Nordic
Innovation

Nordic view on data needs and scenario settings for full life cycle building environmental assessment

Contents

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Preface

This report is a part of the Nordic Sustainable Construction programme initiated by the Nordic Ministers of Construction and Housing and funded by Nordic Innovation. The programme contributes to the Nordic Vision 2030 by supporting the Nordics in becoming the leading region in sustainable and competitive construction and housing with minimised environmental and climate impacts.

The programme supports the green transition of the Nordic construction sector by creating and sharing new knowledge, initiating debates in the sector, creating networks, workshops and best practice cases, and facilitating the Nordic harmonisation of regulation for buildings' climate impact.

The programme runs from 2021-2024 and consists of the following focus areas:

Work package 1 – Nordic Harmonisation of Life Cycle Assessment

Work package 2 – Circular Business Models and Procurement

Work package 3 – Sustainable Construction Materials and Architecture

Work package 4 – Emission-free Construction Sites

Work package 5 – Programme Secretariat and Capacity-Building Activities for Increased Reuse of Construction Materials

This report is a final deliverable for Work package 1, task 2, focusing on data and data management. Work Package 1 is led by the Finnish Ministry of Environment.

The work has been carried out by the IVL Swedish Environmental Research Institute, Finnish environment Institute (SYKE), Natural resource institute Finland (LUKE), and with the help of a large group of other experts in all Nordic countries and Estonia.

All views, interpretations, and recommendations are made by the authors and represent no official statements.

Nordic Sustainable Construction

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Authors:

Martin Erlandsson, Frida Görman, Åsa Thrysin, Tarja Häkkinen, Klas Eckerberg, Janne Pesu, Malin Dalborg, Johan Asplund

And annexes with the additional authors:

Tarja Häkkinen

Klas Eckerberg, Tommi Kaartinen, Allan Schiøtz, Trine Dyrstad Pettersen

Ashraful Alam, Martin Erlandsson, Per Erik Karlsson, Eskil Mattsson, Heli Miettinen, Miia Mänttäri, Frans Silvenius and Eeva-Maria Tuhkanen

Per Erik Karlsson, Eskil Mattsson, Martin Erlandsson

Sirje Vares, Jarmo Linjama, Janne Pesu

Other contributors:

Maria Balouktsi, Nicola Francart, Kai Kanafani, Anni Oviir, Anne Rønning, Ólafur Ögmundarson

Summary and recommendations

Introduction and targets

There is a clear need to harmonise the environmental assessment of buildings. Both the EU and national governments are planning to regulate, if not already regulating, buildings based on the amount of life cycle emissions. According to the new Energy Performance of Buildings Directive (EPBD), it will be mandatory to report a so called life-cycle GWP (Global Warming Potential) indicator result for all new buildings. This includes both greenhouse gas (GHG) emissions embedded into building materials and emission caused in the construction stage, use of the buildings, and end-of-life. This life cycle assessment (LCA) of buildings requires a great deal of data, assumptions, and calculations. Comparable results can only be achieved if the data and the calculation methods are based on the same methodology and scenario settings. The need to standardise or agree on principles is further emphasised by the number of stakeholders related to buildings' design, construction, and operation.

This report is part of the Nordic efforts to harmonise full life cycle environmental assessment. All views, interpretations, and recommendations are made by the authors and represent no official statements.

Main targets for the report are:

1. Establish a common view and understanding of the GWP data for all kinds of resources that are used by the building during its life cycle and the LCA methodology settings needed. LCA methodology settings are preferably based on the existing and applied standards and the current praxis already implemented, and thereby cost-effective.
2. Give recommendations on scenario settings and calculations rules based on both expertise and experience.
3. Study some of the previously identified areas of missing or limited information.

It is important to understand the standards and LCA practices, and highlight issues that have not been considered thus far in the creation of national rules or standards for the assessment of buildings. Since 2021, there has been national building GWP databases and

LCA calculation methods in some Nordic countries. The industry cooperation and feedback has been an important part of improving the databases and methods.

The standardisation and regulation development are ongoing, and all statements in regard to the future are predictions and/or recommendations. Most recommendations are assuming strong EU regulations based on the standardisation process. Following all recommendations, even if a decision would be made today, will require considerable efforts and take time.

This report makes recommendations on future calculations needed for the EPBD life-cycle GWP indicator for buildings. A tiered approach is suggested when a recommendation is worked out, where the first choice is to use the European common method and only when the necessary national specifications or scenario settings or additions are used. Besides referring to the already implemented European standards, the recommendations also refer to the EU work that is already made, e.g. energy decarbonisation scenarios. This approach supports a common agreement of the recommendations worked out, as well as a cost-effective implementation of the LCA.

Due to the needs of planned regulation, some potential areas to be part of a building climate declaration, as well as open questions about those topics, have been selected to be studied further within this project. The following potential topics are handled:

- Inclusion of vegetation on the building plot
- The potential to assess an GWP indicator for existing buildings (old buildings)
- How can sustainable forests be defined and hereby, for instance, potentially in the future, be accounted for a biogenic carbon sink when there are parts of long-lived construction products like sawn timber?

Global Warming Potential (GWP) indicators

The main indicator for climate LCA databases is GWP. There is also a consensus from the standardisation work, as well as EU initiatives that the GWP indicator shall be divided in:

- GWP total: the sum of GWP fossil, GWP biogenic, and GWP land use and land use change (luluc)
- GWP fossil: the sum of all greenhouse gas emissions from fossil sources
- GWP biogenic: emission of all greenhouse gases and biogenic carbon stored in the product and its packaging materials
- GWP luluc: the emission from potential land use and land use change

The use of the GWP total indicator is unproblematic when it includes all information modules from A to C. However, the GWP total as a GWP indicator restricts the comparison between individual modules, as the uptake and emission of biogenic carbon occurs in different modules and only balanced out over the full life cycle to zero. The solution for this is to apply a complementary GWP indicator here, referred to as GWP-GHG (or sometimes named GWP-IOBC). This GWP-GHG indicator can be calculated with the existing mandatory information reported in an EPD (Environmental Product Declarations). This indicator accounts for all greenhouse gases except the biogenic carbon uptake in the product or its packaging and emissions in the end of life. Thereby, the LCA result is comparable information module by module. This is of special interest when limit values do not cover the full life cycle. This is, for instance, asked for in Sweden, where a limit value is also asked for the construction stage (A1-A5). It should be noted that the life cycle GWP indicator, according to the Taxonomy and EPBD directive, is based on the summed impact from A to C, which is why there is no difference in the result whether the GWP total or GWP-GHG was used when the full life cycle is assessed.

A harmonisation of GWP indicator use is needed and must be found on the information given in an EPD. The GWP total shall be used when the impact is summed from A to C. If any nation introduces an additional limit value for a single stage (like A1-A5), the use of GWP-GHG is recommended.

Data

GWP data for generic databases for construction products is based on publicly available information, such as EPDs. The data is still far from perfect as the quality of generic data varies, especially due to the lack of EPDs in some service and product areas. To support the creation and use of EPDs, conservative factors (+20 to +25%) have commonly been applied to cradle-to-gate (A1-3) values. When it is feasible to require specific EPD data for construction products supported by European Commission law, it is possible to phase out the conservative factor in this kind of generic databases.

The construction market is largely domestic for many construction materials that significantly contribute to the GWP. Although common approaches between countries can be applied for the collection of source data, at least the domestic high-volume products should be handled nationally based on national EPDs, and the market share should be taken into consideration if possible when generic data is defined.

Scenario setting

A climate declaration according to the EPBD life-cycle GWP indicator covers the future and thus the scenario settings for modules B and C. These scenario settings need to be harmonised on a common basis to maintain comparability and consistent results for all parties. The recommendation is to define the scenario settings as representative as possible, based on a stepwise approach. This approach should cover geographical representativeness, technology representativeness, time representativeness, use of specific data, and transparency in reporting. Where a simplification is possible, a European common average approach can be used as a default starting point. Nordic or national scenarios can then be created based on the same methodology approach as applied in the European scenario setting. It is further recommended that all scenarios are based either on the parametrisation or otherwise open reporting of the data sources and calculations, rather than a fixed calculated GWP result.

Decarbonisation scenarios are recommended for B and C modules that describes the improved climate impact in future. There are high resolution scenarios developed by the European Commission based on national information and political decisions, which can therefore be used as a common source all over Europe. Also, national scenarios have been created by the national regulators. For simplicity, one decarbonisation scenario is presented for modules B1.2-B5, B7, and C1-C4, and another scenario for B6. The scenario shall not be applied for the carbonisation of concrete and build in carbon, such as biogenic carbon or carbon stored in, e.g. plastic that is released in C3/C4. The suggested decarbonisation scenario for the first above-mentioned information modules is the EU Prime scenario called "Total GHG emissions, excl. international excl. LULUCF". The EU Reference Scenario 2020 is the baseline scenario to assess options informing the policy initiatives in the European Green Deal package adopted by the European Commission. The recommended scenario for B6 is a simplified approach to the EU Prime residential scenario. If a national/local energy scenario(s) exists, these can be used and reported as additional information to maintain comparability across countries and transparency when national regulated scenarios are developed. The energy mix used as the default is the national grid mix.

Recommendations by module

Table 1 below summarises the recommendations for each LCA module. It also adds information on what could be developed in the EPD to support calculations on the building level. More in-depth discussions and recommendations can be found in later chapters.

Module	Recommendation
A1-A3: Product phase	In a building permit: Generic national representative GWP data on at least high-volume construction products must be advised (typically 80% of GWP-GHG A1-5) and publicly available for free and collected in a GWP database. As built: Generic data may be replaced by specific EPDs according to EN 15804 if the product is bought.
A4: Transport	In a building permit: Parametrisation on transport combined with a default transport distance per generic building product valid for the European or national level. As built: Part or all of the generic parameters advised by an authority in the transport scenario may be replaced with specific data if verification exists. EPD support: In an EPD, it is possible to define commonly applicable mix-scenarios for A4 for different European regions and/or countries.
A5 Construction process, Energy (A5.2)	In a building permit: Ready-made default GWP data, i.e. template data, based on different building types are recommended based on a European or national representativeness. As built: measured data and if this is not measured, advised generic data as listed above must be used. EPD support/building permit: It is recommended to develop a common European parametrisation scenario. This default scenario is used for all construction products if the so-called complementary product category rules (cPCR) that are developed for a specific construction product do not develop a more representative parametrisation scenario.
A5 Construction process, Waste (A5.3)	In a building permit: A generic waste factor from the installation process is given per construction product based on a European or national representativeness. The simplified Nordic data to be used is presented here. As built: On-site measured waste generated data may be used if it can be proofed, and if not possible, it is acceptable to use the advised generic data as listed above. EPD support/simplified approach: It is recommended to define a common European waste factor per cPCR developed.
Stage B, C and potentially D	It is recommended to use a decarbonation scenario for scenario settings, These GWP figures can be generated by a simplified so-called three-point-method scenario approach. As the minimum, one scenario shall be applied that should be a WEM or WAM[24] scenario where WEM is the preferred choice.

B1 Use, Carbonation from concrete (B1.1)	A simplified option: A Nordic default figure for all concrete products is recommended and presented here. More specific option: A specific calculation can be made, and it must follow EN 16757 and found on material characteristics for the specific products used. EPD support/simplified approach: It is recommended to define a common European template approach with the most frequent intended use alternatives to be included in the cPCR when it is relevant.
B1 Use, Emissions of refrigerants (B1.2)	A simplified option: A Nordic default figure for all emissions of refrigerants per year and the useful area heated and/or cooled with compressors that use refrigerants is recommended. More specific option: How a more specific value should be calculated needs to be decided in the delegated act or by the national legislation. EPD support: It is recommended to define a common European template approach on leaching with the most frequent intended use alternatives to be included in the cPCR when it is relevant.
B2 Maintenance	GWP data: Data used for A1-A5 can be used for B2-B5 with a decarbonisation scenario, a number of replacements based on the decimal number approach of the estimated service life. Reference study period (RSP): It is suggested that a RSP of 50 years is used for all architypes and that it reflects the time span when a building needs to be rebuilt and modernised. Calculation method: prEN 15987, the decimal number approach is recommended. Estimated service life (ESL): It is recommended that the delegated act includes a European default set of the ESL. These ESLs can be replaced by a generic nationally-defined ESL. These data can be replaced by the EPD data if it is based on a cPCR that includes generic ESL data and/or instructions for a product-specific specified ESL.
B3 Repair	as for B2, where information on the repair can typically be found in statistic information.
B4 Replacement	as for B2
B5 Refurbishment	as for B2, where it is recommended that the B5 refurbishment is more strictly defined to cover the combined upholding exchange activities and process that covers more than one building element.
B6 Operational energy use	A simplified option: Approach A in prEN 15978, as defined for B6, is combined with the energy use data as defined in the national implementation of EPBD. It is recommended to use a decarbonisation scenario based on EU Prime. More specific option: A national scenario can be used if advised by the authority and then reported as additional information. The energy mix used as the default is the national grid mix.
B7 Operational water use	It is recommended that European common figures as part of the delegated act can be used if national data does not exist. EPD support: The same parameterisation can be used in the EPD and then directly used for input on the building level. These GWP values can be replaced by EPD data related to the actual water supply or wastewater treatment, or other specific data in line with the EN 15804 methodology. The simplified Nordic data to be used is presented here.
C1 Deconstruction, demolition	A European generic parametrisation is recommended and the corresponding data to be used is presented here. EPD support: The same parameterisation can be used in the EPD and then directly used for input on the building level.
C2 Transport	Similar to A2 in a building permit, but where a European (one figure) average distance is 50 km, or different distances per material category, can be overruled by national additions or potentially specific distances. EPD support: In an EPD, it is possible to publish several scenarios for C2 for different European regions and/or countries.
C3 Waste processing and C4 Disposal	It is recommended that C3/C4 is based on parameterisation that can be used to develop on a 100%-scenario of different waste treatment scenarios scenarios that are listed in this report. Then the ready-made 100% scenario can be published, representing European averages in the EPBD delegated act. EPD support: The 100% scenario data can be supplied by a EPD that then must include the relevant 100% reported separately and defined in the PCR.
D Re-use, recovery, recycling potential	Not included in the EPBD life-cycle GWP. Optional to add on a national level.

Table 1 Recommendations by module

GWP declaration supervision

The trust of the certificate must be supported by a supervision (auditing) process. The importance of establishing a cost-effective and sufficient supervision process is something that is not fully developed for today's building climate declaration. It is notable that the need for a supervision process will increase when the limit values are launched to support a fair comparison and free competition. As part of the supervision, in order to digitally validate numerical values from building systems parts, it is necessary to introduce a classification system of grouping a 'building element type'. Then, to create a key performance indicator (KPI) per the 'construction element type' that can be used to evaluate if the specific reported value for a building element type can be compared to the statistic normal value, a common reference unit is needed.

