Carbon footprint calculation methods and expertise

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Summary

Climate change is one of the greatest challenges of our time. Even though efforts by all sectors and operators of different fields must do their part in combating climate change and adapting to accommodate the changes it brings, it should be noted that the real estate and construction sectors have a particularly significant impact on the environment.

Different industrial sectors are striving to find and use ways to minimise the environmental impact of their own activities as effectively as possible. In the construction sector, carbon performance assessment is implemented using life cycle thinking and, among other methods, carbon footprinting. These tools allow operators to assess and manage the environmental impacts of their projects.

This guide explores low carbon construction practices through the lens of carbon footprinting. The writers' aim is to present key measures and calculation methods related to carbon footprinting, as well as to expand on the effects of the results of these calculations and offer reallife examples that allow real estate and construction sector operators to reap the full benefits of carbon footprinting.

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This handbook was prepared by a working group consisting of the AINS Group experts Leevi Aihos, Salla Saukkoriipi, and Maija Mattinen-Yuryev.

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Glossary

co2data.fi	The construction emissions database is a free service that provides emission data averages for different construction products, processes and services.
Life cycle carbon footprint	Life cycle carbon footprint refers to the climate impact a product or project has during its life cycle. In terms of buildings, a life cycle carbon footprint covers emissions arising from the manufacture of products, construction, and building use, including maintenance and repairs, energy used and demolition at the end of the building's life cycle (FIGBC, 2020a).
Life cycle stage; module	Describes a single activity that generates emissions during the life cycle of a building or part of a building. A stage in the building's life cycle in accordance with standard 15643.
Life cycle assessment (LCA)	A scientific method to analyse and assess the total impacts of a product or service throughout its life cycle.
Life cycle costing (LCC)	The aim of life cycle costing is to reflect the costs incurred by the building owner throughout its lifecycle. Life cycle costs measure the cost arising from the building all the way from land acquisition to demolition.
EU taxonomy	A regulation-based tool established by the European Union. The taxonomy aims to provide financial markets with transparent, harmonised information on the environmental aspects of different commercial activities, thereby promoting sustaina-ble investment. It also covers construction sector activities.
Carbon dioxide equivalent	Carbon dioxide equivalent or CO2e is a commensurated unit that reflects how much the pollution and emissions caused increase global warming.
Carbon footprint	Describes the climate impact of a product or service. The unit used for carbon footprints is the carbon dioxide equivalent (CO2e).
Carbon handprint	The sum of potential climate benefits created by a product or service expressed as carbon dioxide equivalents.
Emissions	Emissions (also commonly referred to as carbon emissions) refer to greenhouse gas emissions that accelerate climate change (see also Greenhouse gas below).

Climate declaration	A standardised and verified way of presenting the climate impact of a product, i.e. its carbon footprint.
Climate statement	The Finnish Ministry of the Environment is currently preparing a decree delineating how climate statements for buildings should be prepared and which methodology should be used for determining the life cycle of a product or service as low carbon. A climate statement would report the carbon footprint and handprint in accordance with the principles specified in the decree.
Greenhouse gas	A gas that absorbs the sun's energy in the atmosphere, thereby accelerating global warming. Greenhouse gases include gases such as carbon dioxide, methane and CFCs.
Cost accounting	Cost accounting identifies and allocates the costs arising from a construction project. Cost calculations include a bill of quantities of the chosen items along with their respective prices.
Level(s)	European Commission's method for assessing the sustainability of buildings. For more information, see: https://environment.ec.europa.eu/topics/circular-economy/levels_en
One Click LCA	Commercial life cycle assessment software.
Design for deconstruction	A method for designing buildings in a way that allows their materials to be reused and sorted upon demolition.
Product stage	A life cycle stage that consists of raw material procurement, transport and manufacturing of the final product.
Ministry of Environment's method for the whole life carbon assessment of buildings	A method developed by the Ministry of Environment for assessing the carbon performance of buildings. The draft method (2021) is used in parallel with the draft regulation and explanatory memorandum on the climate statements of buildings. The final guidance for the method will be published once the regulation enters into force.
Environmental product declaration, EPD	A standardised, verified way of presenting the environmental impact of a product. The impact is assessed based on a life cycle assessment of the product.

1 Background and purpose

Globally, construction and building maintenance account for up to 40 per cent of harmful emissions to the atmosphere and environment, and consume roughly half of all virgin natural resources used by humans. At the same time, as urbanisation intensifies and the global population grows, the world requires more construction than ever. The increasing amount of greenhouse gases in the atmosphere exacerbates climate change; people all around the world can already see and feel its effects in different areas of their lives. Mitigating the effects of climate change and adapting to it require action from all sectors of commercial life. Various industrial sectors have already taken measures to this end, and the sectors involved in constructing built environments form a significant part of this movement. Housing and housing security are also central for human wellbeing, which is one of the reasons that the construction sector holds such major societal significance. In addition to this, the vast majority of the national wealth of different states is currently tied up in built environments. This means that the construction sector also has a high potential for impacting various other matters.

Identifying, managing and ultimately reducing the emission sources associated with it presents an effective way to minimise the climate impact of the industry as a whole. Carbon footprinting is a way of assessing all the climate impacts associated with the life cycle of the building from raw material production to construction and eventually demolition. This workbook offers operators guidance on how to use carbon footprinting in their own projects and working tasks, and helps them to find concrete opportunities to support different parts of projects they work on.

The carbon footprinting of construction projects is important in terms of individual projects, but also for the development and improvement of the entire sector. The more widespread use of carbon footprint calculations creates a wealth of knowledge and data that can be used to improve industry methods and practices. Some construction sector operators have already integrated carbon footprinting into their own processes and understood its role in developing the sector as a whole.

Do at least this

- Acquire the necessary expertise. Increase the understanding and knowledge of your company and key personnel to interpret carbon footprint and carbon footprint calculations.
- Order a calculation of the carbon footprints of your own sites and ask the party producing the calculations to present the results to your organisation and offer recommendations for reducing emissions.
- Set a carbon footprint objective and identify measures and structural solutions to decrease the carbon footprint of different projects.

1.1 Industry views on carbon footprint calculation

Carbon footprinting is becoming increasingly common in the Finnish construction sector. Many operators aim to prepare well for the government's future policies on emissions arising from the construction sector, but many have also found that emissions management also presents operating advantages. Below, you will find statements from different industry figures detailing their views on the subject.

Arkta Rakennus Oy / Oskari Jokikokko and Markus Karhu

"The construction sector produces a significant amount of greenhouse gas emissions, and therefore has great potential for reducing emissions. Decreasing the carbon footprint of an organisation or a project requires not only information about the carbon footprint of the current operations, but also data on what the current footprint is comprised of.

We need to be able to offer products that are as low carbon as possible, since they are currently considered far more attractive than old housing stock. By looking at the footprints and handprints of their most recent construction projects and comparing them with average benchmark results, operators can gain a comprehensive overall understanding of where they currently stand. The calculations offer insights into what factors are truly significant in a construction project and open up a discussion on how operators could decrease their own carbon footprints and increase their carbon handprint in future. Operators should ask the party performing the calculations to provide them with an introduction into the subject and to give instructions on how to interpret the carbon footprint reports they have produced. It is really worth it to use these reports in your operations and to incorporate them into your design guidance."

Tyvene Oy / Pekka Karsimus Construction Manager

"Carbon footprinting allows us to do our part in reducing harmful emissions. We want to contribute to fighting climate change and feel that it is really important that we minimise our emissions. We have developed quality and construction practice guidance that also includes instructions for achieving low-emission design solutions. The carbon footprint calculations that we have carried out for a few of our sites have revealed which factors affect the carbon footprint in general and how we can reduce our emissions. The best way to get started is to increase your understanding of climate issues by reading professional literature and news reports on the subject. After you have got the basics covered, it is time to order a carbon footprint calculation from an expert in the field. This will help to illustrate your company's emissions and their scale.

Once you have received the results, reflect on the results in terms of your own vision and emission reduction objectives."

University of Vaasa / Tommi Lehtonen Manager (Sustainability and ethics)

"A carbon footprint calculation is essential to get the correct idea of the situation. This in turn is important for avoiding and reducing emissions. The calculation is therefore not the be-all and end-all, but rather a tool to help you reduce your organisation's carbon footprint and help you take the next steps. It is useful to find someone – either a service provider or another trusted partner – who will help your organisation develop and support you in matters related to carbon footprinting. The best way to gain an understanding of your organisation's emissions and measures to reduce them is to do this work yourself, even though consulting may be useful as well."

