671	2,79
Primære bygningsdele	941.687	18,02
Terræn	1.296	0,02
Ydervægge	260.585	4,99
Indervægge	300.734	5,75
Dæk	191.882	3,67
Trapper og ramper	106.350	2,03
Bærende konstruktioner	12.800	0,24
Altaner og altangange	0	0,00
Tage	68.040	1,30
Øvrige primære bygningsdele, bygning	0	0,00
Kompletterende bygningsdele	326.572	6,25
Terræn, komplettering	0	0,00
Ydervægge, komplettering	261.405	5,00
Indervægge, komplettering	27.500	0,53
Dæk, komplettering	0	0,00
Trapper og ramper, komplettering	0	0,00
Lofter, komplettering	0	0,00
Altaner, komplettering	16.785	0,32
Tage, komplettering	20.882	0,40
Kompletterende bygningsdele bygning, øvrige	0	0,00
Overfladebygningsdele	142.590	2,73
Belægninger, terræn	39.358	0,75

LCC BUILD REPORT OF UPCYCLE STUDIOS BENCHMARK

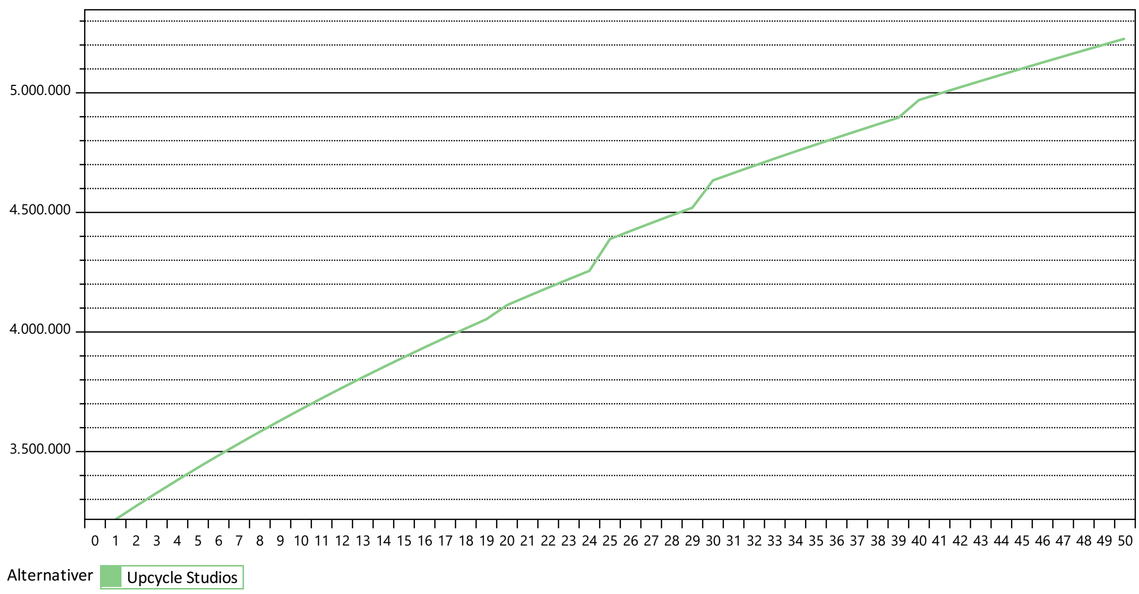
Udvendige vægoverflader	0	0,00
Indvendige vægoverflader	9.552	0,18
Dæk og gulve, overflader	78.048	1,49
Trapper og ramper, overflader	0	0,00
Lofter, overflader	0	0,00
Altaner, overflader	0	0,00
Tage, overflader	15.633	0,30
Øvrige overflader, bygning	0	0,00
VVS-anlæg	168.453	3,22
VVS-anlæg, terræn	3.722	0,07
Affald	0	0,00
Afløb og sanitet	27.039	0,52
Vand (koldt/varmt vand, behandlet vand)	5.238	0,10
Luftarter (gas, trykluft, vakuum, damp)	0	0,00
Køling	0	0,00
Varme (vand, damp, kondens, hedtolie)	81.370	1,56
Ventilationsanlæg	49.135	0,94
VVS-anlæg, bygning, øvrige	1.949	0,04
El- og mekaniske anlæg	135.837	2,60
El- og mekaniske anlæg, terræn	4.322	0,08
Højspændingsanlæg	27.104	0,52
Lavspændingsanlæg	94.185	1,80
Elektronik og svagstrøm	2.374	0,05
Transportanlæg	0	0,00
Mekaniske anlæg, øvrige	0	0,00
Elektriske anlæg, øvrige	7.852	0,15
Inventar og udstyr	0	0,00
Inventar og udstyr	0	0,00
Bygning (drift og vedligehold)	**901.750**	**17**
Bygningsbasis	23.734	0,45
Bygningsbasis, terræn	0	0,00
Fundamenter	4.783	0,09
Terrændæk	18.952	0,36
Primære bygningsdele	254.631	4,87
Terræn	337	0,01
Ydervægge	77.411	1,48
Indervægge	78.250	1,50
Dæk	49.927	0,96
Trapper og ramper	27.672	0,53
Bærende konstruktioner	3.331	0,06
Altaner og altangange	0	0,00
Tage	17.704	0,34
Øvrige primære bygningsdele, bygning	0	0,00
Kompletterende bygningsdele	190.004	3,64
Terræn, komplettering	0	0,00
Ydervægge, komplettering	164.900	3,16
Indervægge, komplettering	7.155	0,14
Dæk, komplettering	0	0,00
Trapper og ramper, komplettering	0	0,00
Lofter, komplettering	0	0,00
Altaner, komplettering	4.367	0,08
Tage, komplettering	13.581	0,26
Kompletterende bygningsdele bygning, øvrige	0	0,00
Overfladebygningsdele	98.777	1,89
Belægninger, terræn	30.792	0,59
Udvendige vægoverflader	0	0,00
Indvendige vægoverflader	6.231	0,12
Dæk og gulve, overflader	40.615	0,78
Trapper og ramper, overflader	0	0,00
Lofter, overflader	0	0,00
Altaner, overflader	0	0,00
Tage, overflader	21.140	0,40
Øvrige overflader, bygning	0	0,00
VVS-anlæg	260.732	4,99