In the long run, it is recommended that a free-to-use European classification system based on the standard IEC/ISO 81346-2 Classification of objects and codes for classes should be established in lieu of different national classification systems. It should be recognised that further developments would be needed since the current IEC/ISO 81346 does not include a granularity for the 'construction element type', where the materials used in a construction element are typically accounted for. Such granularity is essential and is needed to make a digitalised cost-effective supervision possible, since the amount of construction product data that is part of the integrated life-cycle GWP supervision may cover several tens of thousands of data rows.

Data for vegetation

As indicated in Table 1, there is still quite a lot of harmonisation potential, but there are some knowledge gaps even in Product phase (A1-3). One of the more difficult questions has been the calculation of the effect of vegetation, mainly trees. There are few relevant LCA results on vegetation and correspondingly, no data in generic databases. Although most of the current or planned regulation do not require an assessment of the building site and its vegetation, there is a clear market demand to understand the climate impact of vegetation in addition to the building itself. When vegetation is reported as a complement to the mandatory part of the EPBD life-cycle GWP indicator, this kind of information also needs to be produced in a harmonised manner. This information from vegetation can be regarded as an extension of the mandatory information that shall be part of other biogenic sink effects, as asked by the EPBD directive (see Annex V), related to the physical building itself, referred to as: "information on carbon removals associated to the temporary storage of carbon in or on buildings".

The resulting LCA data for trees shows that over a 50-year period, the amount of carbon sequestered by trees is significantly higher than greenhouse gas (GHG) emissions from the planting, maintenance, or removal of a tree. The highest carbon sink is achieved when the existing trees are not cut and remain in the area during a construction phase. Although the removal of trees results in the highest GHG emissions, this can be partly compensated by planting new trees and creating a new sink.

More in-depth discussion and results on the data for vegetation can be found in Annex 4.

Sustainable forestry

The assessment of biogenic materials in construction products has been another frequently raised issue. This work deals with sustainable forests as it is the major source for renewable materials stored in a building. It has been agreed in the LCA methodology currently used (EN15805, EN 15978) that biogenic carbon always will be zero over the life cycle A to C when the product comes from a sustainably managed forest. Since the term sustainable forestry has not been well-defined in these standards, the project arranged for an expert workshop to discuss sustainable forestry in relation to building LCAs. Wood-based products from sustainable forests are also a prerequisite for being considered a potential source for the EPBD declaration of mandatory information on carbon removal associated with the temporary storage of carbon in or on buildings (see Annex V).

A report on the considerations for defining sustainable forestry in LCAs for biogenic carbon can be found in Annex 5.

Data for old buildings

Current construction processes and tools enable good knowledge regarding the material composition of new buildings, but there is little data on the material content of existing buildings here referred to as old buildings. Our building stock volume, which grows through new construction annually, is very limited. According to Eurostat, 85% of buildings in the EU were built before 2000 and it is estimated that 85-95% of the buildings that exist today will still be standing in 2050. The existing building stock and, e.g. transformation, utilisation, and renovations are upcoming focus areas in regulation.

Dealing with the existing building stock in climate regulation is an open question in all Nordic countries, but a discussion has been opened on both the methods and availability of data. If, for example, a renovation would require a climate declaration for the building permit, the deconstruction phase would also need to be assessed to evaluate the deconstruction, transport, waste management, and disposal of the to-be-removed material. However, such existing materials are currently regarded as sank costs in LCAs, and only the new construction materials added are accounted for when the building is refurbished or deeply renovated. The EPBD requires a climate declaration on the same format as for new buildings for renovations that achieve A+ (no other renovations require a climate declaration).

It was proven possible to use archetypes to estimate the amount of main materials in different typical building structures for old buildings. Because such information is very generic, the use of building-specific data is recommended where possible. The existence of generic information opens possibilities for the early planning and rough evaluation of overall material flows.

A report on the data for old buildings can be found in Annex 6.

Databases and interoperability

Most Nordic countries already have a generic GWP database for construction products in operation or refer to others' domestic databases that shall be used when generic data are used. The scope of databases typically follows the current or planned scope of climate declaration. All databases include cradle-to-gate data for construction products, energy wares, and any other resource to be used in module A1-3. The availability of data for other modules and indicators varies.

These national databases are used widely and their GWP data are integrated into a wide range of tools. All databases are free to use and feature simple interoperability based on machine-readable files. However, common formats, naming, and classifications have not been defined to fully facilitate the interoperability; and currently, the databases mostly interface with tools for calculating the GWP impact.

The GWP databases adequately support the needs for current calculation methods, but some development is required to follow the forthcoming regulation and interoperability needs. The adoption of LCA data into BIM requires machine-readable EPDs and generic data preferably in a common format. The most promising and recommended way to achieve this is through the work on product so-called data templates, which will also be used for other aspects of the regulated construction product performance declaration. Another requirement, in practice, is a common classification system of building parts. All classification systems for the built environment have their strength and weaknesses, based on their purpose. It is recommended to base the common classification system on IEC/ISO 81346, which is the only system designed for the life-cycle stable classification and identification of digital objects.

Scope and regulation

The scope of building LCA should be defined according to regulatory targets and their priorities, but it is not easy to decide what is good enough. While the recommendations of this report set the bar high on accuracy and completeness, it tries to take into account what is also doable in practice.

The current plans and related actions of Nordic authorities are in line with envisioned future EU regulations and the recommendations of this report. The situation today, however, is quite different across the countries. The scope of the declared modules, as well as the included building elements, are not harmonised, and neither is the area regarding how much of the services and processes should be product-based and how much on a building level (e.g. emissions /m^2 for a given architype).

Data and databases are not the driving force behind deciding the scope of regulation or calculation method, but decisions on regulation directly affect the cost and effort needed to create and maintain generic data. Overall, it would be interesting to analyse the cost and potential impact of different scopes and regulatory options. A complete life cycle assessment is a multi-faceted and complicated method hopefully, this report can answer some questions, but it is good to keep in mind that standardisation and regulatory work continue, and both questions and answers may change in time.

1. A Review of European development

Introduction

This section introduces and summarises the current situation and ongoing development regarding European regulations that aim at the common understanding and harmonisation of rules and principles applied towards the environmental LCA-based aspects related to buildings during their life cycle. These rules and principles may concern the assessment methods, quality of assessed and/or reported data, and regulations planned or set for reporting data or limit values. Other aspects to consider include requirements for typical GWP data and that their interoperability with relevant services, systems, and software can be ensured. In addition, the aim is also to consider how Nordic data can contribute to a potential EU-wide database if that will be asked for by the European Commission. The status of different initiatives, standards, and proposed regulations, as well as the needs and ways to implement a climate declaration for buildings in the Nordic countries, and potentially needed additional requirements are discussed and suggested in this report. Furthermore, the possibilities of contributing to a potential EU-wide database and thereby influencing EC are discussed.

European level

The new energy performance of buildings directive (EPBD) will set out a common methodology for the reporting of a so-called life cycle GWP indicator, expressed as kg CO_2e/m^2 (of the useful floor area) and averaged for one year of a reference study period of 50 years. The data selection, scenario definition, and calculations shall be carried out in accordance with the latest version of the rules outlined for a building LCA-based declaration (EN 15978) and the delegated act to be launched in 2025. The life cycle GWP indicator result for the building is, in the future, reported as part of the energy performance certificate that will be in force for all new buildings in 2027, and then in 2030, complemented by a limit value.

Besides the single life-cycle GWP indicator as part of the energy performance certificate, there is a mandatory 'digital building logbook' that asks for "all relevant building data, including data related to energy performance, such as energy performance certificates, … … , as well as on the life-cycle GWP and indoor environmental quality which facilitates informed decision making and information sharing within the construction sector, among building owners and occupants, financial institutions and public authorities."

These legally noticed requirements and references given above should be followed when any methodology or scenario setting is suggested in this report. All such specifications developed in the overarching project "Nordic Harmonisation of Life Cycle Assessment" can then be seen as a Nordic contribution when the delegated act will be developed based on the suggested "inclusive stakeholder process".

National level
It will be possible for an individual country to have complimentary requirements. The implementation of the directive in national laws, as for the current EPBD, needs interpretation and must be notified before it becomes law. Also, reporting the national progress is required by the directive and outlined in the EPBD for all Member States.

Construction product level

EN 15804: Environmental Product Declarations (EPD) and Product Environmental Footprint (PEF)

The calculation rules for environmental data based on a Life Cycle Assessment (LCA) for construction products are defined in the international standard ISO 21930 and its implementation in the European context in EN 15804. EN 15804 relates to the ISO family of standards of LCA, such as ISO 14044, providing general principals and requirements for life cycle assessments and ISO 14025 that provides the framework for Type III environmental declarations including EPDs. These standards are used to develop environmental product declarations (EPD) that include a third-party verified LCA used for market communication valid for products and services. Additionally, EN 15804 describes the so-called product category rules (PCR) for all construction products and services that are supplied to any building works during its life cycle. One important rule in an LCA is that the same calculation rules/methodology must be used in all parts of the assessed system. Nevertheless, it is noticed that the EN 15804 is also used for other product groups, especially in the programme operator systems held by EPD International and EPD Norway. Thus, the potential use of the methodology is, in practice, larger than construction products as such.

EN 15804 is developed based on a mandate for European standardisation (CEN TC350) from EC DG

GROW.[1] In parallel, DG Environment has developed a likewise declaration called Product Environmental Footprint (PEF). This is a life cycle approach assessment methodology defined by EC Joint Research Centre (JRC). PEF methodology differs from EN 15804 with some respects. For example, a consequential allocation approach is used for process allocation (called direct substitution). Also, the circular footprint formula (CFF) is an integrated part of the LCA result in PEF, while in EN 15804, it is part of module D that shall be reported separately. Moreover, there is currently no published official PEF declared for any product. However, the PEF methodology is mandatory for climate declarations of batteries (Battery regulation); it has also been suggested as mandatory for limit values for solar photovoltaics (Ecodesign directive) and is planned to be used in future eco-design regulations. The idea that it shall be one common basis for the methodology setting is handled with the core product rules (EN 15804) in the EPD system and the PEF guidance document. To support further specification on individual products groups, the cPCR is developed in the EPD system and the PFCR in the PEF system. The lesson learned from applying the EPD system is that those methodology settings are sometimes not precise enough, and the cPCRs do not cover all matters needed to sort out for an individual product group. Another known drawback from the EPD system is that an individual programme operator may introduce methodology settings in their so-called general programme instruction (GPI), resulting in diverging calculation rules. It should be noticed that there is only one commission recommendation on the EF method resulting in one set of basic calculation rules valid for all EPD PEF-studies, where version EF 3.1 is the most current (see below).

To achieve more harmonisation between the two methods, a new mandate was given to CEN TC 350, and EN 15804 was updated and is now published as EN 15804:2012+A2:2019. As a result of this revision, the major change to EN 15804 was to use the same life cycle impact assessment (LCIA) categories as listed in PEF. Consequently, the environmental impact category indicators originally used in EN 15804 were replaced by the environmental indicators developed by PEF. This creates a similar likeness between the updated EN 15804 (amendment 2) and PEF since the same indicator result appears. However, the LCA result is not comparable since the same underlying inventory method is not used.

The characterisation methods and factors used for the LCA result in EN 15804 shall follow the latest version of the characterisation factors defined by EC JRC (see EN 15804 A2 section 6.5.2 Core environmental impact indicators). In practice, this implies that the characterisation methods and factors used for the LCA result can change whenever EC JRC decides, and is not decided by the CEN TC 350 standardisation working group that is responsible for the revision of all other parts of the standard EN 15804. Such frequent updates hinder full comparability between EPDs, and should therefore be limited as much as possible. The characterisation factors, valid by PEF in 2019 and updated in 2023, will be mandatory. As a consequence, EPDs from 2023 will be based on other characterisation factors for GWP than the EPDs used up to 2019 and the ones used between 2019 and 2023. The most up-to-date characterisation factor will be more in line with the original

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1. European Commission DG Internal Market, Industry, Entrepreneurship, and SMEs (DG GROW).

one used. The difference in the LCA result on a product level is just a few percentages.

In practice, there is a standstill in the development and potential revision of EN 15804 and DG Growth, as the CPR Acquis process is currently in the lead and needs to be finalised first (read more about CPR Acquis below). However, there is a complementary standard EN 15941 on data quality, which regulates data quality aspects concerning the LCA calculations and affects both the EPD for construction products (EN 15804) and on a building level (EN 15978).

Construction Product Regulation (CPR) Acquis process and CE marking

On a general level, EC concludes that the "...existing harmonized technical specifications are mostly incomplete, as they are CPD-based (precursor to CPR) and fail to address the specificities of the CPR. To a large extent, they do not even cover most of the basic work requirements (BWR) set out in Annex I to the CPR".[2] The ongoing CPR Acquis process can be seen in the light of this background, and to deal with some of the improvements already identified based in the existing legislation. Based on the current CPR, the CPR Acquis process will support the implementation of the forthcoming CPR. The CPR Acquis process has ranked all construction product families and started to develop new standardisation requests identifying all relevant essential requirements to be assessed for the declaration of performance, as part of the CE marking process. This work will define the requirements for a future generation of declarations of performance in accordance with the forthcoming CPR, taking into account all essential information required by the Member States, including a mandatory EPD for all harmonised constructions products.

The CPR Acquis process will redefine the standardisation request that EN 15804 was based on, possibly leading to changes in the standard. Also, the revised and renewed harmonised product standards resulting from the CPR Acquis will be streamlined with this work. It may result in the future common mandatory EPDs restricting the use of some aspects that are currently used, or forbidding some aspect that is only allowed by some programme operators, such as biomass balancing approach and the use of green electricity certificates (or not). Per the timetable, most of the EPD specifications have been done in 2023 and the results will be presented in 2024. The so-called essential requirements that are mandated to be declared in an EPD are already set in the CPR Acquis process. Other aspects defined are, e.g. the modular approach for end-of-life scenarios, in order to create a flexible scenario setting on the building level. This approach is outlined in the 'Introduction to life-cycle scenario settings' section.

Eco-design for Sustainable Products Regulation / Digital Product Passport (ESPR)/(DPP)

The proposal for the Ecodesign for Sustainable Products Regulation (ESPR) is an ambitious document that is part of a series of European Commission proposals seeking to redefine the business. This is in line with the European Union's vision for a more

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2. https://single-market-economy.ec.europa.eu/sectors/construction/construction-products-regulation-cpr/acquis_en

sustainable future as part of the European Sustainability Initiative. The ESPR broadens the scope of the current Ecodesign Directive by being applicable to all products, apart from food, feed, pharmaceuticals, and living things. The ESPR (COM(2022) 142 final) was proposed by the European Commission in March 2022, accompanied by a communication "on making sustainable products the norm" (COM(2022) 140 final). The ESPR proposal has been modified through the negotiation processes and is still to be adopted by the co-legislators, and the final text is not yet available. According to the ESPR, the design and content of the digital product passport (DPP) will be decided in delegated acts. The ESPR does not contain detailed information about indicators in the DPP this is something that will be given by the delegated acts.