2 Carbon footprint

Key points

- The life cycle carbon footprint of a building covers all emissions generated throughout the building's life cycle. The carbon footprint is expressed in carbon dioxide equivalents (CO_2e). This aggregate number reflects the climate warming effects of a variety of different greenhouse gases.
- The life cycle of a building stretches from the product stage, i.e. manufacture and transport of the raw materials and products used, to the construction process and the use of the building and the operations performed at the end of the life cycle, such as demolition and waste management.
- In Finland, the method for carbon footprinting of buildings is defined by the Ministry of the Environment. This method is in turn based on the standards used in life cycle assessment.
- As a general rule, saving energy and materials also decreases emissions and costs.
- Taking climate issues into account in your organisation's current operations ensures that your business will remain profitable in the future, when carbon footprinting is required by both national and EU legislation and financial instruments.

2.1 What is a carbon footprint and how can it be applied in the construction sector?

The aim of calculating the carbon footprints of buildings is to identify all greenhouse gas emissions generated during the life cycle of a building. These emissions are then commensurated and added up. The commensurated figure reflects the total effect that the building has had on global warming. It is also colloquially referred to as a building's carbon emissions or climate impact. Carbon footprints are expressed in carbon dioxide equivalents, which reflect the climate-warming effects of a variety of greenhouse gases. In addition to carbon dioxide, greenhouse gases with a significant impact on climate include methane and nitrous oxide. The effect of methane, for example, is 28 times more powerful than that of carbon dioxide. The life cycle carbon footprint covers all emissions from all operations undertaken during the life cycle, from the manufacture and transport of products to construction, using the building, and decommissioning at the end of its life cycle (Figure 1).

The carbon footprint is calculated based on a scientific method, the Life Cycle Assessment method (LCA), which has been developed to systematically analyse environmental impacts in a broad range of applications. The carbon footprint of buildings is calculated based on the Ministry of the Environment's method for assessing the whole life carbon footprint of buildings (first published in 2019, reviewed in 2021), which reflects the level(s) method created by the European Commission. The method is based on European sustainable building standards, such as the EN15643 standard series, the standards EN15978 and EN15804, as well as scientific research. The method breaks the life cycle of a building down into stages, which are also referred to as modules (Figure 2).

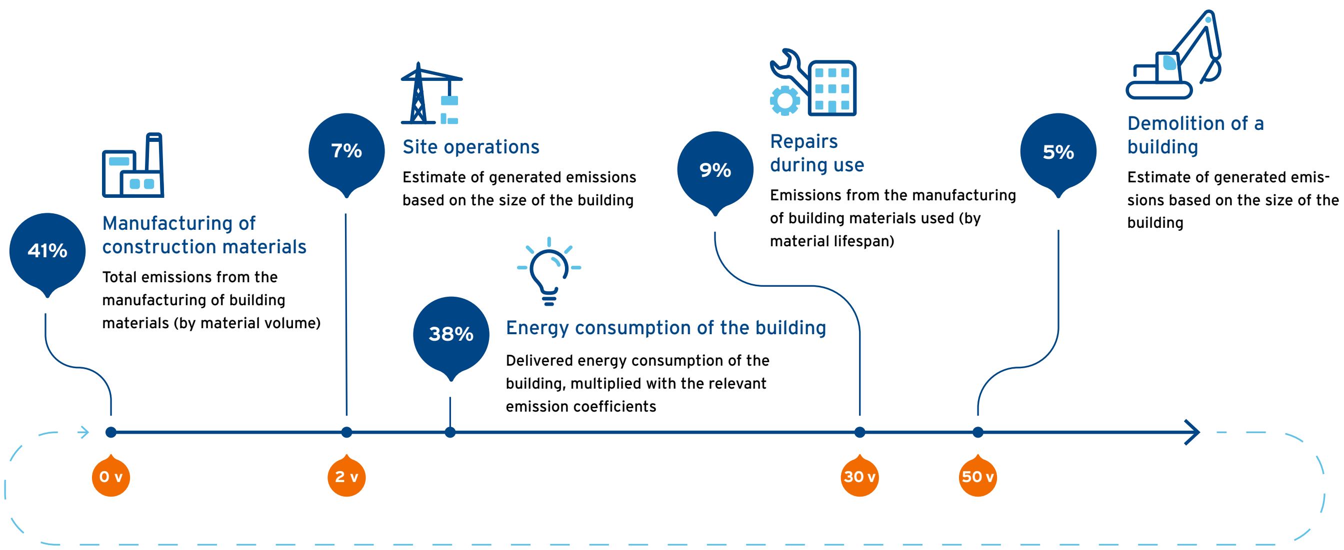

Figure 2. Life cycle stages of a building and modules considered in the carbon footprint calculation.

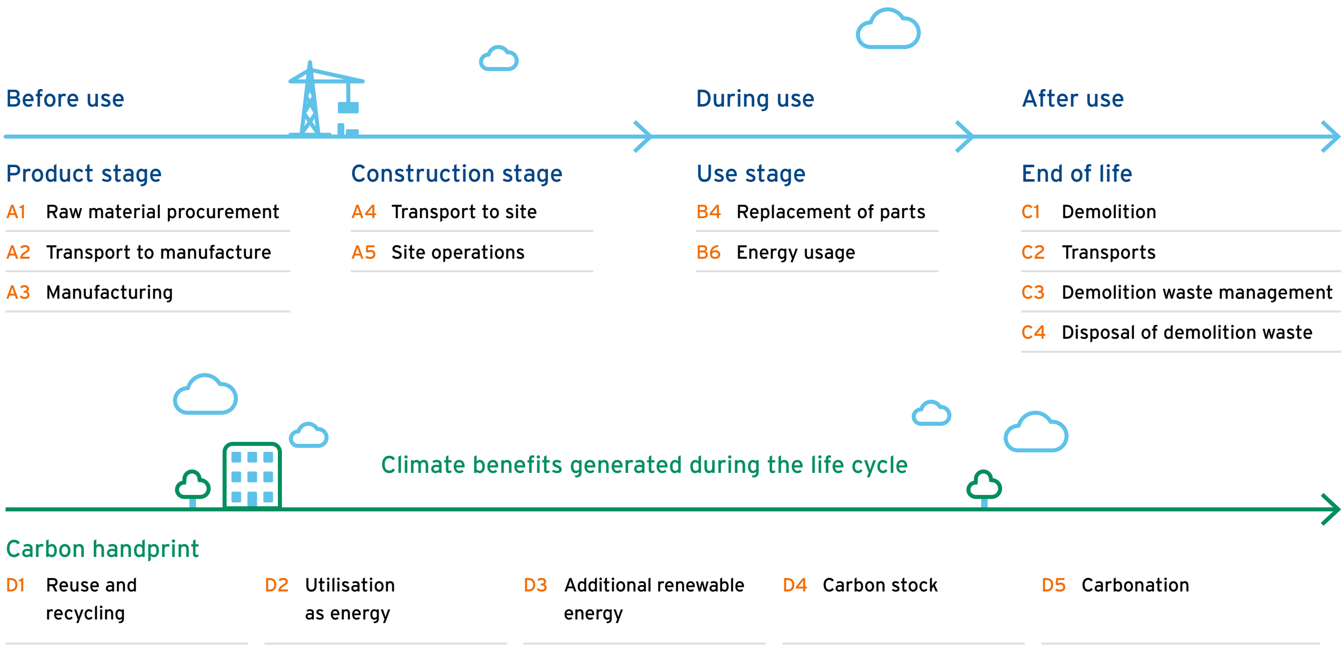

Figure 2. Life cycle stages of a building and modules considered in the carbon footprint calculation.

All activities that utilise virgin materials or fossil fuels will inevitably generate emissions. For this reason, carbon footprinting is relevant for new construction, renovation and refurbishment projects alike. Refurbishment projects usually consist of remodelling the premises in question to correspond to either the requirements of modern life and regulations, or to a new occupant's needs. In addition to individual buildings and renovation projects, the carbon footprint may also be examined at a broader level or even at a regional level when a new local plan is introduced or an existing local plan is changed. In this scenario, the carbon footprint would include the emissions arising from resident mobility and commuting or soil changes.

The method for the whole life carbon assessment of buildings also looks at the carbon handprint of buildings. The carbon handprint reflects the potential climate benefits created during the construction process. These include but are not limited to choices such as using renewable energy solutions, adding green spaces (green roofs and walls), and utilising materials that act as carbon stocks, such as woodbased products. The carbon handprint of a built environment can also be in-creased with circular economy solutions, such as using recycled materials or products that contain recycled materials. However, when reviewing the carbon performance of a building, the carbon footprint and handprint are assessed separately instead of simply adding them up.

2.2 What does carbon footprinting mean in business terms?

A large part of the Finnish national wealth is tied up in built environments, especially in existing real estate. Real estate is a long-term investment, which means that carefully planned maintenance is important for ensuring value retention. Business operations that deal with real estate and buildings should be able to sustain and create value over time, even in a changing market environment.

One of the prerequisites for a profitable business is knowing the market, anticipating its changes and adapting to them. In today's society, consumers are increasingly environmentally conscious, which is also reflected in their choices and actions. In addition to changing consumer behaviour, national and international targets, requirements and financial instruments present another incentive for companies to improve their performance in climate and other environmental issues. A good example of this is Finland's goal to achieve carbon neutrality by 2035, which can be seen as a direct result of the Paris Agreement. In order to respond to the changing consumer preferences and regulation requirements, new production factors are required. This need creates change in the market, and in order to maintain their success companies must adapt to it.