side 4/5

VVS-anlæg, terræn	484	0,01
Affald	0	0,00
Afløb og sanitet	29.398	0,56
Vand (koldt/varmt vand, behandlet vand)	4.259	0,08
Luftarter (gas, trykluft, vakuum, damp)	0	0,00
Køling	0	0,00
Varme (vand, damp, kondens, hedtolie)	139.130	2,66
Ventilationsanlæg	87.460	1,67
VVS-anlæg, bygning, øvrige	0	0,00
El- og mekaniske anlæg	73.872	1,41
El- og mekaniske anlæg, terræn	2.819	0,05
Højspændingsanlæg	21.252	0,41
Lavspændingsanlæg	45.643	0,87
Elektronik og svagstrøm	3.210	0,06
Transportanlæg	0	0,00
Mekaniske anlæg, øvrige	0	0,00
Elektriske anlæg, øvrige	948	0,02
Inventar (drift og vedligehold)	**0**	**0**
Inventar og udstyr	0	0,00
Inventar og udstyr	0	0,00
Forvaltning	**0**	**0**
Forvaltning	0	0,00
Skatter	0	0,00
Forsikringer	0	0,00
Administration	0	0,00
Forsyning	**514.453**	**10**
Forsyning	514.453	9,84
Vand	436.266	8,35
Varme	0	0,00
Electricitet	78.187	1,50
Renhold	**651.266**	**12**
Terræn	3.724	0,07
Udeareal	3.724	0,07
Bygninger, udvendigt	79.620	1,52
Klimaskærm	79.620	1,52
Indendørsarealer og rum	567.922	10,87
Rum	567.922	10,87

Hovedomkostningsgrupper

Figurerne nedenfor viser, hvordan nutidsværdien for det eller de valgte alternativer fordeler sig på hovedomkostningsgrupper.



APPENDIX VI

LCC BUILD REPORT OF THE RESOURCE ROWS

LLC Ressource Rækkerne

Denne rapport er udfærdiget i LCCbyg 2.2.52

Livscyklus-omkostninger resultater af et ressource Rækkerne.

Resultaterne, der udtrykkes, henviser til udgifterne til 1 hus på 150 m2.

Omkostningerne er opdelt i tre kategorier:

- Materialer

- Installationer (såsom elektricitet, maling og ventilation).

- Rådgivnings- og konsulentgebyrer.

For de to sidste kategorier har vi de samlede omkostninger til Resource House-projektet; vi har estimeret forholdet for 1 hus.

Alternativer

Ressource Rows	Building Life Cycle Costs

Antagelser

Generelle beregningsforudsætninger	50 år
Kalkulationsrente	fra og med år 1: 5,00 % fra og med år 36: 5,00 % fra og med år 71: 5,00 %
Prisudvikling generelt	2,00 %
Prisudvikling for drikkevand	4,00 %
Prisudvikling for spildevand	7,00 %
Prisudvikling for energi generelt	4,00 %
Prisudvikling for fjernvarme	3,00 %
Prisudvikling for gas	1,50 %
Prisudvikling for flydende brændsel	4,00 %
Prisudvikling for fast brændsel	3,00 %
Prisudvikling for el	3,50 %
Prisudvikling for skatter og afgifter	2,00 %
Prisudvikling for forsikring	5,00 %
Prisudvikling for administration	2,00 %

Konklusion

Nøgletallene for analysen er opgjort nedenfor. Nøgletallene for analysen viser, at:

- De laveste anskaffelsesomkostninger er på ***2.435.954*** kr. for ***Ressource Rows***
- Den laveste nutidsværdi er på ***3.921.784*** kr. for ***Ressource Rows***
- Den laveste årlige omkostning per kvadratmeter på ***1.432*** kr/m2/år opnås for ***Ressource Rows***
- Det foretrukne alternativ er ***Ikke valgt***.