For construction products, the new CPR will contain the elements of the ESPR and will therefore be considered lex specialis and the main legislation act. The ESPR will function as a safety net to ensure that the product information is required by ESPR. Both legislations require product information to be transmitted digitally in the form of a Digital Product Passport (DPP), which will be first developed within the context of the ESPR. The digital product passport (DPP) will include relevant information to improve products' circularity, energy performance, and other environmental sustainability aspects throughout the product life cycle. In practice, if the DPP in the future introduces a GWP indicator (or several LCA indicators) or any other essential information to be reported in the DPP (see list of items in Annex I), it must be followed by an amendment of the CPR and its EPD. If the building product EPD do not declare the essential information given in the ESPR, the construction material industry will have to declare both an EPD and the missing indicators in a DPP. It is important to note that according to the ESPR, it is enough to have the same LCA indicators as such, but not necessary based on the same underlying characterisation method/factors or inventory methodology. Thus, EN 15804 can still be used for construction products in the future, but the methodology for other product groups is undecided.

By this construction in the ESPR described above, it is still possible for CPR to use the LCI methodology that is based on international LCA standardisation in the future. However, this also means that the LCA indicator reported by the DPP will not necessarily be comparable with the same indicator used in the CPR EPD since the underlying inventory methodology including aspects, such as the allocation of an environmental impact, from a process differs. It should also be noted that it is most likely that the LCA methods used for DPPs will be found in the PEF (product environmental footprint), an approach that is only used within the regulatory context; no official declarations have been published, nor do they exist.

In regard to regulations including LCA-based information on any construction works, it will be problematic in the future that not all products used in the construction phase or during the rest of the building's life cycle fall under the scope of the CPR and its EPD. For instance, the ESPR always applies to all energy-related construction products, fuels and energy wares are handled within other regulations, and likely when using PEF methodology to calculate the GWP indicator for such products. From a user's perspective, a question remains: can this be solved by the double reporting of indicator results for this kind of product that has an intended use related to several regulations?

Building level

Environmental assessment of buildings and EN 15978

The product category rules for buildings are defined in EN 15978, which is under revision. The extended revised standard will, to a great extent, be more precise and cover more aspects. The new standard is based on the experiences learned since the first version of the standard was published in 2011. As the updated EN 15978 standard is significantly improved, it is intended to provide the guidance requested by the market. Nevertheless, it is not published and therefore not potentially a source to refer to. However, the new version of the standard is supposed to impact methodology settings.

It should be noted that both the climate declaration, according to the forthcoming new EPBD directive, and Taxonomy refer to EN 15978 as a major reference. The reference to Level(s) is very limited and restricted to describe the scope of the inventory by listing the mandatory building parts to be considered in the calculations, as well as requirements for the approval of national calculation tools. Since the forthcoming version of EN 15978 will likely overrule the specifications made in Level(s), this system needs to be updated when EN 15978 is published to avoid conflict with the updated standard. Finally, it shall be recognised that the delegated act will specify the final details.

Level(s)

Level(s) is a common EU framework for buildings, aiming at creating "a common language creating a shared understanding of sustainability performance in buildings". The Level(s) framework consists of six macro-objectives regarding sustainability, where the first objective addresses greenhouse gas emissions along a building's life cycle. The indicators for this macro-objective are: 1.1 use stage energy, measured in kWh/m^2/yr., and 1.2 life cycle global warming potential, measured in CO_2eq/m^2/yr.[3]

The Level(s) indicator '1.2 life cycle global warming potential' refers to the standard EN 15978:2011 and EN 15804 for LCA methodology settings when calculating the life cycle GWP of a building. In the EU Taxonomy, Level(s) refers to the scope of the building elements to account for in the inventory, as well as the requirements on calculation tools when a national calculation tool is unavailable. Other calculation tools may be used if they fulfil the minimum criteria laid down by the Level(s) common EU framework. It shall be noted that in all the Nordic countries (Denmark, Sweden, Norway, Finland, and Iceland), different tools can be used to calculate the GWP indicator, although specific calculations rules must be followed.

The included GWP indicators in Level(s) are: GWP fossil (1), GWP Biogenic (2), GWP-GHG (1+2), GWP-luluc (3), and GWP- Overall (1+2+3). The result should be presented as CO_2eq

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3. Nicholas Dodd, Shane Donatello, Mauro Cordella. 2021. Level(s) indicator 1.2: Life cycle Global Warming Potential (GWP). JRC Technical Report. https://susproc.jrc.ec.europa.eu/product-bureau//sites/default/files/2021-01/UM3_Indicator_1.2_v1.1_37pp.pdf

per m^2 useful internal floor area per year, the reference period being 50 years. It is permitted to omit the GWP-luluc as separate information if its contribution is <5 % of the GWP-total over the declared modules, excluding module D.

Initially, indicator 1.2 states that all the stages of a building's life cycle should be included in the calculation (A1-A3, A4-A5, B1-B7, C1-C4, and D). However, two simplified options for calculating the life cycle GWP are also presented. The first option includes A1-A3, B4, B5, and-B6, whereas the second option includes A1-A3, B6, C3-C4, and D.

EU taxonomy

For a construction and real estate company to be aligned with the Taxonomy indicator "Climate mitigation", a climate declaration for the whole life cycle for a building needs to be made. The activity applies to both construction companies and entities that commission a new building, meaning both residential and non-residential buildings. The requirement is part of the EU taxonomy technical screening criteria ('TSC') that are set out for certain economic activities to be considered as a substantial contribution to the objectives of climate change mitigation and climate change adaptation (referred to as Taxonomy-aligned activities). The economic activities should also do no significant harm to any other environmental objectives.

According to the taxonomy substantial contribution criteria for climate mitigation, in terms of GWP, the indicator needs to be calculated for buildings larger than 5,000 m^2. The calculation includes all stages in the life cycle and is disclosed to investors and clients on demand. This implies that the GWP is communicated as a numeric indicator for each life cycle stage. It is expressed as kg CO_2e/m^2 (of the useful internal floor area), averaged for one year of a reference study period of 50 years (the same as the draft EPBD directive climate declaration; see below).

For data collections, scenario definitions, and calculations, the taxonomy refers to EN 15978:2011. The scope of the building elements and technical equipment, as defined in Level(s), shall be applied (see list of building elements in Table 2). Moreover, the taxonomy states: "where a national calculation tool exists or is required for making disclosures or for obtaining building permits, the respective tool may be used to provide the required disclosure. Other calculation tools may be used if they fulfil the minimum criteria laid down by the Level(s)". The approach is thereby the same as the EPBD directive.

In 2022, it was required to report "eligibility" to the Taxonomy requirement. In practice, this means that it was enough to state if the knowledge to perform a climate declaration exists. From this year (2023), it is needed to show "alignment" to all technical requirements. For affected companies, this means, according to the authors' understanding, that the GWP indicator required in Taxonomy Section 7 needs to be calculated.

The new Energy Performance of Buildings Directive (EPBD)

In December 2021, the European Commission published a proposal for a revised Energy Performance of Buildings Directive (EPBD), as part of the 'Fit for 55' package.[4] The latter consists of several legislative proposals to meet the new EU objective of a minimum 55% reduction in greenhouse gas (GHG) emissions by 2030 compared to 1990. It is a core part of the European Green Deal, which aims to set the EU firmly on the path towards net zero GHG emissions (climate neutrality) by 2050.

In 2023, a final agreement was reached in the new EPBD directive, and the following aspects were added:

- Member States shall ensure that the life-cycle Global Warming Potential (GWP) is calculated and disclosed through the energy performance certificate of the building:
  - (a) as of 1 January 2028, for all new buildings with a useful floor area larger than 1000 square meters;
  - (b) as of 1 January 2030, for all new buildings and existing buildings (deep) renovated to A+ class.
- The Commission is empowered to adopt delegated acts that constitute a framework for the national calculation of the life cycle GWP. The first such delegated act shall be adopted by 31 December 2025.
- By 1 January 2027, Member States shall publish and notify to the Commission a ***roadmap*** detailing the introduction of ***limit values*** on the total cumulative life cycle GWP of all new buildings divided into per building type and set targets for new buildings from 2030, considering a progressive national trajectory downward trend, as well as maximum limit values, detailed for different climatic zones and building typologies.

The EPBD climate declaration GWP indicator for the building is defined as: **1) life cycle GWP indicator,** expressed as kg CO_2e/m^2 (of the useful floor area) and averaged for one year of a reference study period of 50 years. It is mentioned in the new EPBD directive that a public database including the performance of buildings will be established. Moreover, it is explained that "in order to populate the database, building typologies may also be gathered. Data may also be gathered and stored on both operational and embodied emissions and overall life cycle GWP". Besides the life cycle GWP indicator, the yearly GWP indicator result for the operational energy shall also be reported in the declaration expressed as: **2)** "**operational greenhouse gas emissions** (kg $CO_2e/(m^2$ y)". See EPBD, Annex V.

Another indicator result that may be reported is: **3)** "information on carbon removals associated to the **temporary storage of carbon** in or on buildings". The new EPBD also addresses: **4)** a '**digital building logbook'** that means "... a common repository for all

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[4] The Council made its decision on the general direction in October 2022 ('Fit for 55': Council agrees on stricter rules for energy performance of buildings - Concilium (europa.eu).

relevant building data, including data related to energy performance, such as energy performance certificates, renovation passports and smart readiness indicators, as well as on the life cycle GWP, which facilitates informed decision-making and information-sharing within the construction sector, among building owners and occupants, financial institutions and public bodies".

In the new EPBD directive (see Annex III in the directive), it mentions that EN 15978 is the core LCA methodology to be applied for the building life cycle GWP indicator:

"The data selection, scenario definition and calculations shall be carried out in accordance with EN 15978 (EN 15978:2011) and taking into account any subsequent standard relating to the sustainability of construction works and the calculation method for the assessment of environmental performance of buildings".

For two specific matters, Level(s) is also addressed in Annex III. The first reference concerns the scope of the building elements to be accounted for in the inventory of a building as a whole. The second matter in reference to Level(s) on the new EPBD directive is: "...where a national calculation tool exists, or is required for making disclosures, or for obtaining building permits, that tool may be used to provide the required disclosure. Other calculation tools may be used if they fulfil the minimum criteria laid down by the Level(s) common EU framework".

Another take from the new EPBD is that a window of opportunity exists, now before the delegated act is published, to influence how the common calculation rules for the climate declaration shall be defined on information asked for on a product level, as outlined below (the EPBD Annex I):

"Where product-specific regulations for energy-related products adopted under Regulation 2009/125/EC include specific product information requirements for the purpose of the calculation of energy performance and life cycle GWP under this Directive, national calculation methods shall not require additional information".

2. Common approach for definition of typical cradle-to-gate values

This section presents the principles for selecting typical GWP values for resources used for the structural building. The approach described here is based on the experiences of developing such generic GWP databases in Finland (CO2data) and from Boverket, Sweden. To be as representative as possible, these databases are the first choice based on relevant environmental product declarations (EPD). The recommendation of developing a national GWP database for generic construction resources is summarised as follows:

European level
If possible, an EC-founded generic LCA database (based on life cycle inventory data) is desirable to be used for EPD calculations for frequently used upstream data (i.e. applicable for construction product EPDs). This database can then also be used for buildings, which would then support the possibility to follow the methodology according to EN 15804 and lower the cost for the end users. Based on the current scope of the content in the new EPBD, there are no plans for the development of a common EC database.

The new EPBD 'life cycle GWP' indicator does not require any sub-division on the GWP total. Since this indicator is reported for the full life cycle from stages A to C, it is numerically equal to the GWP-GHG indicator that accounts for all GHG emissions, except the biogenic carbon uptake in a product or its packaging materials. However, other legislations, like the EU Taxonomy, might require such subdivision of the GWP total.

Nordic level
On the Nordic level, joint efforts could be made for those countries that prefer to develop a generic database for construction products. For low-volume construction products, it is possible to develop a generic database that can be shared between several countries. The preferred LCA data source is a EPD that is selected to be

representative for products consumed in the Nordic market. A product type reported in the GWP database should, as the first choice, be selected based on its functional performance.

To support the EPD, it is recommended to, during the initial stage, use conservative generic data that can be achieved by adding, e.g. 25% extra impact.[5] Consequently, as this 25% rule also affects the definition of the construction product type, the variation in that selection must be less than this 25%. To fulfil this in practice, it requires that a product like floor screeds (where a wide variation exist above +/- 25%) must be further subdivided, typically based on the amount of binder used, or when defining representative data for concrete, a subdivision that takes into account if traditional cement binders are used or alternatives that lower the impact more than 25%. The perhaps most important subdivision is metals, which are often divided in primary or secondary raw materials, and if the raw material origin is not known, the conservative alternative must be used.

In the long run, when EPDs are mandatory according to the CPR, generic data should then preferably be found on typical data (without any factor). As a result, the real impacts are assessed, and communication - as well as monitoring the improvements - is easier if the data used do not have conservative factors and are based on specific data that correspond the actual impact to what is found in the statistics.

The amount of specific data used in a building 'as built' climate declaration will need to increase if limit values are introduced, since the aim is that those GWP values shall reflect the actual impact as built buildings.

There is a potential harmonisation of the names and terms applied for the generic products and services in the databases. Especially the integration of different planning and calculation tools requires a common understanding of the generic products or services. According to the new CPR, the grouping and naming of a product type is decided by the one that puts the construction product on the market and will therefore be different and a uniform naming will not appear. The proposal for a common Nordic approach towards the naming of construction products can be subject for future harmonisation between authorities:

National level
By combining the EPD data for construction products consumed on the national market with the different producers' market share, truly representative data for an individual country can then be established. This approach is recommended for high-volume products in the future when such sources of data are available. If this is impossible, conservative data should be selected. Selecting EPD data for generic

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[5] In theory, if all consumed products have an EPD and their market share is known, individual conservative factors can be calculated, but this is not possible today.

GWP data can still be relevant in creating joint data between countries, while the market share will be handled nationally.

The generic GWP values in the national databases of construction products should be updated in a continuous way to consider the changes in EPDs and the market. The renewal cycle of services and scenarios should also reflect the review cycle of limit values.

Selecting GWP indicators

There exists a consensus from the standardisation work, EN 15804, EU initiatives like Level(s) and PEF, that the GWP indicators shall be divided in:

GWP total	the sum of GWP fossil, GWP biogenic, and GWP luluc
GWP fossil	the sum of all greenhouse gas emissions from fossil sources
GWP biogenic	emissions of all greenhouse gases and biogenic carbon stored in the product and its packaging materials, where the later biogenic carbon always will be zero over the life cycle A to C.
GWP luluc	emissions from potential land use and land use change (luluc)

The new EPBD 'life cycle GWP' indicator does not require any sub-division on the GWP total. Since this indicator is reported for the full life cycle from stages A to C, it is numerically equal to the GWP-GHG indicator that accounts for all greenhouse emissions except the biogenic carbon uptake in a product or its packaging materials. However, other legislations like the EU Taxonomy might require such subdivisions of the GWP total.