Striving to decrease a project's carbon footprint is not always synonymous with extra costs. One of the ways to lower project emissions is to increase material efficiency and reduce waste. Usephase energy consumption also creates significant emissions and costs. This means that constructing more energy efficient buildings will automatically decrease both the total emissions and costs. As a general rule, saving energy and materials also decreases emissions and costs. On the other hand, finding optimised solutions requires time and resources. However, if the organisation's primary goal is to own or construct buildings for the organisation's own use, energy and material efficiency should be taken into account in both new construction projects and the maintenance of existing buildings in order to manage costs and emissions throughout the life cycle of buildings.

Moreover, sustainability can today be seen as practically essential for running a well-functioning and profitable business. While the Ministry of the Environment's whole life carbon assessment method has not yet been finalised (but has been published as a draft), it is reasonable to expect that it will be further refined in the near future. This, along with the associated draft legislation, will have a signifi-

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cant impact on the construction industry. This also means that the ministry will define and publish specific limiting values for all building types and require operators to adhere to them as a part of the building permit process. It can be further expected that regulatory bodies will be placing either requirements or recommendations for operators offering carbon footprint assessments, much in the same way that they have done for service providers who calculate the total energy expenditure of buildings. If the environmental impacts of a project are not assessed properly, this can create risks in the future as the carbon performance of buildings is further highlighted in the market. Taking environmental issues into account early on can therefore be seen as a form of risk management. Life cycle thinking and carbon footprinting are well-established methods that help companies and other operators to assess and manage their environmental and climate impacts.

The carbon footprinting of new construction is also a key element of the EU's new taxonomy regulation. The EU taxonomy is a system designed for assessing the sustainability of various economic activities. Once in force, it will apply to a wide variety of construction sector operations conducted across Europe. Implementing carbon footprinting now – especially for new buildings – will help operators to prepare for the future requirements of the taxonomy.

3 Carbon footprint calculation

Key points

- The most effective way to manage a building's carbon footprint is to take action at the early stages of a project. The earlier the objectives are set and recorded, the more effectively progress towards them can be monitored and taken into account in terms of both design and costs.

- As the project progresses, calculating the carbon footprint and decreasing it requires collaborative effort and exchange of information between those responsible for the design, the contractor, and the party implementing the actual carbon footprint calculations. Carbon footprinting links the data on quantities and energy to the emissions data regarding the materials and energy forms used. Emissions generated in each stage of the life cycle are then calculated based on this aggregated information. The draft method presented by the Ministry of the Environment offers a table of values for estimating emissions generated by building technology, transport, and site operations.

- The most effective way to use carbon footprinting is to calculate the carbon footprint of the project several times during the course of the project: a preliminary carbon footprint calculation at the project design stage, comparative calculations during the proposal design stage, updated calculations during the general planning and implementation planning stage, a calculation reflecting the chosen design solutions in connection with applying for a building permit, and lastly, a final calculation for verification using the actual quantity and material information.

- Operators should calculate the carbon footprint at each stage using software that has been designed expressly for this purpose. They must also ensure that the emission data is as high quality as possible and based on either the environmental declarations of the products used or data from the national emissions database.

- The results of the calculation will help operators to identify key emission sources and potential ways to reduce emissions. Instead of focusing on a single number, it is advisable to try to understand the impacts of a project or building throughout its life cycle and to attempt to identify design solutions and ways to achieve the desired reductions in emissions.

- Emissions from materials and energy consumption form the largest part of a building's life cycle carbon footprint. Therefore, lowemission material choices and energy efficiency can significantly reduce the overall emissions.

3.1 Calculation principles

Since the early stages of the project offer the greatest opportunity to decrease the life cycle carbon footprint of a building, operators should set and record a target carbon footprint for the project already when the requirement assessment is being drawn up. In many ways, carbon footprint management is similar to the cost management of a project. The earlier a carbon performance target is set, the easier it will be for the experts and the developer to steer the project towards this target. For this reason, it is often recommended that carbon footprint calculations should be performed both at the early stages of a project and repeated multiple times during the design stage. This will ensure that project decision makers have more information at their disposal, are better able to compare different options against one another, and thus are able to more effectively manage the size of the generated carbon footprint.

Operators should use different carbon footprint calculation methods at different points of the design stage to ensure that they are able to sufficiently assess the overall carbon footprint of the project (Figure 3). Preliminary carbon footprint calculations can even be performed on the basis of the facility solutions presented during the project design stage. Implementing

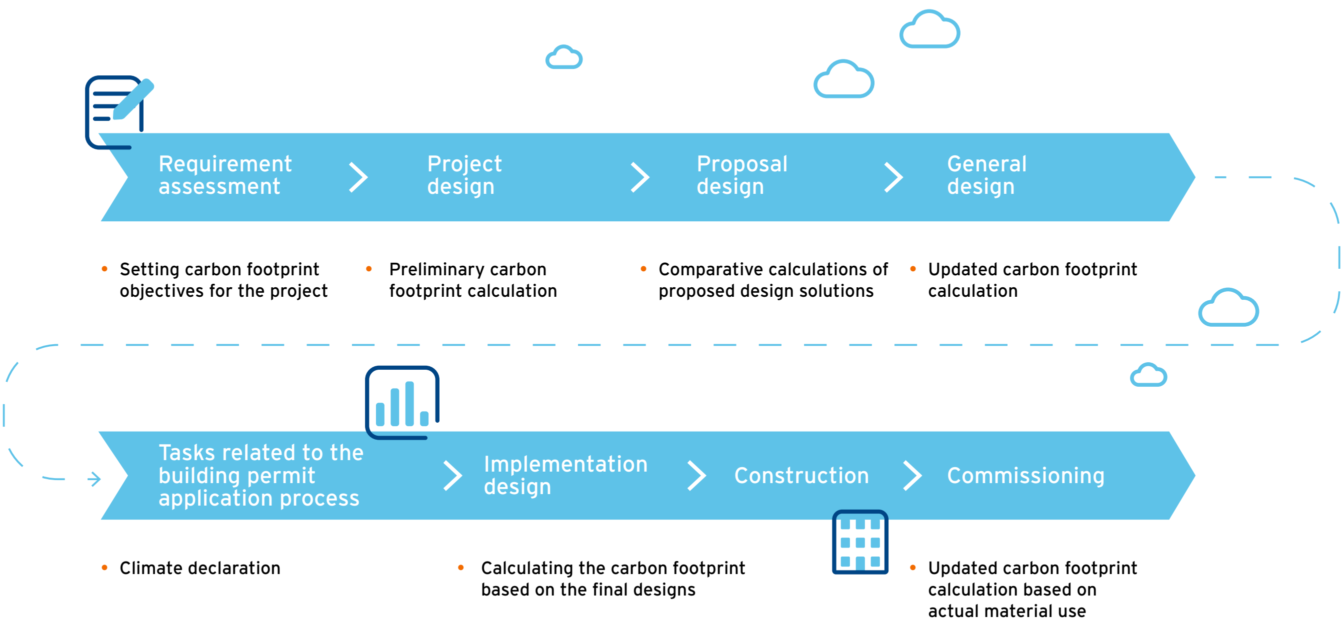


Figure 3. Carbon footprint calculations during the course of the project.

several calculations in parallel with each other allows operators to compare the life cycle cost and emissions performance of different frame solutions, various size related and architectural modelling variables, and predicted energy consumption levels. These comparisons, in turn, help to identify key emissions sources and measures to manage them. The calculations also help to refine concept solutions in a way that takes into account not only carbon performance targets, but also other technical and user oriented objectives.

As the design stage progresses from proposal design to general design, an updated carbon foot print calculation should be carried out based on the selected solution. In the future, the Finnish building permit application process will require applicants to submit a climate statement that presents both the carbon footprint and handprint of the designed building based on the designs submitted to the officials. Later, the operators may want to recalculate the carbon footprint in the commissioning stage based on the actualised plans. This will allow them to verify the final

3.2 Operators involved in carbon footprinting

The carbon footprinting of a construction project is carried out by either a life cycle expert or a carbon footprint calculation expert. This expert may be either a life cycle planner appointed for the project, or a specialist whose expertise complements the skill sets of other design team members. If the project has a specifically appointed life cycle expert, they will guide and manage the design work to ensure that the designs remain in line with the relevant carbon footprint objectives. If they are a part of the design team, the life cycle expert can repeat the calculations in accordance with the ELINK18 task list. This will ensure that the methods and accuracy of the calculations remain consistent throughout the project. This increases the reliability and comparability of the results, which is a key factor in ensuring that the implemented solutions are indeed low carbon.