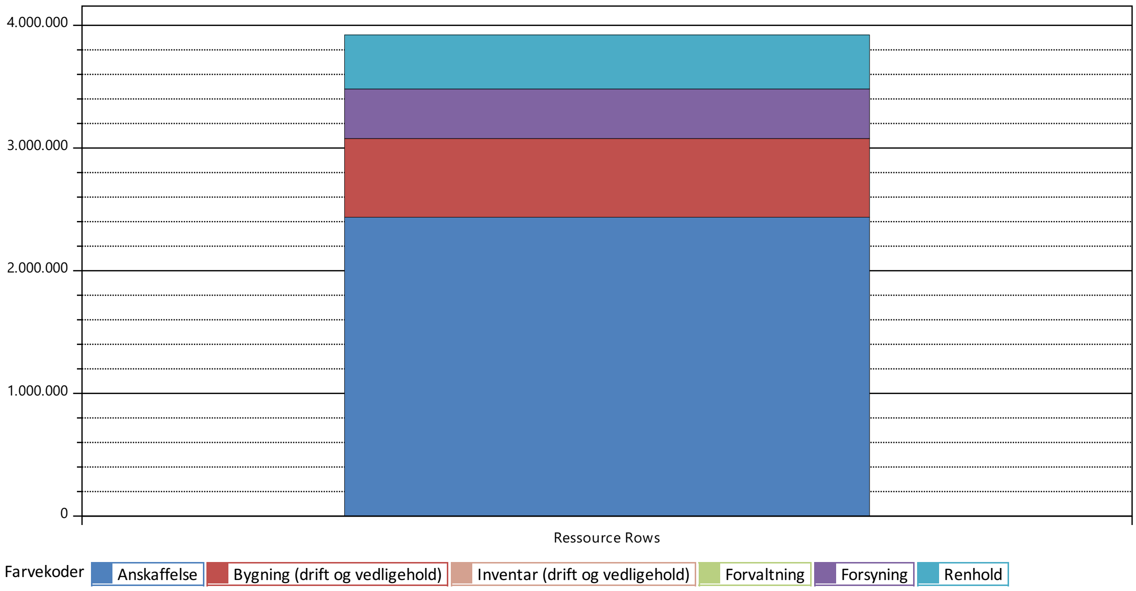
LCC BUILD REPORT OF THE RESOURCE ROWS

Nutidsværdi

	Ressource Rows	%
Anskaffelse	2.435.954	62
Bygning (drift og vedligehold)	641.436	16
Inventar (drift og vedligehold)	0	0
Forvaltning	0	0
Forsyning	404.074	10
Renhold	440.320	11
Nutidsværdi	**3.921.784**	
Nutidsværdi per m2	**26.145**	
Årsomkostning (kr/m2/år)	**1.432**	

Hovedomkostningsgrupper

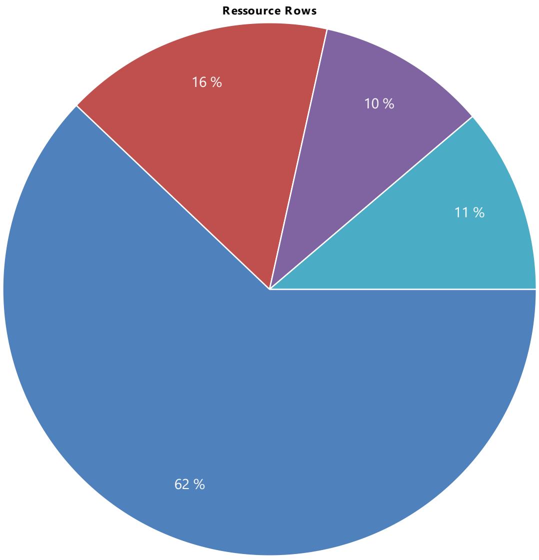
Stavdiagram med alternativers hovedomkostninger



LCC BUILD REPORT OF THE RESOURCE ROWS

Hovedomkostningsgrupper

Figurerne nedenfor viser, hvordan nutidsværdien for det eller de valgte alternativer fordeler sig på hovedomkostningsgrupper.
Cirkeldiagrammerne viser ikke eventuelle indtægter.



Hovedomkostningsgrupper i tal

	Ressource Rows	%
Anskaffelse	**2.435.954**	**62**
Grund, rådgivning og bygherre	969.134	24,71
Bygningsbasis	61.260	1,56
Primære bygningsdele	707.832	18,05
Kompletterende bygningsdele	218.850	5,58
Overfladebygningsdele	216.189	5,51
VVS-anlæg	155.470	3,96
El- og mekaniske anlæg	107.219	2,73
Inventar og udstyr	0	0,00
Bygning (drift og vedligehold)	**641.436**	**16**
Bygningsbasis	8.269	0,21
Primære bygningsdele	199.185	5,08
Kompletterende bygningsdele	94.513	2,41
Overfladebygningsdele	155.464	3,96
VVS-anlæg	146.634	3,74
El- og mekaniske anlæg	37.370	0,95
Inventar (drift og vedligehold)	**0**	**0**
Inventar og udstyr	0	0,00
Forvaltning	**0**	**0**
Forvaltning	0	0,00
Forsyning	**404.074**	**10**
Forsyning	404.074	10,30
Renhold	**440.320**	**11**
Terræn	6.765	0,17
Bygninger, udvendigt	41.621	1,06
Indendørsarealer og rum	391.934	9,99