The use of the GWP total indicator is unproblematic when it includes all information modules from A to C. However, the inclusion of biogenic carbon in the GWP indicator complicates the result comparison module by module. This fact is essential to handle if there are national complementary limit values, such as the proposal in Sweden where the limit value is related to the verifiable part of the life cycle, namely the construction stage (A1-A5). To address this, a complementary indicator called GWP-GHG can be applied. GWP-GHG excludes the biogenic carbon uptake in the product and its packaging, as well as the end-of-life, thereby enabling comparable LCA results module by module. The GWP-GHG indicator is not in contradiction to EN 15804 since it is a prerequisite for the modular approach, and it can be calculated with information provided in the EPD as the biogenic content declaration of the declared product and its packaging material. This problem with the GWP total is the same if a limit value does not cover or cover the full life cycle (see the next section for this case). It should be noted that as the life cycle GWP indicator, according to the Taxonomy and EPBD directive, is based on the summed impact from A to C, this summed result is the same result as if GWP-GHG was used. Thus, the GWP-GHG is a more flexible GWP indicator that supports the modular approach and allows for comparison module by module. The GWP-GHG indicator can be calculated for any construction product cradle-to-cate (module A1-3) with the existing mandatory information reported in an EPD. This cradle-to-cate module A1-3 result from an EPD constitute the basic modular information used in an LCA calculation for any construction works.

It should be noticed that when biogenic carbon in the product is accounted for, in combination with a decarbonisation scenario,[6] as suggested here for stages B, C, and potentially D, the biogenic carbon shall not be part of and multiplied by the decarbonisation (scenario) factor since it would then create a biogenic sink effect.[7] This biogenic sink effect is created by the so-called -/+ biogenic calculation approach that addresses climate neutrality for renewable materials from sustainable sources, where the sequestration creates a negative figure in the forestry and the same amount is them emitted in the end-of-life and the sum is always zero.

To maintain this approach, the biogenic part of the GWP total need to be reported separately, where it is noteworthy that the GWP biogenic indicator result is insufficient in such calculations since it includes more than the inherent carbon stored in the product. Therefore, the GWP total must be combined with information pertaining to biogenic carbon stored in all materials. As an alternative approach to simplify this calculation, the GWP-GHG indicator may be used as the basis for the life cycle GWP indicator. In this case, additional information becomes unnecessary, and the calculation can be made without any modifications. In this context, it should be pointed out that the new EPBD directive states that the amount of biogenic carbon stored in the building may be reported (EPBD Annex V): "information on carbon removals associated to the temporary storage of carbon in or on buildings".

A harmonisation of GWP indicator usage is needed and must be found on information given in an EPD. The GWP total shall be used when the impact is summed from A to C. If any nation introduces an additional limit value for a single stage (like A1-A5), the use of GWP-GHG is recommended.

More extensive materials on GWP indicators are reported in the annexes.

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6. See the section 'Decarbonisation scenario for B1.2-B5, B7 and C1-C4', where this approach of handling scenarios is described. A scenario factor is introduced to create a simplified approach to generate a yearly improved GWP value based on data representative for today. A zero factor indicates that no impact will remain in the future and one is equal to the fact that no progress is made.
7. This -/+ calculation is part of the French regulated climate declaration, where this approach is called a dynamic LCA. However, there is a significant difference with the French calculation method since this approach uses the factor as a discounting factor to reflect the reduced radiative forcing caused by this temporary biogenic sink, and the factors applied are defined to reflect this effect. The French approach is scientifically motivated and addresses the same climate impact as reports on Harvest Wood Products (HWP) in international climate reporting.

Type of LCA data source

It was decided early to use EPDs as the main sources of information for such LCA data based on two aspects:

1. EPDs follow the correct methodology and environmental indicators asked for, namely the European standard EN 15804 *Sustainability of construction works. Environmental product declarations. Core rules for the product category of construction* (2019).
2. The legal right to report and communicate LCA data based on commercial database (also if only a part of the GWP indicator results is based on such licensed data) acts as a trade barrier, as well as license costs that are found irrational.

Based on the new End-user License Agreement (EULA) for generic LCA data (like Ecoinvent and GaBi), limitations currently exist when an LCA result partly based on commercial LCA databases is made publicly available to others. When such data is published digitally as in the national databases, these EULAs require that a fee is paid to the owner of the generic LCA databases, even though none of the underlying data is made publicly available. It is currently unclear if this also applies for EPDs, which are often made digitally available today. Until it is otherwise recognised, we will assume that digitalised EPDs can be used as a source for generic data; but using generic databases, like Ecoinvent and GaBi, requires a license agreement. This potential problem will hopefully be sorted out in CPR/Acquis, or at the latest if a mandatory regulated EPD is required for construction products and there is freely available generic LCA data from EC.

When assessing the relevance of LCA data as source for a common LCA (or climate) database, the following sources were considered (given in order of relevance):

- Domestic LCA sources – if the domesticity rate of a building is high.
- Nordic LCA sources – as manufacturing processes, methods, and markets are often similar, although the energy sources for electricity differ.
- LCA sources from exporting countries are preferred when domestic consumption relies only on imports.
- Generic LCA sources in foreign databases – as those represent average values.

LCA data were searched especially from databases, such as:

- EPD Norway (2022)
- EPD International (Environdec)
- RTS EPD (Rakennustieto)
- EPD Denmark
- ÖkobauDat
- IBU (Germany)
- ICE (data used for GHG reporting calculations).

Besides information about products consumed in the national market, the market share of different manufacturers should be asked for. By combining market shares and EPDs from the actual suppliers, a true market value can be calculated. Experience from developing the GWP database proves that it was, in most cases, impossible to find data on the market share, which is why expert judgment from an informed individual was the best second choice. However, information was received from manufacturers, as well as industry representatives, such as the Confederation of the Finnish Construction Industries RT. Regarding many construction products, even if figures are not available, there is also common knowledge about the biggest manufacturers, market leaders, and the degree of domesticity in the market. It is notable that the construction market is largely domestic for high-volume products.

Another conclusion was that considering the market share revealed differences in the market shares of high-volume construction sector products, although LCA data sources are the same. Therefore, collecting source data can be shared between countries, but high-volume products must be handled nationally and the market share should be taken into consideration if possible.

How to support the use of specific EPDs

In Finland and Sweden, it has been assessed that it is not possible according to EC regulation, to ask for EPDs as a mandatory request,[8] which has led to the search for an alternative solution. Actual data representing a "true" value" was then referred to as "typical" LCA data. The possibility of introducing conservative generic data was launched, and an addition of 20% was introduced in Finland and 25% in Sweden. The benefit of this approach is that it supports the use of as many specific EPDs as possible. On average, the use of EPDs will result in a discount of 20 or 25%, depending on the factor used. This is a driver for high-volume construction products that significantly contribute to the buildings' impact (e.g. concrete, steel products, insulation, boards, wood).

An obvious drawback is that it is used if only the declaration is calculated in the building permit process, since it is then often unknown how that will be the material deliverer. Another problem is that a proceeded reduction given by the rules in reality do not support any environmental improvement, only those deliverers that can afford to publish specific EPDs. These drawbacks are likely acceptable when the climate declaration is not combined with a limit value. However, if a limit value is introduced, it is preferable to use product-specific data for the most part, and the limit value is given as a 'as built' requirement to enable follow-ups.

A product type reported in the GWP database should, as the first choice, be selected based on its functional performance. If different qualities or versions of a product type are available (strength classes, etc.), those are often defined in product standards. As described above, to support EPDs, it is recommended, during the initial stage, to use conservative generic data that can be achieved by adding, e.g. 25% extra impact. This

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8. This is based on the current CPR, which prohibits the mandatory requirement of anything else than a CE mark. It applies to all Member States, but some do violate it. However, the commission is not going to interfere.

25% rule affects the definition of a construction product type, so that the variation is less than this 25%. To fulfil this in practice, it requires that a product like floor screeds is further subdivided based on the amount of binders used; concrete if traditional cement binders are used, or alternatives that lower the impact more than 25%. The perhaps most important subdivision is metals, which can therefore be divided in primary or secondary raw materials; if the raw material used is unknown, a conservative alternative must be used.

As some EPDs represent average data, they are thus more like typical data instead of product-specific data. Regarding this, it is important to define what is meant by product-specific values and avoid a situation where conservative values are replaced by other average values, but which values are not multiplied with the conservative factor just because the average values are taken from an EPD. It is important to define what is meant by product-specific data that can be used instead of conservative data. The principle should be that the conservative values can only be replaced by product-specific values, but not product type-specific values (i.e. an EPD from a competitor), or average data.

Establishing and operating a national GWP database

Creation and maintenance of generic databases

The development and maintenance of a generic database requires considerable and continued efforts. A common approach regarding the practical issues of keeping the database up-to-date would be cost-effective and benefit all parties.

A good example of potential harmonisation are the names and terms applied for generic products and services in the databases. Especially the integration of different planning and calculation tools requires a common understanding of generic products or services. In the CPR Acquis process, this pertains to the product family and product type used. A product family is typically related to the naming used in European standards concerning the CEN product technical committees working with so-called harmonised standards (hEN) and part of the CE marking as defined in Regulation (EU) No 305/2011 for Construction Products Regulation (CPR). As the grouping and naming of a product type is decided by the one that puts the construction product on the market, it will therefore be different and a uniform naming will not appear.[9]

A common Nordic approach for naming construction products can be subject for future harmonisation between authorities.

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9. The proposal for the new CPR (COM(2022) 144 final, 2022/0094 (COD)) states: It is necessary for manufacturers of construction products to determine the product type in a precise and unequivocal manner in order to ensure a precise basis for assessing the compliance of such product with Union requirements. At the same time, in order to avoid circumvention of the applicable requirements, manufacturers should be prohibited from creating ever new product types where the products in question are, in view of the crucial characteristics, identical.

Extension of national databases with new data

The types of different construction products included in generic databases are selected and defined to cover a major share of all materials and products used in different building parts, and to represent a major share of the carbon footprint of a building.

A generic database cannot include representative values for all products that could be used as building materials. Boverket, in their climate database work, has developed preliminary criteria as a guide of determining when to add construction products to the generic climate database. Four main criteria are suggested, but all criteria do not need to be met for a construction product to be added to the database.

1. The construction product is widely used and in large quantities in the Swedish construction sector or causes more than 1% of the total climate impact of the constructed building.
2. Generic climate data are based on more than one environmental product declaration (EPD), or according to a report (referenced source) where the standard EN 15804 has been applied and preferably data on the market share in the Swedish construction market.
3. Construction products where there are alternatives within the product group with a significantly reduced climate impact.[10]
4. The name of the construction product should not be associated with a trademark.

These above-mentioned criteria are proposed as the Nordic approach as well.

Cycles of data renewal

A relatively rapid renewal of data may be reasonable in the beginning because there is a rather rapid increase in the number of EPDs. On the other hand, if the values are changed often, it causes problems for the development of emission limit values for buildings.

In principle, the generic database should reflect the reality continuously as well as possible. The typical values for different product types should be based on good-quality EPDs. Those should also be based on average values considering the market shares of different products within the group. Thus, the values in the generic database should change when EPDs change due to true changes in manufacturing processes, and when the number of EPDs increases as new EPDs are published for products in the market.

The role of the generic database as the source of information for climate declarations and the limit values for the carbon footprint of buildings complicate the issue. Generic values will be applied if there is no information about the specific products to be used. If there are considerable changes in generic values, limit values should also be re-evaluated. To avoid frequent changes in regulations, the generic database should remain relatively stable. On the other hand, the development and use of better products should be

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[10] This principle has been removed from Boverket´s routine, since they think it is unclear.

encouraged, and the generic data should represent the market condition.

Databases and interoperability today

Interoperability has been an important factor in developing generic databases. Most of the efforts for interoperability have been concentrated on the use of generic data in environmental assessment tools capable of making the necessary calculations for building LCAs. Correspondingly, a wide range of calculation tools have already integrated data from generic databases. These tools include popular commercial tools, as well as internal tools of consulting companies that offer life-cycle assessment services. Lately, there have been integrations with multi-function tools where LCAs have been combined with other functionalities, such as cost estimations. A planning tool that continuously shows both the cost and carbon footprint of the design considerably enhances the chances of a climate-friendly design.

The Swedish and Finnish databases have a common specification of their machine-readable interface (a JSON file and XML). This specification follows the common naming conventions of EPD data, but includes only the fields necessary for generic data. This type of integration with a specification and JSON files for the contents of the database has been well-taken by the parties making integrations. Data in a tabular spreadsheet form has also been a frequent request. This simple format is better for many research purposes where people are analysing the data themselves.

Today, the interoperability of generic databases falls short mainly in two ways. First, inadequate technical interoperability breaks the digital flow of information between some actors, and second, the naming and classification conventions cause misunderstandings and erroneous linking between systems.

Technical interoperability requires well-defined common formats that can be used by every system of all related actors. Today's technical interoperability is quite good between generic databases and many LCA calculation tools, but interoperability with BIM, for example, is practically non-existent. A potential solution for technical interoperability is the previously described data template.

Another problem with interoperability is that there has been virtually no generic data within the scope of building products. This has caused problems in linking generic data to specific or other generic data since the naming is not unambiguous. There have been no comprehensive naming or classification schemes, and the fast pace of development has made it impossible to create exhaustive naming and classification systems. Despite the problems, the generic data has been well-adopted into relevant tools, though common classifications and formats will be needed in the future when the interoperability needs will most likely explode.

Accessibility – the interoperability with people

Even though technical integrations with other tools will facilitate most of the interaction between users and generic data in databases, the user interfaces in the web will remain convenient places to view the data as well. It is important to make these websites accessible, easy to use, and easy to understand with little chance of misunderstanding.

A corresponding piece of legislation, the Web Accessibility Directive (Directive (EU) 2016/2102) has been in force since December 2016, requiring all websites of public sector bodies to be accessible by making them 'perceivable, operable, understandable and robust'. The technical requirements of the legislation are based on the Web Content Accessibility Guidelines (WCAG), which contain a large number of detailed technical requirements. Currently, public sector websites are expected to fulfil WCAG 2.1 standard's A and AA level criterion.

In practice, there are several technical requirements for a website and the information within. Technical requirements for a website are typically handled by web developers while developing websites (like the user interface of a generic database). A more relevant issue to discuss is the accessibility of the content itself. All text, images, infographics, videos, online forms, and files stored on websites are subject to accessibility requirements. Some examples of the requirements are adequate contrast, an alternate description for all non-text content, consistent navigation, and compatibility with assistive technologies. During the operative phase of a website and content maintenance, the accessibility mainly needs to be considered when creating new content in the form of documents. Technically, the documents can be checked with software tools – either internal or separate software. What these tools cannot check is the understandability of the language and the content itself. A concrete example of making the content better understood is to have multiple names for products that have several commonly used names.