To ensure the reliability and credibility of the calculations, it is advisable to have them carried out by a person who is familiar with both the construction sector and the environmental and life cycle issues pertaining to the sector. A specialist in life cycle assessment and carbon footprinting will be able to identify the factors that affect the total emissions and the causes and effects related to the emission potential of different design solutions. They will also be able to make recommendations for reducing emissions based on the preliminary calculations. In

Finland, upcoming legislation is expected to introduce a carbon footprint calculation requirement for the building permit application process. This will likely also lead to the introduction of set qualification requirements for the parties who implement the carbon footprint calculations. At present, no such requirements have been defined by regulatory authorities.

Since carbon footprinting requires not only data on quantities and energy related factors, but also information about the technical characteristics of the materials used, successful carbon footprinting requires collaboration and communication between designers and the party implementing the actual calculations. This is especially important when calculating several carbon footprints that are to be compared against each other, or if the project uses multi objective optimisation in terms of costs and technical features, for example.

Carbon footprints are always calculated based on the most up-to-date data on materials and material emissions. Today, material manufacturers are increasingly committed to ensuring the optimal carbon performance of their products. Thanks to the introduction of Environmental Product Declarations (EPD), comparing different product options is also becoming easier. EPDs present standardised, reliable information on the environmental impacts of a variety of products. In addition to a range of other impacts, EPDs also include data on the climate impacts of each product. This allows designers, carbon footprint calculators and procurers to use this information in their initial product comparisons alongside other factors.

3.3 Calculation tools and software

The most commonly used commercial tool for carbon footprint calculation of buildings is the web based One Click LCA software. The tool is easy to use and provides ready for use interfaces to several widely used databases, such as co2data.fi and the most central EPD databases. As the requirements for calculating carbon footprints and climate declarations are further specified, the calculation software offering will also evolve to better fit the analytics requirements at different project stages.

The Finnish Environment Institute SYKE maintains and develops co2data.fi, a free database on emissions from building materials and processes. The website includes average emissions data that can be applied for carbon footprinting of both general construction and infrastructure construction projects. The contents of the database will be further complemented and refined in the future. Going forward, it is also likely that environmental declarations will be published for an increasingly wide range of construction products, and the relevance and usability of these declarations will increase.

The city of Helsinki's assessment method for the carbon performance of local detailed plans (asemakaavojen vähähiilisyyden arviontimenetelmä, HAVA) makes it possible to assess carbon footprints at a local detailed plan level. This allows authorities and operators to estimate and compare the effects that different changes to the local detailed plan have on the carbon footprint of the area, and utilise the results of these calculations in the relevant decision making processes.

3.4 How does the carbon footprint calculation process work in practice?

In a nutshell, the carbon footprinting process consists of collecting the initial data on quantities, energy and other relevant variables, and combining this information with the relevant emission coefficients (Figure 4). The process will also define the net heated area of the building. This number reflects the share of the area inside the interior surfaces of the exterior walls that are continuously heated. The assessed time span is generally 30 to 50 years. The Ministry of the Environment's climate assessment requires an assessment period of 50 years. Quantity data from costing can also be used for carbon footprinting, as the costing process is largely similar to the carbon footprinting process (Figure 4). For example, the cost data drawn from an estimate of required building components can easily be used to assess all structures with a similar quantity accuracy. The assessments and reports used in life cycle management should therefore be drawn up in parallel with relevant costing activities.

Material quantities are calculated based on the up todate designs. The structural elements included in the Finnish Construction 2000 classification system are presented in Table 1 in accordance with the Ministry of the Environment's draft method. It is noteworthy that the draft method does not cover the effects that structures or buildings demolished to make way for a new building have on the overall carbon footprint of a project. Oftentimes, precise designs are not yet available during the early stages of a project. If this is the case, the preliminary emission calculations will be conducted using approximate quantities determined based on the building geometry. For example, the One Click LCA software's Carbon Designer function generates an estimate of a building's life cycle emissions based on the area, frame material, foundation method, facade solution and intended use of the building. Material and product volumes defined as a result of the quantity calculation are linked to the corresponding emissions data. In order to ensure the quality and accuracy of the

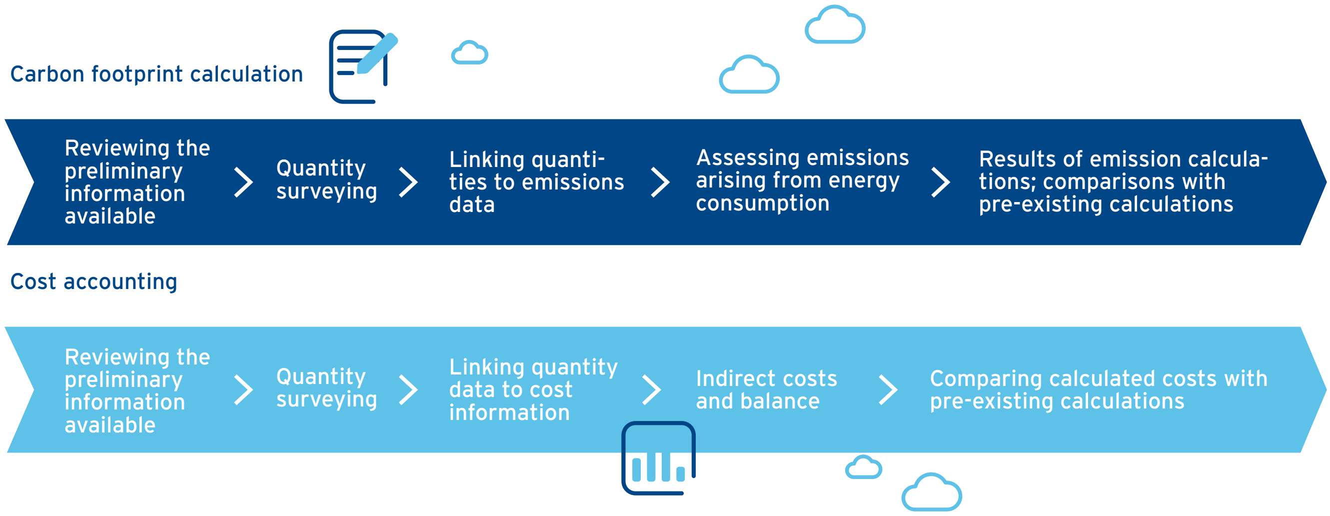


Figure 1. The stages of carbon footprint and costing processes.

assessment, the emissions data linked to the materials quantity data must be as high quality as possible (Table 2).

The Ministry of the Environment's draft method presents a table of values pertaining to areas that are generally speaking challenging to assess accurately. Building technology is one of the areas where the material and component quantities are significantly affected by the intended use of the building and the objectives set for it. Therefore, research-based average tabular values are used for calculating the material emissions arising from building technology. The building's intended use and scale have been factored into these values. If the project in question is a renovation project, the building technology material quantities are estimated separately based on the scope of the renovation or refurbishment. In addition to building technology, the emissions arising from the transport of building materials, site operations, energy used for repairs during use, demolition and waste management are generally calculated using tabular values during the design stage.

Although the aforementioned emission sources are estimated using tabular values, this does not mean that the actual emission associated with them cannot be managed or minimised. Contractors can significantly reduce site emissions through their own actions, and the scope of building technology used for each building can be optimised with the right design solutions, which can also facilitate the recycling of materials at the end of the building's life cycle.

The E rating calculation provides an estimate of the annual energy consumption of the building during use. This information is then linked with the relevant coefficients for the energy sources used (Table 3). Future emission trends have been factored into the emission values determined for different energy sources. In practice, this means that the emission factors used for electricity and district heating will fall sharply as fossil fuels are gradually phased out.

Table 1. Structural elements to be considered in the carbon footprint calculation.

The Finnish Construction 2000 classification system	Included in the assessment	• Not included in the assessment
Site elements	1.1.1 Ground elements 1.1.2 Supports 1.1.3 Surface finishing 1.1.5 Site constructions	• Excavations, trenches and canals • Site equipment • Structures or buildings to be demolished to make way for a new building • Vegetation, soil and water
Building elements	1.2.1 Foundations 1.2.2 Ground floors 1.2.3 Structural frame 1.2.4 Facades 1.2.5 External decks 1.2.6 Roofs	• Separately acquired nails, screws, adhesives, sealants, materials used for seams and other fixtures not included in other products. • Smoke exhaust structures • Product packaging
Internal space elements (infills)	1.3.1 Internal dividers (partitions, doors, stairs) 1.3.2 Space surfaces (floors, ceilings, walls) including surface treatments 1.3.3 Internal fixtures (fixed furniture, kitchen equipment) 1.3.4.2 Chimneys and fireplaces 1.3.5 Box units, e.g. bathroom modules	• Mouldings and angled reinforcement elements • Handrails • Indoor signage • Separately acquired nails, screws, adhesives, sealants, materials used for seams and other fixtures not included in other products. • Product packaging
Building technology	• Main elements of the heating system • Main elements of the water and sewage system • Main elements of the ventilation system • Main elements of the cooling system • Main elements of the sprinkler system • Main elements of the electrical system • Lifts and escalators	• Information technology systems • Main building automation systems • Emergency power systems • Separate machinery and equipment • Product packaging
A maximum of one gravimetric per cent of a single structural component included in the evaluation may be excluded from the scope of evaluation.		
The tabular values provided in the national emissions database may be used to support the assessment of building components.		