Hovedomkostningsgrupper i tal med undergrupper

	Ressource Rows	%
Anskaffelse	**2.435.954**	**62**
Grund, rådgivning og bygherre	969.134	24,71
Byggegrund	792.436	20,21

side 3/6

LCC BUILD REPORT OF THE RESOURCE ROWS

Rådgiverhonorarer	176.698	4,51
Bygherreomkostninger	0	0,00
Bygningsbasis	61.260	1,56
Bygningsbasis, terræn	0	0,00
Fundamenter	49.760	1,27
Terrændæk	11.500	0,29
Primære bygningsdele	707.832	18,05
Terræn	29.400	0,75
Ydervægge	182.402	4,65
Indervægge	256.040	6,53
Dæk	80.620	2,06
Trapper og ramper	142.200	3,63
Bærende konstruktioner	0	0,00
Altaner og altangange	0	0,00
Tage	17.170	0,44
Øvrige primære bygningsdele, bygning	0	0,00
Kompletterende bygningsdele	218.850	5,58
Terræn, komplettering	0	0,00
Ydervægge, komplettering	70.764	1,80
Indervægge, komplettering	33.716	0,86
Dæk, komplettering	83.420	2,13
Trapper og ramper, komplettering	0	0,00
Lofter, komplettering	2.900	0,07
Altaner, komplettering	0	0,00
Tage, komplettering	28.050	0,72
Kompletterende bygningsdele bygning, øvrige	0	0,00
Overfladebygningsdele	216.189	5,51
Belægninger, terræn	0	0,00
Udvendige vægoverflader	68.925	1,76
Indvendige vægoverflader	42.885	1,09
Dæk og gulve, overflader	551	0,01
Trapper og ramper, overflader	0	0,00
Lofter, overflader	13.751	0,35
Altaner, overflader	0	0,00
Tage, overflader	10.560	0,27
Øvrige overflader, bygning	79.517	2,03
VVS-anlæg	155.470	3,96
VVS-anlæg, terræn	574	0,01
Affald	0	0,00
Afløb og sanitet	9.297	0,24
Vand (koldt/varmt vand, behandlet vand)	28.580	0,73
Luftarter (gas, trykluft, vakuum, damp)	0	0,00
Køling	0	0,00
Varme (vand, damp, kondens, hedtolie)	55.094	1,40
Ventilationsanlæg	61.925	1,58
VVS-anlæg, bygning, øvrige	0	0,00
El- og mekaniske anlæg	107.219	2,73
El- og mekaniske anlæg, terræn	1.455	0,04
Højspændingsanlæg	1.936	0,05
Lavspændingsanlæg	72.681	1,85
Elektronik og svagstrøm	6.270	0,16
Transportanlæg	0	0,00
Mekaniske anlæg, øvrige	0	0,00
Elektriske anlæg, øvrige	24.877	0,63
Inventar og udstyr	0	0,00
Inventar og udstyr	0	0,00
Bygning (drift og vedligehold)	**641.436**	**16**
Bygningsbasis	8.269	0,21
Bygningsbasis, terræn	0	0,00
Fundamenter	6.474	0,17
Terrændæk	1.795	0,05
Primære bygningsdele	199.185	5,08
Terræn	11.884	0,30
Ydervægge	58.235	1,48

LCC BUILD REPORT OF THE RESOURCE ROWS

Indervægge	66.621	1,70
Dæk	20.977	0,53
Trapper og ramper	37.000	0,94
Bærende konstruktioner	0	0,00
Altaner og altangange	0	0,00
Tage	4.468	0,11
Øvrige primære bygningsdele, bygning	0	0,00
Kompletterende bygningsdele	94.513	2,41
Terræn, komplettering	0	0,00
Ydervægge, komplettering	46.862	1,19
Indervægge, komplettering	8.773	0,22
Dæk, komplettering	21.706	0,55
Trapper og ramper, komplettering	0	0,00
Lofter, komplettering	2.576	0,07
Altaner, komplettering	0	0,00
Tage, komplettering	14.597	0,37
Kompletterende bygningsdele bygning, øvrige	0	0,00
Overfladebygningsdele	155.464	3,96
Belægninger, terræn	0	0,00
Udvendige vægoverflader	10.375	0,26
Indvendige vægoverflader	82.874	2,11
Dæk og gulve, overflader	1.549	0,04
Trapper og ramper, overflader	0	0,00
Lofter, overflader	25.695	0,66
Altaner, overflader	0	0,00
Tage, overflader	14.280	0,36
Øvrige overflader, bygning	20.690	0,53
VVS-anlæg	146.634	3,74
VVS-anlæg, terræn	75	0,00
Affald	0	0,00
Afløb og sanitet	3.950	0,10
Vand (koldt/varmt vand, behandlet vand)	23.152	0,59
Luftarter (gas, trykluft, vakuum, damp)	0	0,00
Køling	0	0,00
Varme (vand, damp, kondens, hedtolie)	57.910	1,48
Ventilationsanlæg	61.548	1,57
VVS-anlæg, bygning, øvrige	0	0,00
El- og mekaniske anlæg	37.370	0,95
El- og mekaniske anlæg, terræn	949	0,02
Højspændingsanlæg	1.518	0,04
Lavspændingsanlæg	24.938	0,64
Elektronik og svagstrøm	8.479	0,22
Transportanlæg	0	0,00
Mekaniske anlæg, øvrige	0	0,00
Elektriske anlæg, øvrige	1.487	0,04
Inventar (drift og vedligehold)	**0**	**0**
Inventar og udstyr	0	0,00
Inventar og udstyr	0	0,00
Forvaltning	**0**	**0**
Forvaltning	0	0,00
Skatter	0	0,00
Forsikringer	0	0,00
Administration	0	0,00
Forsyning	**404.074**	**10**
Forsyning	404.074	10,30
Vand	325.010	8,29
Varme	0	0,00
Electricitet	79.064	2,02
Renhold	**440.320**	**11**
Terræn	6.765	0,17
Udeareal	6.765	0,17
Bygninger, udvendigt	41.621	1,06
Klimaskærm	41.621	1,06
Indendørsarealer og rum	391.934	9,99