Current Nordic generic databases for the assessment of buildings

This section introduces the present generic GWP databases for construction products available in Sweden, Norway, Finland, and Denmark. The databases are typically based on the scope of the climate declaration as such, and/or a limit value. All databases include cradle-to-gate data for construction products, energy carriers, and any other resources used in A1-A3, but also in A5, and typically also B2-B6 and C1-C4 when they are part of the current declaration scope. Estonia and Iceland have not published any databases thus far, nor have they given advice for references for generic data on different generic construction products.

Climate database from Boverket

A Swedish database with generic climate impact data for building products has been developed to be used in climate declaration for all buildings. This climate declaration is required by Swedish law, where all new buildings that apply for a building permit, from 2022 onwards, must report a climate declaration for the construction stages A1-A5. The GWP values in the database are conservatively set, i.e. about 25% higher than the average values calculated for the product group. The aim is that the generic GWP values per products are based on an average value, and when possible, to use existing environmental product declarations (EPD) from the supplier on the market.

The GWP indicator is given as GWP-GHG, meaning that all greenhouse gases are accounted for except the uptake and emission from biogenic carbon stored in the products and its packaging material. This approach supports the modularity principle that was the basic idea when those modules were launched in ISO 21930 and known as the modular principal.

The overall purpose of the Swedish regulation on climate declarations for buildings is to decrease the climate impact from buildings, i.e. to stimulate the use of construction products with climate impact as low as possible, in order to reduce the GWP impact of the whole building. The climate declaration can only be made based on the generic and conservative generic GWP data that is part of the Boverket´s Climate - database, as no other generic data sources are allowed. However, it is allowed (and preferred if possible) to replace these generic data with product-specific data if it is an EPD from a construction product manufacturer for the product delivered to the building.

The database is developed jointly by the IVL Swedish Environmental Research Institute and the Finnish Environment Institute (SYKE). The generic GWP data in the database covers a major share of different kinds of building products used in building parts included in the climate declaration, which is why installation products and surface materials are excluded from the declaration inventory, as well as GWP data for resources used in the remaining parts of the life cycle stages B, C and D. The database is updated annually and will be expanded, as the inventory scope of the climate declaration will be in force. The next major expansion of the GWP database will add those construction products for validation for the currently missing building parts (surface materials, furnishings, and installation services). This is likely to happen when the GWP limit values in relation to the climate declaration is in force, which is proposed to be introduced in July 2025 at the earliest and will also include a declaration of all building parts (listed above), including the groundwork below the building and the foundation. Subsequently, the GWP data required for stages B, C, and D need to be added to the database for a full life cycle that likely will be valid when the climate declaration, according to the forthcoming EPBD climate declaration, is supposed to be in force.

A web-version of the generic database is available at:
www.boverket.se/sv/klimatdeklaration/klimatdatabas/klimatdatabas/.

Additionally, the database is accessible via a webservice (API) and as an Excel file.
Öppna data - Klimatdatabas - Boverket

CO2data.fi database from the Finnish Environment institute

In Finland, the GWP database for building products and services CO2data was developed at the Finnish Environment Institute (SYKE) by the request of the Ministry of the Environment. The main target of the database is to support the design for low-carbon and resource-efficient buildings by providing typical environmental data for products, services, and systems to be used in the assessment of alternative design solutions. An essential function of the CO2data database is to enable the preparation of climate declarations for new buildings (YM 2022a, 2022b). The new Building Act (Act 751/2023) comes into force on 1 January 2025, but the decree of climate and building product declaration has not been given yet, and it will come into force 1 January 2026. The climate declaration will be used to prove conformation to the GWP limit values in 'as built' phase.

The main GWP indicator in the CO2data database is given as "GWP FOSSIL". As a supplement to this figure, "GWP BIOGENIC" is also reported, and GWP LULUC has been estimated as zero for all products thus far. However, in terms of this report, "GWP-FOSSIL" is equal to GWP-GHG and GWP BIOGENIC is equal to GWP-BIO as defined in EN 16485, i.e. limited to only the uptake and emission of biogenic carbon in the product.

The required climate declaration can be calculated by combining the emission data based on CO2data with the information about the energy consumption and energy sources, and the information based on the bill of quantities. The database provides typical GWP data for:

- building products and building service systems.
- transportation, construction, deconstruction, and waste management services,
- fuels and energy services.

The database covers a major share of different kinds of building products and services. All the data are also supported by a background report on the method of estimation, parameters, and references to source data. These reports are separate documents that can be freely downloaded from the 'results' page of any selected item.

The database also supports the consideration of potential carbon benefits of the building and benefits beyond the building's life. In accordance with the new Building Act (Act 751/2023), the benefits include potential avoided emissions, called carbon handprints, which are divided into five parts covering avoided emissions because of:

- the recycling or reuse of materials and products.
- energy recovery, or using it as an energy source in power plants with efficiency ≥65%.
- surplus renewable energy.
- biogenic or technological carbon storage.
- the carbonation of cement-based products after their service life.

With the help of this project, the database will be supplemented by adding data on urban trees (see separate annex) to support the carbon footprint and carbon handprint assessment for the building plot as well.

In addition, the database supports the reporting of the content and the origin of materials. The building materials and products are described by information about the types of main materials' contents, harmful substances' contents, and information about the origin in terms of the renewability of materials and secondary materials.

The database includes roughly 250 products and services. The building products of the database include insulation and waterproofing products, building boards, concrete products, other mineral materials and glass, steel and metals, wood products, floorings and surface materials, and HVAC products and electrical installations. Services include energy services, transportation services, and construction and demolition services. In addition, the database provides emission values for building service systems. There is also a separate section for conservative service life data per building part.

The generic database is available via a web-version (CO2data.fi), machine-readable JSON file for integrations (file API and specification), and as an Excel file.

The methods used for the selection of indicators and the definition of the values for indicators are described in the Häkkinen T. (2023) LCA database for building products, services, and systems. The description of the content and working methods, Reports of the Finnish Environment Institute 48 / 2022, are found at: http://urn.fi/URN:ISBN:978-952-11-5545-1.

Generic database used in Denmark

Denmark uses, for instance, the LCAbyg and LCCbyg calculation tools, developed by BUILD (former Danish building research institute), Aalborg University with financial support from various actors in Denmark. LCAbyg is a nationally freely available tool.

The GWP indicator used in the climate declaration is GWP TOTAL, which means that only the result for a full life cycle can be used for comparison. The underlying database used is Ökobaudat, which includes all indicators as defined in EN 15804 version A2. Since the Danish climate declaration is reported and communicated as the sum from A to C, the result is the same for GWP TOTAL and GWP-GHG.

LCAbyg has been developed for the Danish construction industry and has focused on a Danish context from the beginning. The development was carried out by BUILD in a broad collaboration with many stakeholders in the Danish construction industry from 2014 until today. The first version was launched in 2015 in collaboration between SBi (now BUILD) and the Danish Energy Agency, as part of a construction policy strategy from the government in 2014. The development of LCAbyg was based on the Excel tool SBi (now BUILD), developed for the Green Building Council Denmark for the DGNB certification of construction in Denmark since 2011.

A new beta version of LCAbyg has been launched. This version has adapted to the upcoming requirements regarding the climate impact of buildings, which will be a part of the building regulations on 1 January 2023. LCAbyg 2023 has been released as a beta version for testing between the 3rd and 28th of October. This release does not include any added new generic GWP data in the underlying database.

The tool is limited for using ready-made data for different building elements and parts. Besides the data, the user can enter the building's energy consumption and other scenario settings. In addition to the integrated generic database Ökobaudat, it is also possible to obtain environmental product declarations (EPDs) via the tool. The underlying generic database thereby reflects the GWP valid for a German context. There is no assessment available where the difference between the market for construction products in Germany and Denmark is evaluated and, for instance, recommendations on which construction products that preferably should be found on the EPD in order to reflect the Danish construction market.

A list of LCA tool and the advised generic database is available on: www.lcabyg.dk/en/download-legacy/.

Generic data can also found here: https://bygningsreglementet.dk/-/media/Br/Kap_11_Energi/Baggrund_Energi/Bilag-2/BR18-bilag-2-tabel-7-version-2-201222.xlsx .

And the reference to Ökobaudat is: http://www.oekobaudat.de/no_cache/en/database/search.html.

Note that several LCA tools that have access to the generic Danish database can be used.[11]

Norway TEK17

The Norwegian building regulation Byggteknisk forskrift (TEK17, 18.08.2023): Veileder for utarbeidelse av klimagassregnskap /Supervisor for preparation of greenhouse gas accounts, allows generic data from several sources. A generic database has not been developed in Norway; instead, the following databases are allowed to be utilised:

- Sweden: Boverket
- Finland; CO2data
- Denmark: Ökobaudat

Independent of the generic database used, 25% shall be added to generate a conservative value (if not already done, as in the Swedish database). The Finnish database reports the so-called typical value that can be used and then multiplied by 1.25 to be used in the Norwegian context, and the same needs to be done before using the data from Ökobaudat.

The GWP indicator used in the Norwegian climate declaration is GWP-GHG, which is referred to as GWP-IOBC (Instantaneous Oxidation of Biogenic Carbon).

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11. See an example list of LCA tools used in Denmark: https://byggeriogklima.dk/viden/lca-vaerktoejer/.

3. Nordic approach to life cycle scenarios

Introduction to life-cycle scenario settings

The motivation to require a "life cycle GWP" in a regulatory perspective is the need to inform the market actors about the relative impact of the different parts of the building cycle in a uniform format based on the different information modules and building parts. The construction stage A1-A5, representing 'as built', can be evaluated by real data and does not need scenario settings for the construction stage. Although a climate declaration covering a full life cycle can never be verified by real data, scenario settings can be developed to cover the future parts on a common basis in a harmonised way. Subsequently, the influence of the person responsible for the LCA calculation is being minimised. One must be aware of the fact that the basic assumption for such a scenario setting is very simplified, where the building after the construction stage is used during an analysis period of 50 years and then assumed to be demolished, while it most likely will be rebuilt at this stage. The mandatory demolition (module C1) is not what the society aims at or what is likely to happen; it is just a simplification that describes 'what happens if' when such a linear life cycle is assessed (or a worst-case scenario).

By introducing an LCA covering a full life cycle, it could in theory be justified to use materials with a higher climate impact in the construction stage as part of a more durable technical solution if the overall impact is then reduced over the analysis period. This thinking is important from a regulatory perspective and as an instrument for climate improvement and understanding the overall impact. We notice that one option is to only regulate such aspects that can be verified, typically the building 'as built', or to expand, for instance, a limit value to include the full life cycle based on scenario settings. In the latter case, the rules for these scenario settings must be as precise as possible. This is to ensure that regardless of which consultant calculates the impact from the scenario-bases modules, the result remains the same. It can, of course, be disputed if a limit value should include such value bases scenario settings that cannot be verified and based on scenarios and therefore only account for A1-A5 that can be evaluated. This problem regarding limit values is dealt with in a separate project parallel to this one, and therefore not dealt with in this report.

To account for a whole building life cycle, it can always be motivated by the fact that it gives supportive information, and where there are significant aspects that affect the future scenario, these must be handled with an uncertainty assessment. The development that we can see now for construction products – that it is asked for – is that an EPD for a construction product shall include information for the full life cycle, and the wish is the possibility to reuse EPDs at the building assessment level. In reality, often only the modules A1-A3 can be controlled by the material manufacturer; in that respect, they are the only part of the life cycle where the producer can guarantee the life cycle performance. Other parts of the life cycle may vary and they are often out of the manufacturer's control. In most cases, the scenario settings for a construction product are very free to set for modules A4 to C4, which is why the information from an EPD seldom can be used as a source on the building level as it is now.

Nevertheless, the regulators would like that future so-called Product Category Rules (PCR) for a specific product group or types of construction products will be developed to include more generic applicable end-of-life scenarios. For instance, it is suggested that the EPD for modules C3-C4 and D includes a 100% scenario. In an EPD, a 100% scenario is several scenarios for C3 and A4 that can be (re)used to create any desirable waste scenario. Such user-defined scenario can be a mix on the building level based on real end-of-life data, or defined per country based on country-specific settings set by national regulators, etc. This kind of scenario setting is in accordance with the new CPR Acquis process, which describes a needed development for future regulated EPDs. Such scenarios are then typically based on European average scenario settings. Therefore, it is most likely that the market will respond by mandating material producers to define the scenario settings in the most representative way to be used in an average European context. This kind of EPD information can then be used for benchmarking with other producers of the same product type. However, it is not representative for a specific product in a specific building.

As exemplified in the CPR Acquis process, the 100% scenario approach suggested for stage C for construction products, EPDs can then, when used on the building level, easily be modified to be representative for any nation or scenario setting for any waste mix. When this text is written, the outcome from the part of the CPR Acquis process dealing with EPDs for construction products is not published. It is, however, likely that CPR Acquis defines different 100% scenarios relevant for the European averages that then can be reused on the building level and adds a mix based on these 100% alternatives per product. The prerequisite in EN 15804 (where the construction product sector’s opinions are accounted for) is that any construction products should be assessed in the context of its final intended use, which is why the final assessment is only valid in the specific project and takes the specific requirements into account. If the aim is that the EPD for construction products should support the assessment on any construction work level, the scenario has to be modular and include the background information for calculation in any scenario-based information module. If the EPD, for instance, only includes a single scenario-mix for a specific country for stage C, such results will, in practice, only be valid for benchmarking within an EPD PCR product group, but they will never be applicable to real-life conditions.

The above-mentioned scenario setting modularity and flexibility can also be achieved by reporting the data source used for the LCA calculation, rather than a fixed calculated GWP result. An advantage of this approach is that parts of the scenario settings can be regionalised or country-specific. For instance, the current biocomponent respective fossil mix used in diesel for transportation purposes in different regions or countries can easily be adjusted if the common scenario settings described the equation to achieve the GWP result, rather than only the resulting GWP figure without its underlying data. If the scenario setting for transportation is divided in different parts, such as fuel type, vehicle type, and energy use, and if all this information is reported as scenario settings for a building or part of an EPD for a construction product, such flexibility may be achieved.

One could ask if this sort of a very fine-grained scenario setting may be practical for utilising LCA tools and ensuring expeditious assessment processes on a building level. The answer is that these kinds of features are already included in most LCA tools used for buildings; if not, it will be a development that users will ask to be implemented. This kind of parameterised scenario setting, 100% modularity, will both streamline and make the calculation results more robust.

General guidance for scenario settings in the context of European legislation

The scenario settings for a whole building life cycle LCA are preferably found in commonly agreed specifications that are given in the product category rules (PCR) for buildings, namely EN 15978 and its latest version, and if relevant, also Level(s), as is referred to in the EPBD directive concerning a few aspects. Besides these more general scenario settings found in the PCR standard, complementary specifications are required if the result should be uniform. Such specifications will likely be published in a delegated act related to the EPBD directive and its mandatory climate declaration for new buildings. So far, a few specifications are known for the so-called "life cycle GWP" indicator [(kg $CO_2e/(m^2 \cdot y)$]. It is currently known that the functional unit should be reported per useful floor area and the integrated climate impact is calculated as GWP_{total} over an analysis period of 50 years. The scope of building system parts to account for in the inventory is given as listed in Level(s). Besides the so-called overall life cycle GWP indicator result covering modules A to C, it will also be needed to report B6 energy use separately and stored in national databases that will be an interconnected database within the EU (see EPBD Article 19).