Table 2. Emissions data quality.

Construction product data	**When applying for a building permit:** Product or product group specific environmental declaration information (if the materials to be used have already been selected and a valid environmental declaration is available) Data from the national emissions database You should be able to find all the necessary information from the sources specified in points 1 and 2. If the products selected for the building to be assessed are highly unusual, you can also consider the sources specified under points 3 and 4. However, the sources under points 1 and 2 are always preferable. If there is no environmental declaration available for the product, and the emission data of a comparable product cannot be found in the national emissions database, you may consider using other commonly used emissions databases. Data from peer reviewed scientific research, if the research is less than 10 years old and is otherwise applicable to Finnish circumstances **During the commissioning stage:** If available, use the information from the environmental declarations of the building products for calculations pertaining to the building. Otherwise, use the sources defined under points 2 and 3.
Amount of supplied energy	The energy declaration prepared for the building permit application, or an updated version of it If no energy declaration has been drawn up for the building, determine the corresponding information in accordance with the method defined for preparing an energy declaration and use this information to calculate the amount of delivered energy
Emission coefficients of different energy forms	Data from the national emissions database In addition to the national emissions data, you can also use the regional emission factors for district heating or cooling. However, regional emission coefficients cannot be used to replace data in the national emissions database.
Transports, energy used onsite	Values specified in the tables presented in the national emissions database If you want more accurate information on emissions arising from transports, use actual data

Emission coefficient	2020	2030	2040	2050	2060	2070
Electricity (efficiency method)	153	89	59	45	34	22
District heating (efficiency method)	147	114	82	54	29	21
District cooling	42	26	18	13	10	7
Fossil fuels	306	306	306	306	306	306
Biofuels	27	27	27	27	27	27

Table 3. National energy emission coefficients (source: CO2data.fi).

3.5 How to correctly interpret and best use the results

The carbon footprint and handprint of a building are expressed in kilograms of carbon dioxide equivalent per square metre of net heated area per year (kg CO2-ekv/m2/a, see Figure 5). So far, no target levels or thresholds have been set for either the carbon handprint or footprint. When reviewing the results, the most important thing is to identify the most significant stages of the life cycle and spot the structures and materials causing the most emissions. A carbon footprint that specifies the shares of different materials can help to identify the key materials that cause emissions, allowing operators to look into alternative materials with a better carbon performance. However, material choices also affect factors such as thermal insulation capacity. For this reason, it is essential to concentrate on finding the solutions that minimise the carbon footprint throughout the building's life cycle.

Generally, emissions related to materials and energy are the most significant sources of a building's life cycle carbon footprint (Figure 6). The accumulation of the carbon footprint of a building and its life cycle is presented in Figure 7. The construction stage creates a significant amount of emissions. Once the building is in use, the generated emissions are associated with energy consumption. Replacing building parts and repairs also cause temporary increases in the overall emissions. Emissions generated by demolition, waste management and transport are reflected at the end of the life cycle.

Carbon footprinting can be used as a

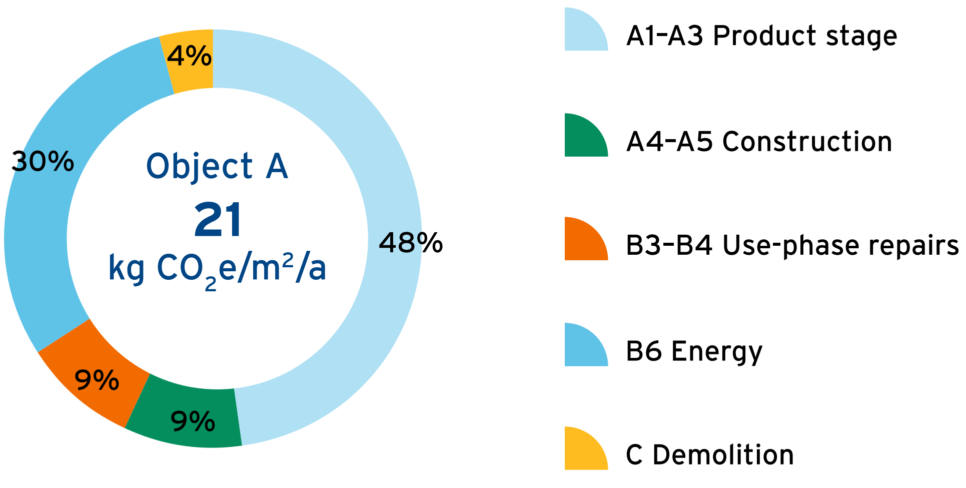


Figure 5. Example of the carbon footprint of a building presented by life cycle stage.

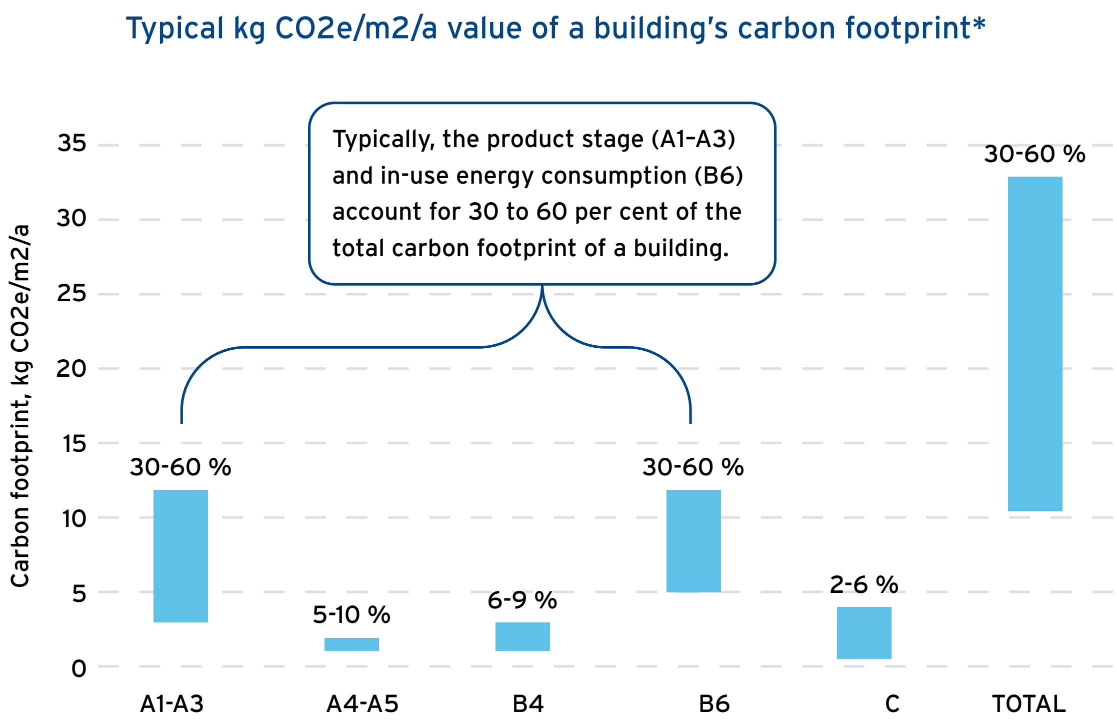


Figure 6. Typical carbon footprint values of newly constructed and renovated buildings by life cycle stage. The percentage ranges represent the module's contribution to the overall carbon footprint of the project.
*** The** typical value represents the typical level as of 2022. Typical values may change as methods and emission coefficients are updated.

supporting tool to evaluate whether it is more cost effective to demolish or renovate a building. Usually, renovating a building is more efficient when considering the carbon footprints of the two options, as the need for virgin resources is usually lower. In renovation and new construction projects, life cycle emissions are typically distributed as shown in Figure 8.

In practice, calculating a carbon footprint always involves some assumptions and uncertainties. These include but are not limited to the quality of the base data, the expertise of the party implementing the calculation, as well as the availability of emission data on the materials used. Therefore, a carbon footprint is always an estimate. It provides information that can be used to compare different alternatives and support the design process. Especially comparative carbon footprint calculations, which examine several alternatives in parallel, are most useful when used alongside (life cycle) cost assessments.

The uncertainties associated with the calculation process can be reviewed using a sensitivity analysis. This analysis can define more specific ranges for the results that are most likely, or shed light on how the most significant assumptions affect the carbon footprint. As carbon footprinting becomes increasingly common, published research on the subject is also more readily available, and the typical carbon footprint values become more established.