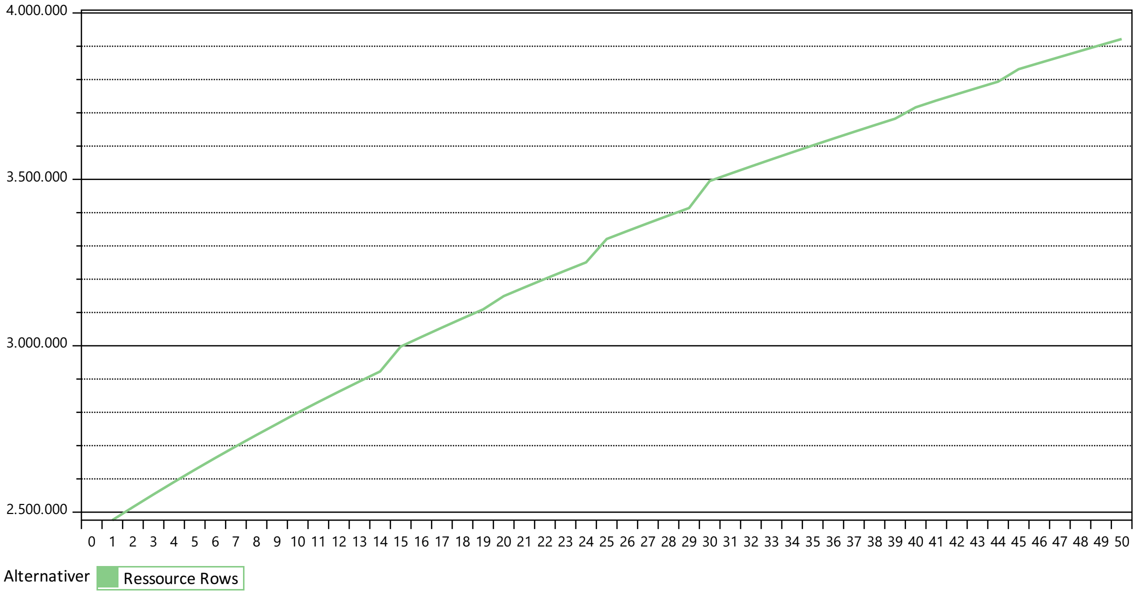
side 5/6

LCC BUILD REPORT OF THE RESOURCE ROWS

Rum	391.934	9,99

Hovedomkostningsgrupper

Figurerne nedenfor viser, hvordan nutidsværdien for det eller de valgte alternativer fordeler sig på hovedomkostningsgrupper.



APPENDIX VII

LCC BUILD REPORT OF THE RESOURCE ROWS BENCHMARK

LLC Ressource Rækkerne

Denne rapport er udfærdiget i LCCbyg 2.2.52

Livscyklus-omkostninger resultater af et ressource Rækkerne.

Resultaterne, der udtrykkes, henviser til udgifterne til 1 hus på 150 m2.

Omkostningerne er opdelt i tre kategorier:

- Materialer

- Installationer (såsom elektricitet, maling og ventilation).

- Rådgivnings- og konsulentgebyrer.

For de to sidste kategorier har vi de samlede omkostninger til Resource House-projektet; vi har estimeret forholdet for 1 hus.

Alternativer

Ressource Rows Benchmark	Building Life Cycle Costs for one benchmark building

Antagelser

Generelle beregningsforudsætninger	50 år
Kalkulationsrente	fra og med år 1: 5,00 % fra og med år 36: 5,00 % fra og med år 71: 5,00 %
Prisudvikling generelt	2,00 %
Prisudvikling for drikkevand	4,00 %
Prisudvikling for spildevand	7,00 %
Prisudvikling for energi generelt	4,00 %
Prisudvikling for fjernvarme	3,00 %
Prisudvikling for gas	1,50 %
Prisudvikling for flydende brændsel	4,00 %
Prisudvikling for fast brændsel	3,00 %
Prisudvikling for el	3,50 %
Prisudvikling for skatter og afgifter	2,00 %
Prisudvikling for forsikring	5,00 %
Prisudvikling for administration	2,00 %

Konklusion

Nøgletallene for analysen er opgjort nedenfor. Nøgletallene for analysen viser, at:

- De laveste anskaffelsesomkostninger er på ***2.472.116*** kr. for ***Ressource Rows Benchmark***
- Den laveste nutidsværdi er på ***3.977.633*** kr. for ***Ressource Rows Benchmark***
- Den laveste årlige omkostning per kvadratmeter på ***1.453*** kr/m2/år opnås for ***Ressource Rows Benchmark***
- Det foretrukne alternativ er ***Ikke valgt***.