There is an aim that the climate declaration for buildings shall be supported by information from environmental product declarations (EPDs) for all kind of resources used during the building's life cycle. EPDs are based on product calculation rules for construction products, as defined in EN 15804 and its latest version. It is likely that this kind of EPD will be mandatory, and the ongoing CPR Acquis process will define how this EPD will be defined and approved. If a building climate declaration is asked for as part of a building permit, it must be based on generic data, and if a climate declaration is asked for 'as built', it can be based on specific data. When a climate declaration 'as built' is asked for, the goal is that a significant number of representative EPDs for specific products (as delivered to the construction site) shall be used. In order to report the amount of specific data used on the building level, the amount of specific data actually used in an individual EPD must also be added. This requirement to report the actual amount of specific data used in an EPD, in respect to the GWP indicator A1-3, is currently only required by one program operator, namely EPD International.

What is known about the scope of the new EPBD directive is it that there will be a climate declaration in 2028 and the limit value added to the declaration as such that will be required for all new buildings from 2030. Furthermore, by 1 January 2027, Member States must publish a roadmap detailing the introduction of limit values on the total cumulative life cycle GWP and notify this to the Commission. However, this describes the minimal level of implementation, and limit values can potentially be added to national legislation for, e.g. the construction stage (A1-A5), and be based on the same modular information that the EPBD climate declaration is comprised of. In order to ensure that GWP results will comply with set limit values, a climate declaration or mandatory complementary reporting to the climate declaration is necessary. They should be more transparent than the single-value life cycle GWP indicator mandated by the directive. This enhanced reporting is needed for facilitating limit values, particularly in scenarios where the full life cycle is not considered. Although the potential of including limit values is addressed in another project, it is worth noting that they do not necessarily have to include all building information modules and life cycle stages.

Moreover, a national limit value may require a climate declaration as part of the building permit and some may require a 'as built' climate declaration, or both. Presently, this is not defined in the EPBD directive climate declaration. The recommendations given in this report aim to provide guidance on defining scenario settings that are as representative as possible, following on a stepwise approach.

Where a simplification is possible for any scenario setting and when a European common average approach can be used as a default starting point, this will be a preferable alternative. If this is not possible, a more localised scenario is needed; such specifications can be developed by those countries that ask for this, preferably based on the same methodology approach as applied in the European scenario setting. Such a tiered approach may also – in theory at least – include specifications for a local context related to the actual building site.

Geographical representativeness
If it is possible to define commonly applicable European scenario settings for an individual information module that sufficiently captures a European geographical representativeness, this is the preferred option. If the relative importance of geographical representativeness is inferior, a common European scenario settings can still be accepted for an information module if its GWP contribution is relatively small regarding the full life cycle, modules A to C . If using a typical European

average scenario setting does not provide enough accuracy, a regional alternative, such as a Nordic scenario, could be considered. Alternatively, if higher representativeness is required, national scenario settings can be defined. If national scenario settings are chosen, the same methodology used on the European level should always be the first choice.

Technology representativeness
When default and typically generic GWP data is developed and published to be used in any information module, the aim is to also disclose the reference flow or recipe used to calculate these GWP results. This transparency supports the modification and enhancement of the GWP data for better national representation. This approach will also support and simplify the update of the GWP data published. Furthermore, this approach simplifies data updates and allows for more specific data usage when necessary. If appropriate, different aspects of the reference flow or recipe can be parameterisation in a machine-readable format, aiding the digitalisation and streamlining of national and site-specific adaptations based on generic data settings.

Time representativeness
The aim of climate declaration and its "life cycle GWP" indicator is to support climate mitigation and decarbonisation strategies. Considering the uncertainties that are related to a scenario fifty years into the future, we propose simplifying scenario settings by using a three-point method. We also suggest that, if possible, those national scenarios should be found on sources that are an outcome from any common EC-related work or statistics. This method describes: 1) the present situation, 2) a future situation based on long-term forecasts, and 3) thereafter a constant development until the 50-year reference service life ends. These scenarios can be commonly defined based on a European average or national scenario, and as an extreme for a local district heating net, etc.

Specific data
When a building climate declaration is required as built or when it is used as a basis for a limit value, the amount of specific data should be as large as possible to accurately represent the actual building. EPDs do not always provide 100% specific data, so this information needs to be added to the current EPD rules if the declaration shall serve its legislative purpose. An EC regulator cannot achieve this if an additional data quality requirement is introduced for EPDs for construction products (and its delegated act), as it is not covered in EN 15804 or in the supplementary data quality standard EN 15941. When such a data quality indicator is available on product level EPDs, it can be used to calculate data at the building level, typically for the construction stage A1-5. This is also essential for using LCA data in fair procurement processes.

A indicative achievable amount of specific data A1-5 based on the EPD is currently at least 60% (fulfilled by less EPDs for less than five product groups), and if a mandatory EPD will be required for all construction products in the future, it should be more than 90% specific data for a realistic figure.

Transparent reporting

To compare the building climate declaration result in an EC common way across different buildings with more details than what is required in EN 15978 and Level(s), a common classification system is needed. This can be limited to a matric limited to A1-5 but it is likely better for the full life cycle A to C. It is recommended to divide the GWP indicator result per information module, with only A1-3 being merged. This impact can then be reported per building part and further into building element types, which is crucial for a proper and fair supervision. Additionally, climate declaration reports should transparently divide the result into internationally or European agreed building parts and potentially building elements. This kind of granularity result supports the comparison and benchmarking across countries and is needed for supervision. The new EPBD directive requires a digital logbook that could constitute the basis for a more transparent and detailed reporting format. It shall however be noticed that this granularity reporting based on a building classification system is not required as part of the climate declaration as such. However, it is noticed that it will be the case if/when the building digital logbook shall be established, as outlined in the EPBD directive. This kind of digital logbook is then voluntary: "…if these apply in the relevant Member State" (see EPBD Annex V).

If the climate declaration, according to the EPBD directive, is also intended to be used as a source for any limit value not based on the full life cycle from A to C, a complementary report is needed where the LCA result is reported at least module by module.

In brief, scenario settings should be based on the following principals: 1) cut off and reporting voluntary, 2) tiered approach, 3) parametrisation, and 4) 100% modular information, which can be elaborated below.

1. Such modules, or part of the scope of a module that is of minor interest in a life cycle's perspective, or regarded through a regularity perspective not relevant for inclusion in the declaration can be handled as a **cut off**, but it should always be possible to report on voluntary bases to support all parts of EN 15978.
2. A **tiered approach** means that the first solution is a simplified method that can also be motivated that its overall impact is low, and if needed, replaced by a more detailed method if significant. Note that if the life cycle stages A4 and A5 are part of the climate declaration as a building permit, this could also be justified based on the data gap.
3. Instead of a fix, the GWP shall, whenever possible, be found on data sources of **parametrisation**. This supports flexibility and transparency, and makes it

easier to make specific adjustments if wanted. See transport A4 as an example.

4. The **100% modular** approach is a suggestion that is recommended when alternatives exist, such as in C3-4 (and D).

Current climate declaration reporting scope, country by country

Scope of life cycle stage and module

The table below is based on information from the authorities that work with this matter in their respective country. In many countries, this information is continuously updated, and the table below shows the status of February 2024.

Module	Finland	Denmark	Norway	Sweden	Iceland	Estonia
A1-A3: Product phase	O	X	X	X	O	O
A4: Transport	O	O1)	X	X	O	O
A5 Construction process, Waste	O	O1)	X2)	X2)	O	O2)
A5 Construction process, Energy	O	O1)	-	X	O	O
B1 Use	-	-	-	-	-	-
B2 Maintenance	-	-	X	O	-	-
B3 Repair	-	-	-	-	-	-
B4 Replacement	O	X	X	O	O	O
B5 Refurbishment	-	-	-	-	-	-
B6 Operational energy use	O	X	-	O	O	O
B7 Operational water use	-	-	-	-	-	-
C1 Deconstruction, demolition	O	-	-	O	O	O
C2 Transport	O	-	-	O	O	O
C3 Waste processing	O	X	-	O	O	O
C4 Disposal	O	X	-	O	O	O
D Re-use, recovery, recycling potential	O	X	-	-	O	-
Limit value stage, scope	**O: A to C**	**O: A to C**	**O: A1-5**	**O: A1-5**	**-**	**-**

Table 2 Modules in the normative building LCA in Finland, Denmark, Norway, Sweden, Iceland, and Estonia.
X = included in the regulation,
O = suggested or planned but not decided or in force yet

1. A report related to the legislation suggests the inclusion of module A4-A5 in the Danish legislation (Kanafani, Magnes, Garnow, Lindhard, & Balouktsi, 2023).
2. Regarding materials that become waste during construction, only the emissions from production and transport to the construction site are included. Emissions related to the waste management of these materials are excluded.

More detailed information on the respective information modules is found below in regard to how a module is implemented nationally. The scope and methodology for each information module is given in their respective sections, including recommendations for future common implementations.

Scope of building elements

Both the EU Taxonomy criteria for climate mitigation in new construction and the EPBD directive refer to Level(s) as the primary method to define the inventory scope for a building’s climate declaration (see Table 3). The listed “building parts” are not based on a formal classification system and only used to define the scope of the building parts to consider in the inventory.

The conceptual approach of listing different subsets parts and elements of the physical building (or in a worst case on the resource level) to describe an inventory scope can be very problematic if not all elements are clearly defined. Therefore, a nationally applied classification system is normally used for this purpose. Refer to the section 'Use of a common classification system in the context of building LCA', where we suggest an improved implementation in which an internationally recognised classification system is recommended to be used instead. A pragmatic interpretation of the Level(s) inventory scope table for decarbonising buildings is that it can be simplified, where the inventory scope of the physical building is defined by the boundary to its surroundings as:[12]

> all building elements above the drainage layer are accounted for as part of the building climate declaration.

For recommendations on how standardised classification can be made on a system level, refer to the section 'Use of a common classification system in the context of building LCA'. This section also outlines when a national system may be used, for instance, for supervision.

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[12] An operation subdivision of the Level(s) scope table is to divide the building into, e.g. 1) Foundation, 2) Superstructure, 3) Core, and 3) External works.

Building parts	Related building elements
Shell (substructure and superstructure)	
Foundations (substructure)	Piles Basements Retaining walls
Load bearing structural frame	Frame (beams, columns, and slabs) Upper floors External walls Balconies
Non-load bearing elements	Ground floor slab Internal walls, partitions, and doors Stairs and ramps
Facades	External wall systems, cladding and shading devices Façade openings (including windows and external doors) External paints, coatings and renders
Roof	Structure Weatherproofing
Parking facilities	Above ground and underground (within the curtilage of the building and servicing the building occupiers)1)
Core (fittings, furnishings and services)	
Fittings and furnishings	Sanitary fittings Cupboards, wardrobes, and worktops (where provided in a residential property) Ceilings Wall and ceiling finishes Floor coverings and finishes
In-built lighting system	Light fittings Control systems and sensors
Energy system	Heating plant and distribution Cooling plant and distribution Electricity generation and distribution
Ventilation system	Air handling units Ductwork and distribution
Sanitary systems	Cold water distribution Hot water distribution Water treatment systems Drainage system
Other systems	Lifts and escalators Firefighting installations Communication and security installations Telecoms and data installations
External works	
Utilities	Connections and diversions Substations and equipment
Landscaping	Paving and other hard surfacing Fencing, railings and walls Drainage systems

1) If the share of underground car parking (usable area plus traffic area) area accounts for more than 25% of the total useful floor area, the traffic area of the underground parking must be subtracted from the total useful floor area.

Table 3 Minimum scope of building parts and elements according to Level(s).

Since the EPBD directive only covers the building, external works can be considered to be excluded from the inventory scope of the EPBD climate declaration. Then, it might be necessary to simplify the inventory work. As in all LCAs, approximating with zero when a data gap exists is the worst approximation. Therefore, any building elements or systems excluded from a comprehensive building inventory shall not be set to a zero value, but rather handled with a default proxy figure.

European level
The system boundary between the surroundings and the building inventory scope is suggested to account for all building elements above the drainage layer.

National level
Depending on the national status and experience with accounting for and calculating the GWP, simplifications to this scope may be needed; for instance, one or several building elements may be replaced with default figures instead of a detailed inventory of all resources used in the construction stage A1-5. These default figures should be conservative to support an assessment using specific data (as optional), and it is likely that default values will need to be provided for different archetypes to enhance representation. It is preferable to have a nationally-regulated establishment of a mapping of these simplifications to an existing classification system. It is then required to list the GWP data for those listed building elements that are handled in a simplified way by using default data, which optionally can be replaced with a full inventory and specific data.

Reporting of results and supervision/auditing

Energy performance certificate

When considering the reporting of the life-cycle GWP indicator in accordance with the new EPBD directive, it is, in its most aggregated form, handled as a single indicator result for a specific building and made available to the public as part of the energy and climate declaration. The building 'climate declaration' and its life-cycle GWP indicator result is formally a part of the EPBD energy certificate, expressed as kg CO_2e/m^2 (of the useful floor area), for each life-cycle stage and averaged for one year of a reference study period of 50 years. The division of the result "for each life-cycle stage" is just mentioned once in the EPBD (see Annex III, 1a), and can be interpreted as the result that shall be subdivided in stage A Construction stage, B Usage stage, and C End-of-life stage. Besides a mandatory limit value for the full life cycle, it is possible that individual countries also require a limit value for those parts that can be evaluated by real data. This is a suggested approach for at least Swedish and Norwegian legislation.

The basic methodology to use and the building's full life cycle covered is referred to as stage A, B, and C, which is defined in the category rules in the standard EN 15978:2011. This methodology for buildings is coordinated and in line with the product category rules for all construction products and services EN 15804: 2012:A1+2019:A2, and based on a mandate related to Construction Product Regulation (CPR). These life cycle stages are further divided in information modules (see Figure 1), including the introduction of new sub-modules. The LCA methodology that is considered here is based on a draft of the new version of EN 15978. The delegated act regarding EPBD will be launched in December 2025; when writing this document, the new version of EN 15978 will most likely be published and therefore the latest version to refer to (when referred to) in the delegated act.