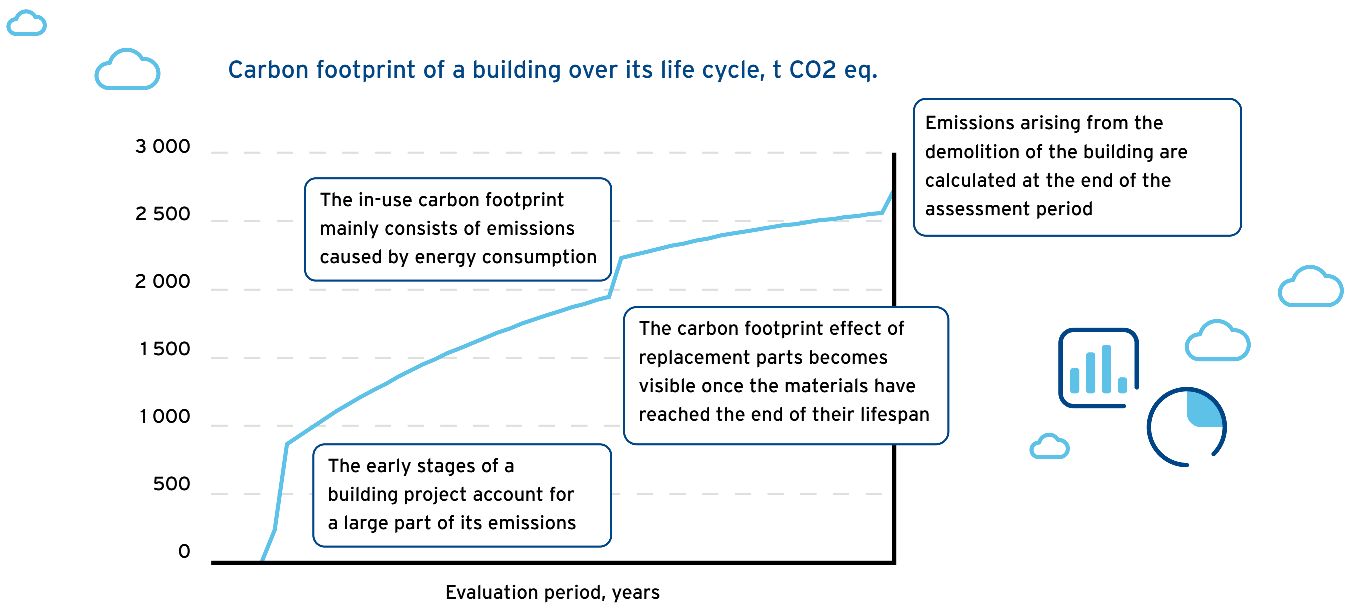
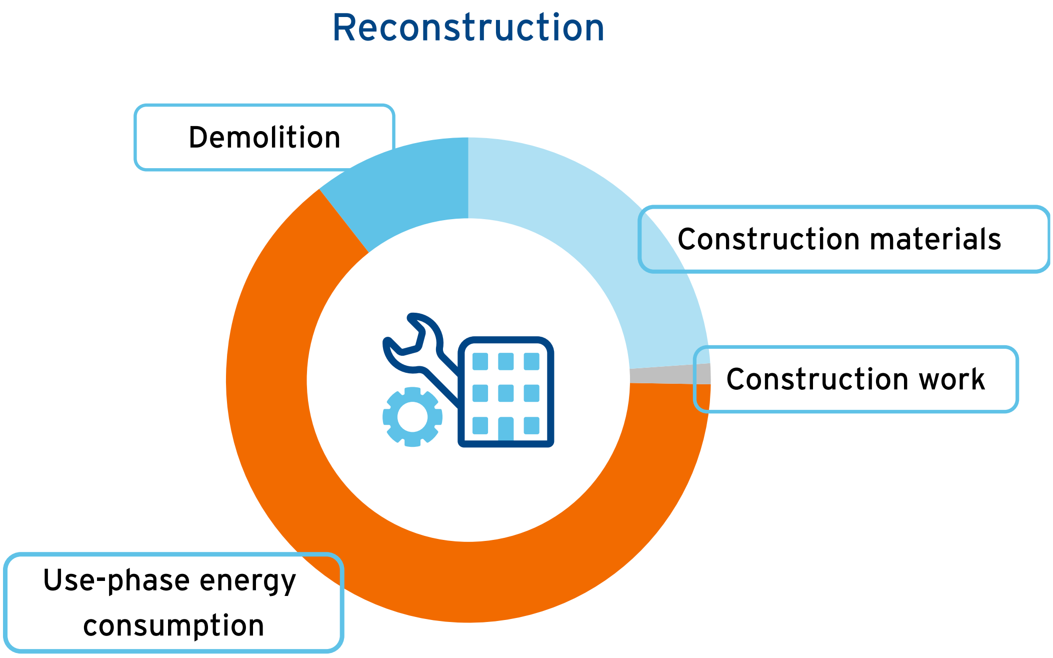


Figure 7. An example of the accumulation of a building's cumulative carbon footprint over time.



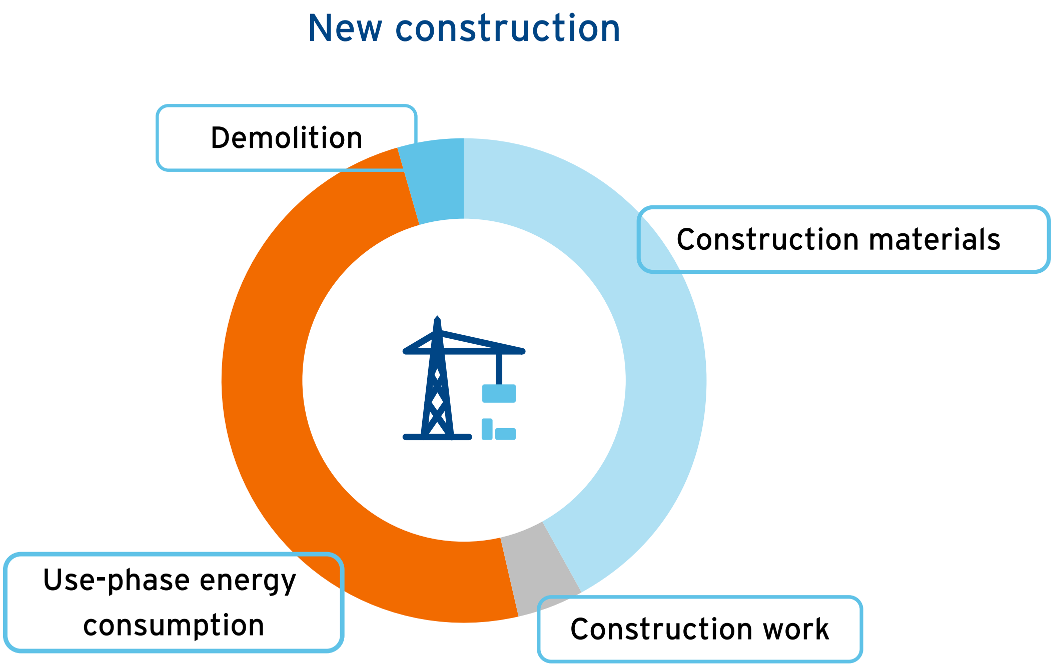


Figure 8. Distribution of emissions of typical renovation and new construction projects by life cycle stage.

4 Examples

Key points

- In companies, carbon footprinting is used to determine the current situation, assess the impacts of different options and measures, and to guide design.
- Projects should prioritise material efficiency, low carbon materials and energy efficiency above other aspects. There is a wide range of measures that can be used to reduce emissions, but in order to achieve the best results, the applicability of these measures should be assessed on a project-by-project basis.

4.1 University of Vaasa campus area

University of Vaasa has launched a project to develop its campuses, aiming not only to decrease costs, but also to make more efficient use of its facilities. In 2019, it was established that real estate makes up about one sixth of the university's total carbon footprint. The project is to be completed in 2024. .

A consultancy company provided a comparison of the in use emissions of the university's six buildings at present and after a potential renovation, if energy and space utilisation efficiency was increased and one of the buildings was no longer in use. The report also assessed the effects of renewable energy on the carbon footprint. The company provided a comparison between different forms of heating, commissioning a solar electricity system, and switching to renewable energy.

The material quantities used for the alterations, refurbishment, etc. in the context of the renovation were estimated based on the relevant designs and expert judgement. The energy data were based on actual data and on energy declarations drawn up for converted and solar power solutions. The calculations were implemented using the One Click LCA and the Ministry of the Environment's draft method for the whole life carbon assessment of buildings.

The assessment included several potential scenarios on the use of different energy solutions. This allowed to project staff to easily compare different options (Figures 9 and 10). The calculation showed that the renovation of campus buildings, improving space utilisation efficiency and decommissioning one of the buildings would reduce the overall carbon footprint by more than 50 per cent over the next 30 years, despite the material emissions associated with the renovations.