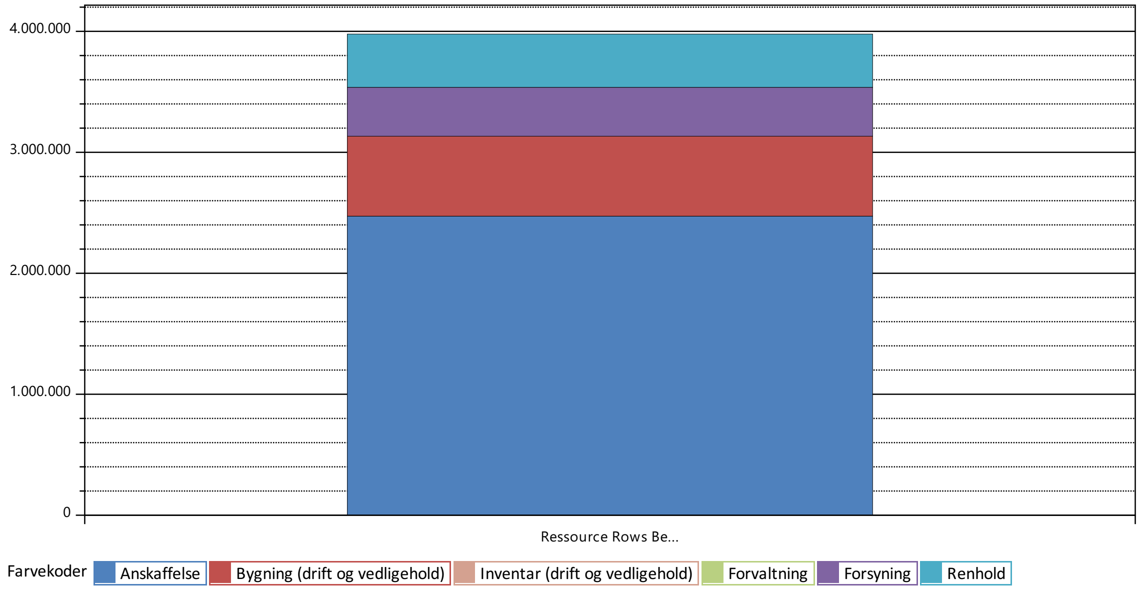
LCC BUILD REPORT OF THE RESOURCE ROWS BENCHMARK

Nutidsværdi

	Ressource Rows Benchmark	%
Anskaffelse	2.472.116	62
Bygning (drift og vedligehold)	661.123	17
Inventar (drift og vedligehold)	0	0
Forvaltning	0	0
Forsyning	404.074	10
Renhold	440.320	11
Nutidsværdi	**3.977.633**	
Nutidsværdi per m2	**26.518**	
Årsomkostning (kr/m2/år)	**1.453**	

Hovedomkostningsgrupper

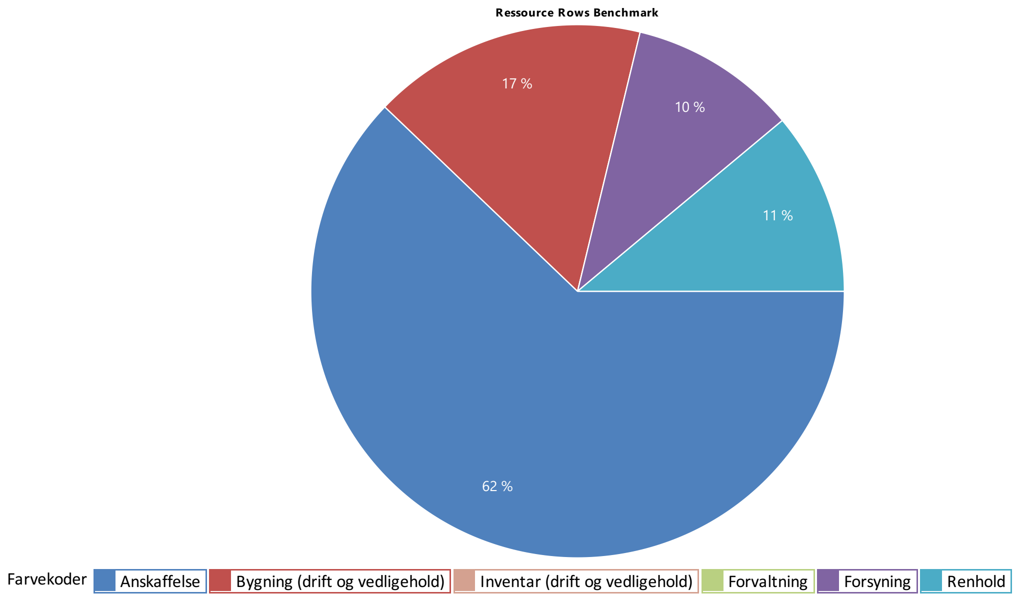
Stavdiagram med alternativers hovedomkostninger



LCC BUILD REPORT OF THE RESOURCE ROWS BENCHMARK

Hovedomkostningsgrupper

Figurerne nedenfor viser, hvordan nutidsværdien for det eller de valgte alternativer fordeler sig på hovedomkostningsgrupper.
Cirkeldiagrammerne viser ikke eventuelle indtægter.