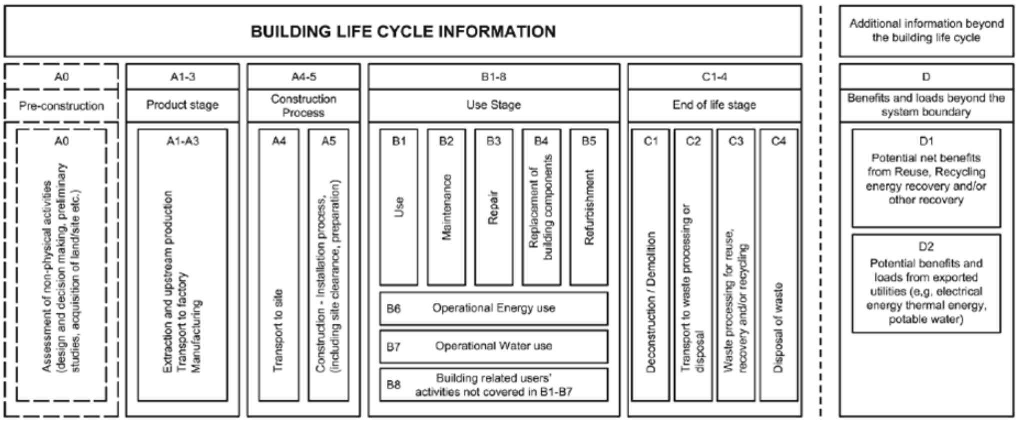

Figure 1 Life cycle stages and modular information used to divide the LCA result in different common parts as a basis for the building assessment (prEN 15978).

The life cycle GWP indicator result shall be calculated and disclosed through the energy performance certificate of the building; as of 1 January 2028, it will be required for all new buildings with a useful floor area larger than 1000 square meters, and as of 1 January 2030, for all new buildings. Besides the requirement for new buildings, there is one requirement for deeply-renovated existing buildings to declare the life-cycle GWP indicator (EPBD), formulated as:

“Member States may define an A+ energy performance class corresponding to buildings with a maximum threshold for energy demand which is at least twenty percent lower than the maximum threshold for zero-emission buildings, and which generates more renewable energy on-site annually than its total annual primary energy demand. For existing buildings renovated to A+ class, Member States shall ensure that the life-cycle Global Warming Potential (GWP) is estimated and disclosed through the energy performance certificate of the building. … … The data stored shall be machine-readable and accessible via an appropriate digital interface. … … The public information shall be updated at least twice per year”.

It shall be noticed that concerning a rebuilding/(deep) renovation/refurbishment, EN 15978 states: “the environmental impacts and aspects of the production of the refurbishment materials and reconstruction/ installation processes are allocated to modules A1 to A5”. In practice, this means that a refurbishment, when the function of the building is upgraded, is methodologically comparable with a new building, which is why, for instance, a limit value could theoretically be the same for rebuilding existing ones and new buildings. If so, this kind of implementation of a building's climate declaration would then really support circularity, where the environmental gain with rebuilding is visual compared to a new building.

Other exceptions where reporting a certificate according to the EPBD (Article 5) directive is not needed are:

- small buildings less than 50 m^2,
- temporary buildings,
- buildings for defence purposes, buildings used as places of worship and for religious activities, and
- residential buildings, which are intended to be used less than four months of the year.

All individual building certificates will (see, e.g. Article 19) be published in a database established by each member state, which allows data to be gathered on the performance of individual buildings and on the overall performance of the national building stock.

Moreover, the Commission states (Article 7.5): "By 1 January 2027, Member States shall publish and notify to the Commission a roadmap detailing the introduction of limit values on the total cumulative life cycle GWP of all new buildings and set targets for new buildings from 2030, considering a progressive downward trend, as well as maximum limit values, detailed for different climatic zones and building typologies". When these limit values are in force, the building life-cycle GWP performance will be complemented with such limit value(s).

Other indicator results that are found in the EPBD that may be reported if decided on a national basis are:

- "Information on carbon removals associated to the temporary storage of carbon in or on buildings". See Annex 5 for how a definition of sustainable forestry supports this approach.
- In addition to primary energy use, additional indicators of non-renewable and renewable primary energy use, and of operational greenhouse gas emissions produced in $kgCO_2eq/(m^2.y)$.
- Moreover, it is explained that "in order to populate the database, building typologies may also be gathered. Data may also be gathered and stored on both operational and embodied emissions and overall life cycle GWP".
- The new EPBD also addresses a 'digital building logbook' that means "... a common repository for all relevant building data, including data related to energy performance such as energy performance certificates, renovation passports and smart readiness indicators, as well as on the life cycle GWP, which facilitates informed decision making and information sharing within the construction sector, among building owners and occupants, financial institutions and public bodies".

If a digital log book is introduced, it is assumed that it will follow the same so-called data template approach (ISO 12006-3, ISO 23387) that is outlined for the Taxonomy log book, the Digital Product Passport, and the performance declaration according to the new Construction Product Regulation (CPR) (see section 'Machine readable EPD and LCA data adopted to BIM'). The digital format for reporting the GWP/LCA result of a building declaration should be aligned with an extended version of the data template format for EPDs (ISO 22057) valid for construction products adopted for buildings. This requires forthcoming standardisation work, which can start when prEN 15978 is approved and published.

If there are additional reports for supervision, it is required in a national implementation to report with a higher granularity than the single life-cycle GWP indicator result. Such more detailed reports will typically be divided:

- by the life cycle stage and its underlying information module.
- per building part, preferably based on a European common building classification system (see Annex 3).
- in a kg CO_2e per m^2 or m^3 building element type that allows artificial intelligence (AI) to support the review of the digitally supplied LCA result and its underlying data used for proper supervision, especially when a limit value is introduced (see argumentation in Boverket 2023[13] and in section ‘Standardised building classification’).

It shall follow an international harmonised classification system and building parts that are about the same, as given in prEN 15978. Such a common classification system like IEC/ISO 81346 is recommended, which covers about the same “building system”, as outlined in EN 15978. Mapping based on this premise is made (in this project) to ICMS Level(s) and other national applied systems (see annex 3).

European level
The EPBD building certificate sets the mandatory minimum required reporting and a harmonised way to calculate the climate potential impact from buildings. The directive includes several optional indicators to report in the certificate related to its climate impact (see list above).

National level
Based on the same source of information gathered for the EPBD energy certificate and its life cycle GWP indicator, it is assumed that Member States are free to add national additional requirements after the notification. It is assumed that supervision will be decided in each nation, and that an increased granularity of the GWP indicator result is then needed to secure a fair competition. Additional aspects and requirements might therefore be:

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[13] Gränsvärde för byggnaders klimatpåverkan och en utökad klimatdeklaration. Rapport 2023:20, Boverket, maj, 2023.

- Additional limit values for a building type restricted to the verifiable part of the lifecycle, namely the construction stage A1-A5, or with other words, the GWP result 'as built'. It is noticed that this result on individual buildings can be added up to the national result, which, for instance, can be used for quantifying the yearly GWP contribution from all new building added to the building stock, and to follow the decarbonisation trend for the construction of buildings. Note that such indicator results must be found on the GWP-GHG[14] indicator in order to make the result from the construction stage (A1-A5) comparable.
- A data quality indicator that specifies the amount of real primary data used in the calculation of the building 'as built' (module A1-A5). A representative life-cycle GWP performance indicator result requires a high amount of such primary data, and can only be achieved by using EPDs from the specific deliverer of a construction product that is delivered to the construction site. One can also consider the aimed data quality of the GWP declaration needs to be increased when limit values are introduced. The increased data quality must also support the use of as much specific data as possible; it also must partly allow generic data where the specific data is not realistic or cost-effective to be considered, such as emissions from different types of vehicles that in this context can be considered specific if it is parametrised sufficiently (see Table 4).
- Additional aspects related to the building and its surroundings, such as adding an optional-life-cycle indicator for the earthwork made for a specific building, and/or the impact from vegetation on the building spot before its exploration and development in the nearest 50 years (see Annex 4 for an example of such calculation methods).
- The EC common way to describe the inventory scope of mandatory building parts to be included for the building parts and its underlying building elements should be found on the common internationally-identified classification system, i.e. IEC/ISO 81346. The same classification can then be used if national implementation is required to divide the life-cycle GWP indicator result into different building system parts as part of the supervision and/or as part of the additional limit value for the construction stage A1-5).
- In the long run, it is recommended that instead of different national classification systems, a free-to-use European classification system based on IEC/ISO 81346 should be established. It should be noticed that further development is then needed, since the current IEC/ISO 81346 series do not include a granularity for 'construction element type', where the materials

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14. The GWP-GHG indicator includes all emissions for the GWP-total except the uptake and emission of biogenic storage in products and their packaging material, which always will be equal to zero over the life cycle A to C (equal to the definition of carbon neutrality for renewable biogenic carbon from natural sources).

used in a construction element are typically accounted for. Such granularity is essential and there is a need for digitalised cost-effective supervision, since the amount construction product data that is part of the integrated life-cycle GWP supervision may cover several tens of thousands of data rows.

Aspects related to supervision

The trust of the certificate must be supported by supervision (auditing). The importance of establishing cost-effective and sufficient supervision is something that is not fully developed for today's building climate declaration (in countries and certification systems that act as a frontrunner here). It is notable that the need for supervision will increase when limit values are launched to support a fair comparison and free competition.[13] It is likely that requirements will be partly included in the delegated act that is supposed to publish in December 2025.

The basis for supervision requires that a complete bill of recourses (BoR)[15] is used for the calculations as a start. Based on the existing calculations, it is noteworthy that the number of resources to handle within an information module, and used for the construction and installation process (A5), will dominate all other information modules (A to C, including D). When supervision is based on 'as built', the digital trade system and economical bookkeeping (such as PEPPOL) can be used as a source to list all resources used in the construction stage (A5) for verification and proof. In both Norway and Sweden,[16] such a system is under development, as well as where the dispatched advice (delivery note) is used to establish the full BoR and as a basis for proof. This system is found on PEPPOL, which is primarily a system to send invoices to customers in the public sector and is developed as an EU standard. Since 2020, all public sector institutions and authorities in the EU have been required by law to receive PEPPOL invoices. It is, in a business relation, not always realistic that contractors will publish or send their invoices for a building work to the developer; the dispatch advice can be used instead, but then it has to be implemented by the actors on the market.

It shall be noticed that the BoR reflects the data used as input for the LCA calculation and differs from the final LCA data that describes the result of a building LCA calculation. In order to digitalise the work, there is therefore a need for common digitalised formats to communicate:

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15. Bill of Material (BoM) is often limited to the amount of materials within a building, meaning that waste generated in the construction and installation process is not accounted as different services or processes used to achieve the construction results. Therefore, the term 'Bill of Resources' is used instead to indicate all kind of resources and wasted parts of the construction products delivered to the construction site.
16. The development of the Swedish implementation of PEPPOL can be followed here: https://byggforetagen.se/miljodata-nu/.

1. the export of the final LCA result and necessary documentation related to this, which is typically part of the public declaration (see section above).
2. the BoR used for the LCA calculation and the documentation on the data and scenario setting used, which is typically used for supervision (or auditing if it is a building classification system).

A digital machine-readable specification already exists for the communication of EPD and LCA data, to be implemented in BIM, for all kind of construction products and services. This format is based on the so-called data template approach ISO 22057 (see section; Machine readable EPD and LCA data adopted to BIM), and it can be elaborated further to be used for buildings found on EN 15978. Such a new working item proposal is supposed to be worked out by ISO TC 59 WG in the spring of 2024. The development of such a digital communication format that is applicable for buildings according to the new updated EN 15978, will, for instance, include other so-called 'group of properties' to partly report other documentation requirements related to modules A4 to D than what is found in ISO 22057:2019. Moreover, the new EN15978 includes more information modules than what is found in EN 15804. There is no such format for the BoR for construction works like an established building, and this needs further development. When the data template is developed for any building system, it should be found on the information model like ISO 12600-2, and when implemented in a webservice (API) and as a stand-alone file (e.g. based on JSON) for construction works, the format should follow the structure and schema given in, e.g. ISO 12006-3.

As part of the supervision, in order to digitally validate numerical values from building system parts, it is needed to introduce a classification system to which a 'building element type' is grouped into. Then, to create a key performance indicator (KPI) per 'construction element type' that can be used to evaluate if the specific reported value for a building element type can be compared to the statistic normal value, a common reference unit is needed. This use of a classification system is further elaborated in the section 'Standardised building classification'.

European level
There is a need to support the supervision of EPBD building certificates. Parts of this supervision can be harmonised in a European way by developing a digital format for: 1) reporting the GWP result, and 2) documenting the source data used for the calculation of the GWP result.

National level
National additions can be added to a common digital format related to the life-cycle GWP, and when the same addition is required in several countries, these additions shall also be subject for harmonisation.

When limit values are launched, proper supervision is required where the building classification is also reported with a high granularity on the element type. Today, this is, for practical reasons, only possible to use national classification systems that are already in use. With such a development where the KPI is created by sampling statistic information on reporter certificates, a benchmarking can be made that can, if implemented, support verification on the numerical GWP value for individual building parts and thereby strengthen a fair comparison and competition.

Basis for setting a reference study period (RSP)

In brief, it can be found that a common generic reference study period (RSP) needs to be defined for modules B and C to make comparisons possible between different individual buildings. EN 15978 does not suggest any RSP.

In theory, the specification of the minimum technical lifespan of a building can be different based on the client's brief. However, this kind of a basic durability aspect is normally in line with the minimal requirements given in the building code, which often uses 50 years for load-bearing structures or other essential parts of the building construction.

For some buildings, the actual lifespan is much longer than this theoretically-based lifespan of 50 years used in LCA calculations. For example, buildings are being rebuilt to perform and fulfil the tenants' need for the modernisation and implementation of cost-effective improvements. Also, rebuilding and making use of the existing built environment supports circularity. However, the current evaluation method in EN 15978 has a linear approach, assessing buildings as they are built, used, and then always demolished, instead of being rebuilt and transformed into competitive "new" buildings. While we acknowledge this issue, we do not present any solutions in this first generation of a common whole life cycle climate declaration, but for future developments.

Based on the argument given above, a reasonable approach to define the RSP is to instead consider a longer life cycle that covers the initial use of a building before it is rebuilt. Subsequently, the assessment of rebuilding an existing building can then be done in the same way and compared to the climate declarations for new buildings. In this context, 50 years seem reasonable.

We can then view the End-of-life (EoL) stage as a theoretical added scenario that is attributed to the whole life cycle assessment of a building as a conservative approach. This stage C will also indicate the relative importance between different stages assessed from A to C. Module D then indicates the environmental benefits of different recycling routes.

It is suggested here that an RSP of 50 years is used for all architypes, and that it reflects the time span when a building needs to be rebuilt and modernised.

Future scenarios for decarbonisation in modules B and C

The objective of decarbonisation is to eliminate our carbon dioxide emissions. The ultimate target is to achieve carbon neutrality, meaning a greenhouse gas (GHG) concentration as low as the natural concentration in the atmosphere before human intervention. This section presents a concept to include future decarbonisation scenarios in the assessment. Although the scenarios will not be correct, we need to produce estimations as best as possible to create a decision supported with our current knowledge. To reflect the uncertainty of estimating what will happen 50 years into the future, we will use a simplified *three-point-scenario* method (see Figure 3).