The report also looked into the carbon footprints of the buildings during use. Carbon footprints were calculated for scenarios where existing district heating and electricity solutions were replaced with various onsite or renewable energy sources. Compared to the starting point in 2019, improvements in space utilisation efficiency (renovation), using a geothermal solution, solar energy solution and solar energy were shown to allow the university to reduce in use emissions from energy to near zero.

In addition to the general carbon footprint of the campus area as a whole, the assessment examined the effects the renovation and various energy related improvements would have on the development of the carbon footprint. The results allow the campus improvement team to assess which buildings' carbon footprints could be improved the most with suitable solutions, and which ones already were functioning relatively efficiently with the systems currently in place. The study also found that actively monitoring the emissions arising from the campus buildings could benefit the university and the project alliance both in terms of costs and image.

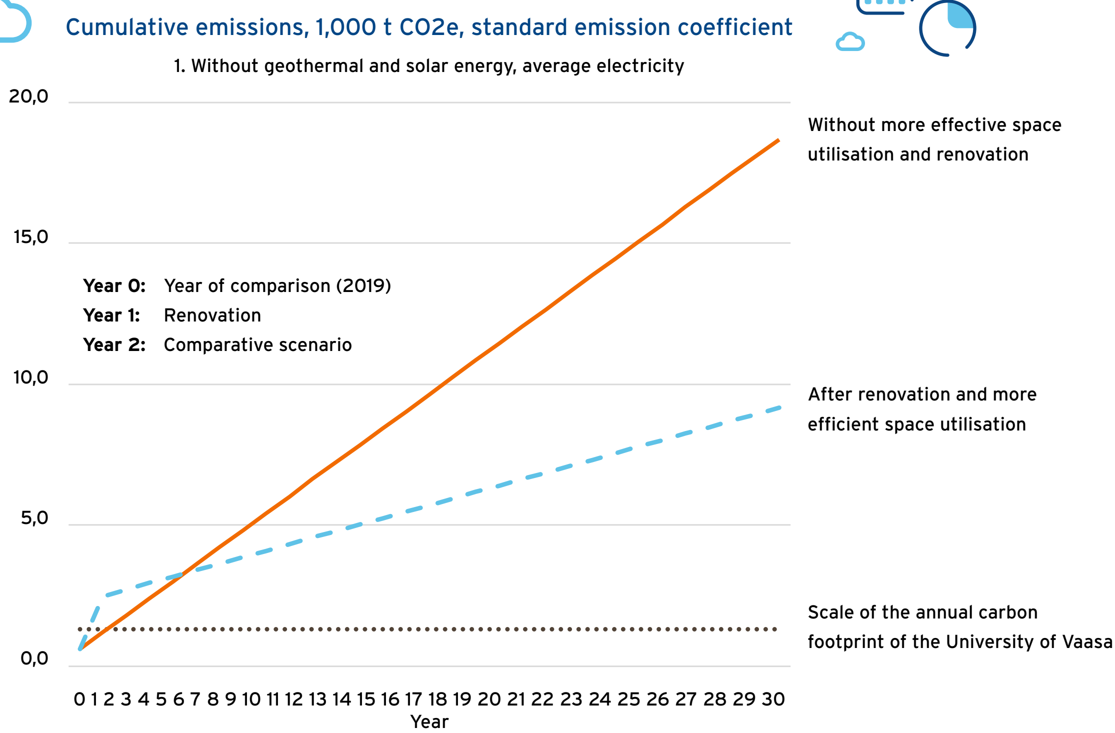


Figure 9. Cumulative in use emissions of the University of Vaasa campus project under different scenarios.

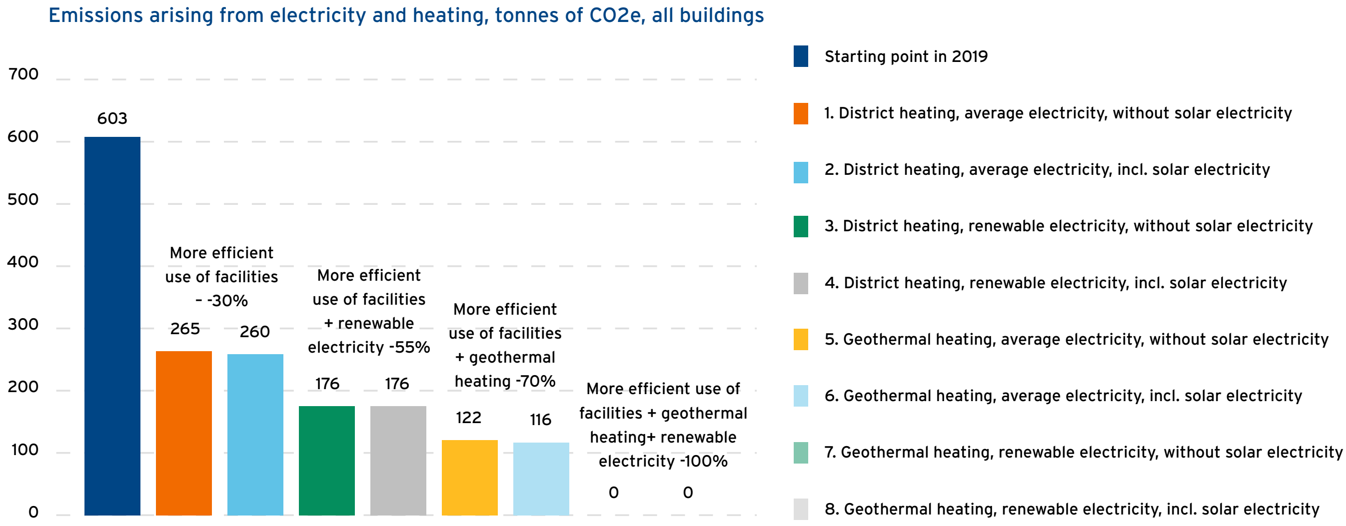


Figure 10. Emissions from heat and electricity under different scenarios.

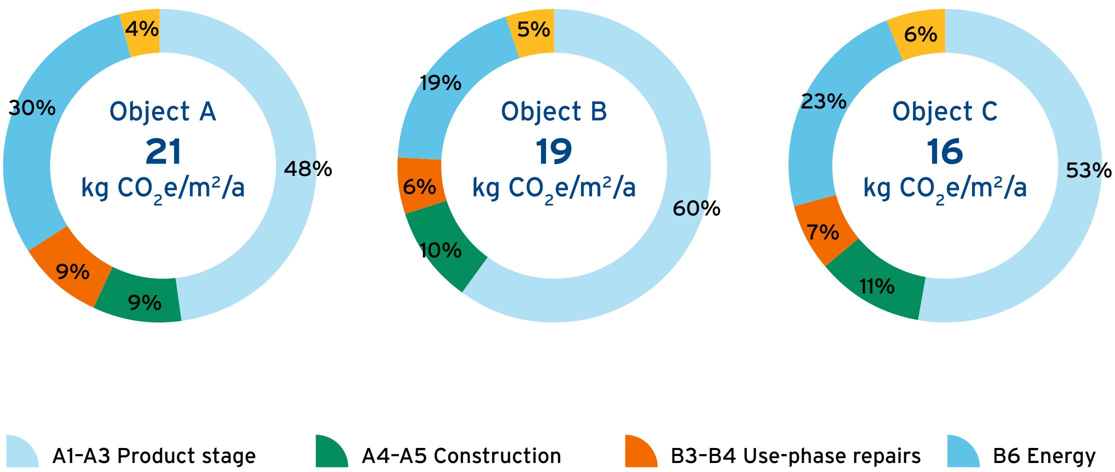
4.2 An apartment building built as new construction

A carbon footprint calculation was prepared for the building permit process of three new ARA-funded apartment buildings owned by NAL Asunnot Oy. The calculations were based on the energy declaration and designs submitted as a part of the building permit process (Table 4). The developer wanted to perform these calculations to determine the steering effects of the design requirements and guidelines used in the organisation in terms of carbon performance, and to facilitate further improvement of these requirements and guidelines. Even currently, the organisation's target energy efficiency class for all projects is A. In addition, the possibilities for installing both geothermal energy systems and solar panel solutions are assessed for every site.

The calculations showed that in use energy consumption formed accounted for a smaller percentage of the carbon footprint of buildings that used renewable and on site energy sources buildings than buildings that used district heating. For buildings A to C, the share of in use energy consumption was between 20% and 30%, whereas in buildings that used district heating the corresponding figure was up to 50%. For energy efficient buildings, the most effective ways to improve the buildings' carbon performance are ensuring material efficiency and choosing low carbon material options. Optimising structures to make them as lightweight as possible (while maintaining structural integrity) was considered to be the most effective way to reduce material consumption and decrease the overall carbon footprint.

The implemented calculations provided NAL Asunnot Oy with useful information on which factors generally affect emissions in construction projects, and how these emissions can be reduced. For apartment buildings, materials are selected based on e.g. which piles are suitable for the soil type at the site, or which frame structure type presents the most cost efficient solution. For the buildings presented here, steel piles and a concrete frame were determined to be the only possible option. The calculations also provided information about the scale of the carbon footprints of future buildings, thus allowing NAL Asunnot to improve its building designs' carbon performance in the future.