Hovedomkostningsgrupper i tal

	Ressource Rows Benchmark	%
Anskaffelse	**2.472.116**	**62**
Grund, rådgivning og bygherre	969.134	24,36
Bygningsbasis	61.260	1,54
Primære bygningsdele	652.188	16,40
Kompletterende bygningsdele	280.659	7,06
Overfladebygningsdele	238.442	5,99
VVS-anlæg	155.470	3,91
El- og mekaniske anlæg	114.963	2,89
Inventar og udstyr	0	0,00
Bygning (drift og vedligehold)	**661.123**	**17**
Bygningsbasis	8.269	0,21
Primære bygningsdele	185.921	4,67
Kompletterende bygningsdele	115.602	2,91
Overfladebygningsdele	161.254	4,05
VVS-anlæg	146.634	3,69
El- og mekaniske anlæg	43.442	1,09
Inventar (drift og vedligehold)	**0**	**0**
Inventar og udstyr	0	0,00
Forvaltning	**0**	**0**
Forvaltning	0	0,00
Forsyning	**404.074**	**10**
Forsyning	404.074	10,16
Renhold	**440.320**	**11**
Terræn	6.765	0,17
Bygninger, udvendigt	41.621	1,05
Indendørsarealer og rum	391.934	9,85

Hovedomkostningsgrupper i tal med undergrupper

	Ressource Rows Benchmark	%
Anskaffelse	**2.472.116**	**62**
Grund, rådgivning og bygherre	969.134	24,36

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LCC BUILD REPORT OF THE RESOURCE ROWS BENCHMARK

Byggegrund	792.436	19,92
Rådgiverhonorarer	176.698	4,44
Bygherreomkostninger	0	0,00
Bygningsbasis	61.260	1,54
Bygningsbasis, terræn	0	0,00
Fundamenter	49.760	1,25
Terrændæk	11.500	0,29
Primære bygningsdele	652.188	16,40
Terræn	29.400	0,74
Ydervægge	126.758	3,19
Indervægge	256.040	6,44
Dæk	80.620	2,03
Trapper og ramper	142.200	3,57
Bærende konstruktioner	0	0,00
Altaner og altangange	0	0,00
Tage	17.170	0,43
Øvrige primære bygningsdele, bygning	0	0,00
Kompletterende bygningsdele	280.659	7,06
Terræn, komplettering	0	0,00
Ydervægge, komplettering	70.764	1,78
Indervægge, komplettering	33.716	0,85
Dæk, komplettering	125.990	3,17
Trapper og ramper, komplettering	0	0,00
Lofter, komplettering	2.900	0,07
Altaner, komplettering	0	0,00
Tage, komplettering	47.289	1,19
Kompletterende bygningsdele bygning, øvrige	0	0,00
Overfladebygningsdele	238.442	5,99
Belægninger, terræn	0	0,00
Udvendige vægoverflader	68.925	1,73
Indvendige vægoverflader	42.885	1,08
Dæk og gulve, overflader	551	0,01
Trapper og ramper, overflader	0	0,00
Lofter, overflader	13.751	0,35
Altaner, overflader	0	0,00
Tage, overflader	10.560	0,27
Øvrige overflader, bygning	101.770	2,56
VVS-anlæg	155.470	3,91
VVS-anlæg, terræn	574	0,01
Affald	0	0,00
Afløb og sanitet	9.297	0,23
Vand (koldt/varmt vand, behandlet vand)	28.580	0,72
Luftarter (gas, trykluft, vakuum, damp)	0	0,00
Køling	0	0,00
Varme (vand, damp, kondens, hedtolie)	55.094	1,39
Ventilationsanlæg	61.925	1,56
VVS-anlæg, bygning, øvrige	0	0,00
El- og mekaniske anlæg	114.963	2,89
El- og mekaniske anlæg, terræn	1.455	0,04
Højspændingsanlæg	9.680	0,24
Lavspændingsanlæg	72.681	1,83
Elektronik og svagstrøm	6.270	0,16
Transportanlæg	0	0,00
Mekaniske anlæg, øvrige	0	0,00
Elektriske anlæg, øvrige	24.877	0,63
Inventar og udstyr	0	0,00
Inventar og udstyr	0	0,00
Bygning (drift og vedligehold)	**661.123**	**17**
Bygningsbasis	8.269	0,21
Bygningsbasis, terræn	0	0,00
Fundamenter	6.474	0,16
Terrændæk	1.795	0,05
Primære bygningsdele	185.921	4,67
Terræn	11.884	0,30

LCC BUILD REPORT OF THE RESOURCE ROWS BENCHMARK

Ydervægge	44.972	1,13
Indervægge	66.621	1,67
Dæk	20.977	0,53
Trapper og ramper	37.000	0,93
Bærende konstruktioner	0	0,00
Altaner og altangange	0	0,00
Tage	4.468	0,11
Øvrige primære bygningsdele, bygning	0	0,00
Kompletterende bygningsdele	115.602	2,91
Terræn, komplettering	0	0,00
Ydervægge, komplettering	46.862	1,18
Indervægge, komplettering	8.773	0,22
Dæk, komplettering	32.782	0,82
Trapper og ramper, komplettering	0	0,00
Lofter, komplettering	2.576	0,06
Altaner, komplettering	0	0,00
Tage, komplettering	24.609	0,62
Kompletterende bygningsdele bygning, øvrige	0	0,00
Overfladebygningsdele	161.254	4,05
Belægninger, terræn	0	0,00
Udvendige vægoverflader	10.375	0,26
Indvendige vægoverflader	82.874	2,08
Dæk og gulve, overflader	1.549	0,04
Trapper og ramper, overflader	0	0,00
Lofter, overflader	25.695	0,65
Altaner, overflader	0	0,00
Tage, overflader	14.280	0,36
Øvrige overflader, bygning	26.480	0,67
VVS-anlæg	146.634	3,69
VVS-anlæg, terræn	75	0,00
Affald	0	0,00
Afløb og sanitet	3.950	0,10
Vand (koldt/varmt vand, behandlet vand)	23.152	0,58
Luftarter (gas, trykluft, vakuum, damp)	0	0,00
Køling	0	0,00
Varme (vand, damp, kondens, hedtolie)	57.910	1,46
Ventilationsanlæg	61.548	1,55
VVS-anlæg, bygning, øvrige	0	0,00
El- og mekaniske anlæg	43.442	1,09
El- og mekaniske anlæg, terræn	949	0,02
Højspændingsanlæg	7.590	0,19
Lavspændingsanlæg	24.938	0,63
Elektronik og svagstrøm	8.479	0,21
Transportanlæg	0	0,00
Mekaniske anlæg, øvrige	0	0,00
Elektriske anlæg, øvrige	1.487	0,04
Inventar (drift og vedligehold)	**0**	**0**
Inventar og udstyr	0	0,00
Inventar og udstyr	0	0,00
Forvaltning	**0**	**0**
Forvaltning	0	0,00
Skatter	0	0,00
Forsikringer	0	0,00
Administration	0	0,00
Forsyning	**404.074**	**10**
Forsyning	404.074	10,16
Vand	325.010	8,17
Varme	0	0,00
Electricitet	79.064	1,99
Renhold	**440.320**	**11**
Terræn	6.765	0,17
Udeareal	6.765	0,17
Bygninger, udvendigt	41.621	1,05
Klimaskærm	41.621	1,05

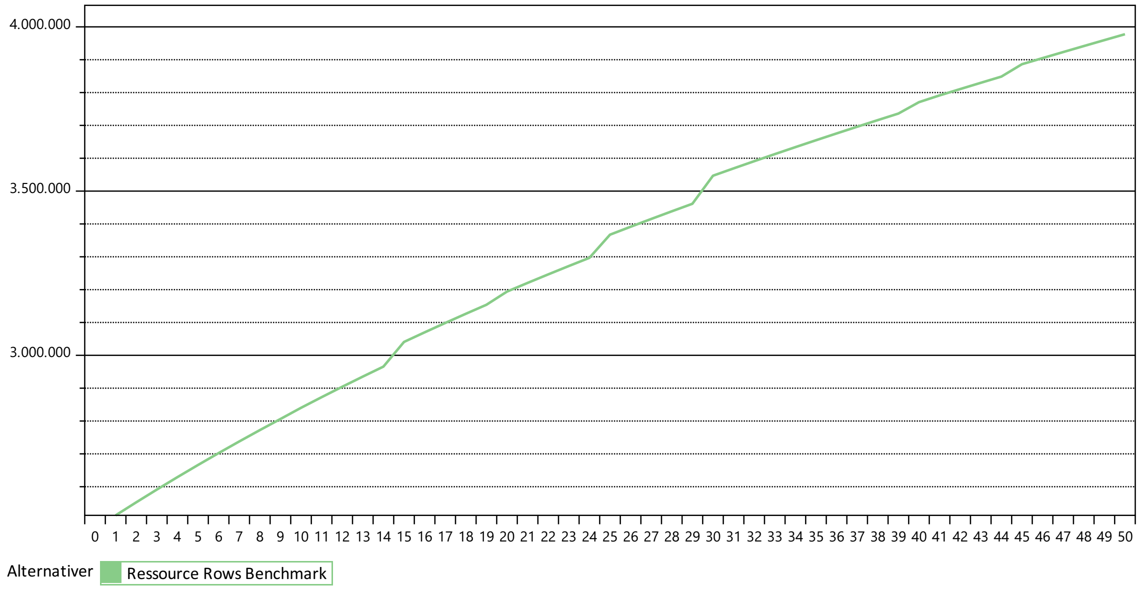
side 5/6

LCC BUILD REPORT OF THE RESOURCE ROWS BENCHMARK

Indendørsarealer og rum	391.934	9,85
Rum	391.934	9,85

Hovedomkostningsgrupper

Figurerne nedenfor viser, hvordan nutidsværdien for det eller de valgte alternativer fordeler sig på hovedomkostningsgrupper.



Sustainability - Upcycle Studios & The Resource Rows

Made by Lendager Group for NREP.

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