In addition, the carbon footprint showed that the type of foundation used and the conditions in which the foundations are laid have a significant effect on the overall carbon footprint of a project. Unfortunately, steel tube piles are the most expensive and emission heavy foundation type available. There are a variety of aspects that are worth considering before implementing a renewable energy solution. Possible regional or city specific regulations regarding facades and roof surfaces must also be taken into account and reviewed when considering solutions that use solar energy.



An apartment building (new construction)	Building A	Building B	Building C
Area	4,700 gross m2 (8 floors)	3,200 gross m2 (6 floors)	5,200 gross m2 (11 floors and a basement)
Use of renewable energy	Solar power plant	Geothermal heating system	Geothermal heating system
Total energy expenditure of the building	74 kWh/m2/a (A)	75 kWh/m2/a (A)	-
Frame structure material	Concrete (with a brick exterior)	Concrete (with a brick exterior)	Concrete (with a brick exterior)

Table 4. Data and carbon footprint of apartment buildings by life cycle stage.

4.3 Best practices for reducing the carbon footprint of construction projects

Construction sector operators are increasingly interested in what is considered low carbon construction. There is currently no clear definition for what constitutes a low carbon project – a fact that the industry must address in the near future. At present, the few pioneers in the field are able to set their targets themselves, as nationally defined ranges for what can be considered a low carbon building are expected to be published in 2025 at the earliest. If the organisation is going to set a threshold value for the carbon performance of buildings, its decision makers must take into account future developments in legislation, energy production and products. However, the road to reducing emissions is almost the same regardless of the time action is taken: operators must identify emission sources and measures to reduce emissions, implement the identified measures, and develop their own operations in accordance with what they have learned as a result of the process.

There is a wide range of measures available to reduce emissions. Measures targeting the most significant emissions sources will naturally produce the greatest impacts, but in the fight against climate change, every little bit helps. Developments in various areas of society and commercial life will aid future efforts to mitigate the climate change. The general knowledge levels regarding the issue, calculation methods and emission performance of site operations and energy are also expected to improve in the near future.

For example, energy efficiency and use are not always fully managed or optimised in all projects. When commissioning calculations, owners and developers can usually assume that certain package solutions (structural solutions) will help them to increase the energy efficiency of all their buildings to the same, uniform target level. While it is true that certain measures, such as improving the thermal insulation properties (U-values) of cladding, efficiently sealed windows and other structures, will in principle improve the energy efficiency of any project, they will not automatically guarantee that the desired results are reached. Similarly, from a carbon footprint perspective, it is easy to assume the carbon footprint of all sites can be minimised using identical means. Each project has its own specific set of characteristics, and is thus unique in terms of which emission sources emerge as the most significant. Reducing a project or building's carbon footprint is a sum of many interchangeable parts, and operators should take care to choose the most suitable ones for each project, both in terms of practical implementation and costs. Businesses and the industry in general should there-fore explore and attempt to compile a range of set standard solutions for different applications that improve the carbon performance of the sector as a whole.

Life cycle thinking should be considered a central principle of construction projects, and it should be applied throughout the life cycle of both the project and the resulting building. Investments in solutions that are more efficient at a life cycle level may increase initial costs. This investment will, however, be repaid during in the longer term, as the solutions create cost savings during use.

Projects should primarily prioritise low carbon materials and energy efficiency. Energy solutions should also be regarded as a priority, although electricity and district heating producers also aim to make their own operations carbon neutral in the medium term. Table 5 presents examples of measures that lower emissions.

In new buildings, especially public buildings such as schools, operators should promote shared use, and this should also be taken into account in the designs. Allowing external operators to rent out the space outside standard opening hours can increase the occupancy rate of the building and thus contribute to resource efficiency and a better carbon performance. Although increasing occupancy increases the overall energy consumption, it is more efficient to use the existing building stock to meet a more diverse range of needs than to build entirely new facilities.

4.4 Carbon footprint characteristics of different types of structures

Figure 11 shows the average carbon footprints of the most common structure types. The figure clearly shows that structure types that use concrete and steel-based materials have a larger carbon footprint per structural square metre. Since foundations are notoriously difficult to assess as a whole, they have not been included in the figure. It can, however, be noted that out of all foundation types, pile foundation produces the most significant amount of emissions.

Figure 11. Average carbon footprints of different types of structures. The calculation is based on conservative emissions data from the co2data.fi database.

Energy	• Systematically examining the potential for using geothermal heating and solar panels in all projects. However, the carbon payback period of solar panels must be taken into account (the devices are manufactured using minerals that cause significant emissions), and the investment costs must be included in the life cycle costing. • When choosing electricity for buildings and users, always prioritise fossil-free options. • Buildings with a large number of rooms that require cooling must always be equipped with a heat recovery system. • If the project in question is a complementary development project, parties involved must look into potential solutions to utilise recovered waste energy from other buildings in the area. • Considering energy efficiency from a life cycle perspective: noting that using too much electrical equipment may increase emissions at the beginning of the project, which in turn can cause an emissions spike that exceeds the potential benefits.
Design and materials	• A location or plot comparison conducted by a project developer to determine the location with the best conditions for constructing a foundation (to avoid piling, as this method generates the most emissions) • Comparing alternative paste or frame solutions for each project. If the site is small, preference is given to solutions utilising wooden structures (wooden facade/frame) • During the structural design stage, the structures are designed to be as lightweight as possible, minimising the use of materials that produce significant amounts of emissions (such as concrete), however with regard to the whole construction (e.g. technical and functional considerations) • Increasing the convertibility of the building. Solutions such as dividing spaces with partition walls, designing structures for demolition (DfD approach), ensuring the maintainability of building components or constructing the building to be maintenance free. Sharing and renting out spaces to increase the building's rate of utilisation are an efficient choice in terms of the building's life cycle performance. • Implementing an EDP based comparison in the most significant purchases of all projects. • Taking circular economy standpoints into account: design for demolition, design to ensure maintenance and repair access to structures throughout the building's life cycle.

Construction	• Carbon collaboration projects, such as using recycled materials or aggregates, mass balance • Contractor’s carbon performance, encouraging or requiring the use of low emission machinery and transport equipment and renewable fuels. Ensuring sufficient monitoring and that key stakeholders are committed to the carbon performance objectives, rewarding successes. • Minimising waste, utilising new innovations, such as inventories of surplus materials between sites, using empty spaces of existing buildings as site offices. • Effective waste management, recycling and monitoring adherence. • Optimising site logistics, ensuring every load is full and implementing procurement jointly with various contractors.

Repairs	• Energy efficiency improvements as part of large scale renovations, including
	  • installation of equipment related to systems used to produce energy
	  • installation of equipment for monitoring and measuring energy consumption (including water consumption)
	  • structural improvements and sealing (replacing windows, doors, additional insulation of the cladding structures)
	  • Systems that indirectly decrease energy consumption, such as equipment for charging electric vehicles

Purkuvaihe	• Contractor’s carbon performance, encouraging or requiring the use of low emission machinery and transport equipment and renewable fuels, optimising transports. Ensuring sufficient monitoring and supervision. • Demolition assessment, identifying materials for materials recovery and ensuring they are utilised. • If the project is a renovation project, striving to utilise any existing structures that are in a good condition as efficiently as possible.

Table 5. Measures to reduce the emissions arising from a construction project.

Attachment 1: Key carbon footprinting materials

Table L1. Key standards, guidelines, tools and other materials on carbon footprint assessment and management.

Standards	
Life cycle assessment	EN ISO 14040, 14044
Carbon footprinting, general level standards	EN 15643 and EN ISO 14067
Carbon footprints of buildings	EN 15978
Carbon footprints of products	EN 15804
Methods, instructions	
The Ministry of Environment's method for the whole life carbon assessment of buildings	Draft method, 2021. Finalized method forthcoming.
ELINK18 task list for life cycle experts	RT 10-11291
Carbon neutral buildings	How to assess your operations and construct a carbon neutrality claim
Designing buildings to withstand the effects of climate change	A guide for developers and property owners
Carbon neutral buildings	
Carbon footprinting of buildings	One Click LCA, Carbon Designer (paid software) One Click LCA Planetary, free software for product stage assessments
Databases	
Construction related emissions data (construction and infrastructure construction)	www.co2data.fi
Environmental Product Declarations published in Finland, RTS-EP	https://cer.rts.fi/epd-ymparistoseloste/selaa-epd-ymparistoselosteita/
International EPD System's environmental product declaration library	https://environdec.com/library
EPD-Norway's environmental product declaration library	https://www.epd-norge.no/epder/
A general Global EPD Database	Ecoinvent, https://ecoinvent.org/

Table L1. summarises key standards, guidelines, tools and other useful materials on the carbon footprint of buildings.

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