The decarbonisation scenario is divided into two categories, the energy sector and all sectors. The energy scenario is used when calculating B6, and the other scenario is used to assess a decarbonisation scenario for all resources used by the building throughout its life cycle.

It shall be noticed that the three-point-scenario method results in a decarbonisation (scenario) factor for each year that will be multiplied by the GWP indicator result that is representative for any resource used in the building sector today. However, when calculating the future climate impact from the use of products with inherent carbon (fossil as biogenic), this factor shall not be applied. In practice, this means that the following emissions shall not be multiplied by the decarbonisation factor:

- Biogenic carbon sequestration and storage in the product and its release or accounting for the next product system in the end of life.
- Fossil emissions in the end of life from combustion, etc.
- Uptake of carbon dioxide by carbonisation in cementitious or other pozzolan materials.

The consequences of these exceptions listed above are that those emissions must be handled and separately reported in the LCA tool in order to be accounted for in a correct manner in the LCA calculation tool. This also affect how generic databases are structured, as well as reporting requirements for the EPD, where the minimum requirement is that:

- Future EPDs must report the amount of carbon stored in the product.

Currently, this is only required for biogenic materials, and this has to be considered in the CPR Acquis process settings, the standard for future EPDs for construction products and future updates of EN 15804.

The decarbonisation of the energy system, as well as the shift to a more renewable energy source, will affect the climate impact from the use of materials and products in the future. In other words, the impact from the energy use and material and product use will likely decrease. Therefore, decarbonisation scenarios are applied not only for B6 but also for B1.2-B5, B7, and C1-C4.

There is an ongoing discussion of how to include the expected decarbonisation of the energy system into the assessment. Finland[17] and Denmark[18][19] already have published future scenarios for the decarbonisation of different energy carriers based on existing measures that shall be used when calculating B6. Furthermore, building certifications, like NollCO2 in Sweden, have applied a goal-based approach reaching close to 100% reduction in 2045. Even though a static scenario (BAU) can be seen as outdated and unrealistic, a goal-based approach seems like a "too-good-to-be-true"-scenario when the political incentives are not being decided upon. Also, a goal-based scenario risks implying that nothing or little needs to be done to lower the impact from the use stage. Furthermore, other LCA modules than B6 are affected by the decarbonisation; however, Finland and Denmark only apply their decarbonisation scenarios to B6. Norway, Sweden, Iceland, and Estonia have not yet developed future scenarios.

In prEN 15978, a dynamic approach may be used even if a static approach remains the default approach, since the standard prioritises verifiable information that require Business as Usual, BAU, which is the classical approach used in the EPD. Furthermore, prEN 15978 suggests that where a specific approach is dictated (from relevant international, national, or regional regulations), these shall be used.

The future scenarios by Finland[20] and Denmark[21] consider different methods and time spans. For the assessment from different Nordic countries (and the EU) to be comparable, the scenario applied for the energy system should be based on the same principles. Hence, scenarios from EEA[22] and EU Prime[23] have been studied as possible sources of decarbonisation scenarios to be used for the use of energy and materials, as well as waste management. The two sources of decarbonisation scenario have been chosen based on: regular updates, scenario coverage (EU/Europe, as well as specific countries), and that they are based on WEM/WAM[24] scenarios.

After evaluation, the chosen scenarios are from EU Prime due to the availability of scenarios being presented as intensity scenarios. In other words, the CO_2 is presented per energy unit (kWh or toe). The EU Reference Scenario 2020 is the baseline scenario to assess the options informing the policy initiatives in the European Green Deal package adopted by the European Commission.[25] EU Prime is also the scenario approach chosen by the Level(s) framework for calculating B6. *Figure* 2 also depicts the comparison between EU Prime and EEA scenarios.

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17. https://co2data.fi/rakentaminen/reports/Energy_service_R01.00.pdf
18. https://bygningsreglementet.dk/Bilag/B2/Bilag_2#1f165e42-7a97-45dd-9f4d-5b6373522e23
19. A new emission factor report from Denmark is published, which is expected to be used from 2025: https://sbst.dk/udgivelser/2023/emissionsfaktorer-for-el-fjernvarme-og-ledningsgas-2025-2075.
20. https://co2data.fi/rakentaminen/reports/Energy_service_R01.00.pdf
21. https://bygningsreglementet.dk/Bilag/B2/Bilag_2#1f165e42-7a97-45dd-9f4d-5b6373522e23
22. https://energy.ec.europa.eu/data-and-analysis/energy-modelling/eu-reference-scenario-2020_en
23. https://www.eea.europa.eu/en/datahub/datahubitem-view/4b8d94a4-aed7-4e67-a54c-0623a50f48e8
24. With existing measures (WEM), with additional measures (WAM)
25. https://energy.ec.europa.eu/data-and-analysis/energy-modelling/eu-reference-scenario-2020_en

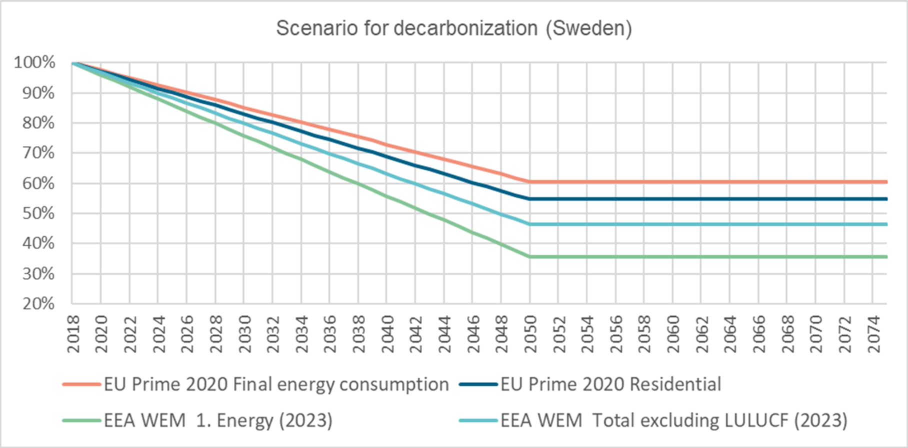

Figure 2 Simplified scenario for decarbonisation based on EU Prime and for comparison with other references. the result from EEA is also illustrated.

Given the unpredictability of future scenarios, a simplified approach is recommended to avoid implying a greater level of predictability beyond our actual knowledge. The simplified *three-point-scenario* approach uses a starting value from when the building is taken into operation and a linear interpolation is then applied to the last year of the data from a chosen scenario (e.g. 2050); after this, the value is constant (see Figure 3).

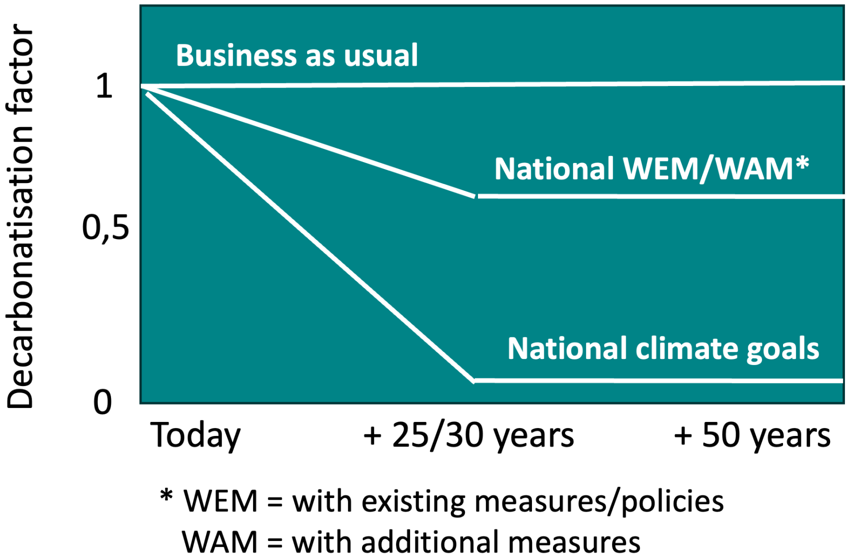

Figure 3 The simplified three-point-scenario method defines a decarbonisation scenario, using linear interpolation resulting in yearly decarbonisation factors used in combination with GWP values that are valid today.

The recommendation for a decarbonisation scenario is that a dynamic approach shall be used, meaning that the decarbonisation of grid energy will be taken into account. For simplicity, and since the future is impossible to predict, it is recommended to use a simplified three-point-method scenario approach. Furthermore, a minimum of one scenario shall be applied; the scenario should be a WEM or WAM scenario where WEM is the preferred choice. However, if a national/local energy scenario exists, this can be used and reported as additional information.

The recommended scenario is presented under each section below.

Decarbonisation scenario for B1.2-B5, B7 and C1-C4

For simplicity, one scenario is presented for B1.2-B5, B7 and C1-C4 that shall be applied for all resources except energy use in B6. The scenario shall not be applied for the carbonisation of concrete and built-in carbon, such as biogenic carbon or carbon stored, in e.g. plastic that is released in C3/C4. The suggested scenario is EU Prime and Total GHG emissions, excl. international excl. LULUCF (see .Table 4 and Figure 4). The scenario is based on an absolute reduction of GWP in the specific country and/or EU. A national approach is preferred to be in line with general LCA methodology, and a national absolute value is assumed to better reflect the change in the climate impact from material usage over time.

National/EU	Scenario	Intensity/territorial	System boundary
National	EU Prime 2020 Total GHG emissions, excl. international excl.	Territorial	All sectors

Table 4 Studied decarbonisation scenario for all resources except energy in B6, intensity/territorial, and system boundary.

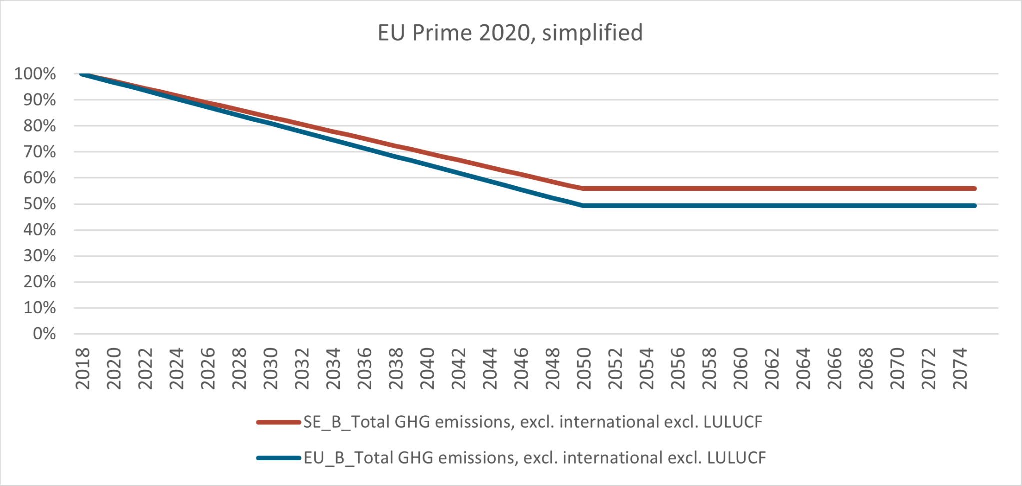

Figure 4 Decarbonisation scenario for all resources except energy in B6, EU Prime 2020, for Sweden and the EU.

The recommended scenario is the simplified three-point-method scenario approach based on country-specific data from EU Prime, given under the heading "Total GHG emissions, excl. international excl. LULUCF for the specific country", and if a national scenario is not available, the EU scenario shall be used.

If a national/local energy scenario(s) exists, these can be used and reported as additional information.

Decarbonisation scenario for B6

The chosen scenario for B6 is presented in Table 5 and plotted in Figure 5. The scenario plotted is an example for Sweden. For B6, an intensity scenario is assumed to best reflect the change for the energy system over time, which was only available in EU Prime. Furthermore, the residential scenario is chosen since it covers only the development in the residential sector.

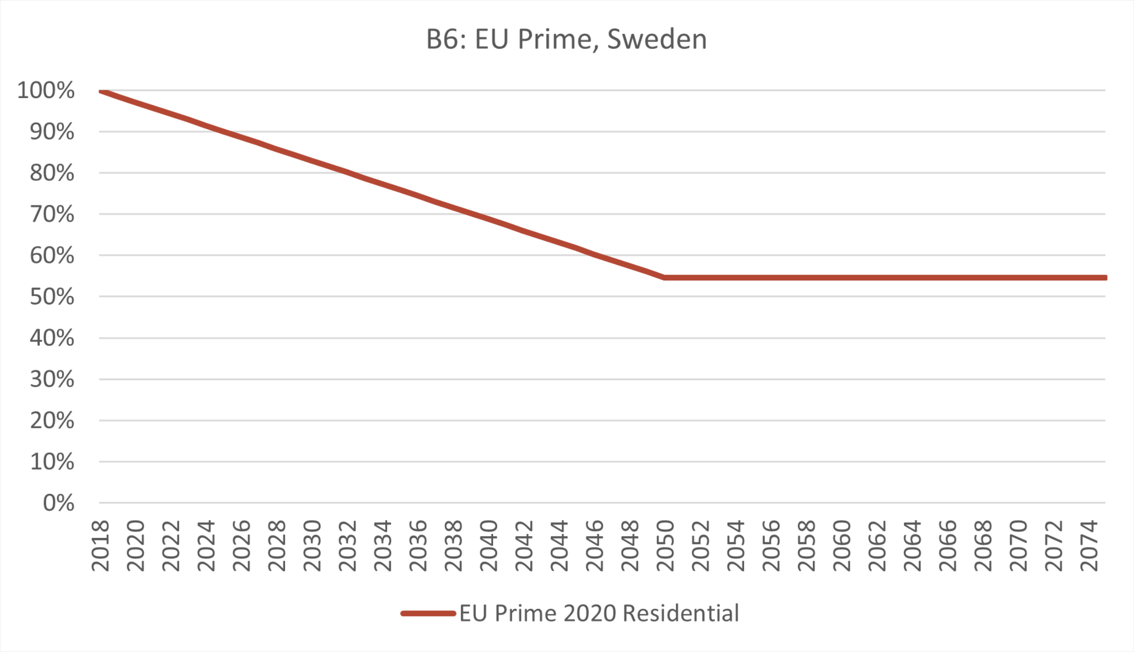

Figure 5 Scenario for decarbonisation of energy use in B6 according to EU Prime 2020 and the three-point-method, Sweden.

National/EU	Scenario	Intensity/territorial	System boundary
National	EU Prime 2020 Residential	Intensity*	Energy use in real-estate

*CO_2e per energy unit

Table 5 Studied decarbonisation scenario energy use in B6, intensity/territorial, and system boundary.

The recommended scenario for B6 is a simplified approach to the EU Prime residential scenario.

If a national/local energy scenario(s) exists, these can be used and reported as additional information. The energy mix used as the default is the national grid mix. This double reporting is motivated since it can make a remarkable difference, and by the requirement to always report, the result based on a commonly agreed scenario comparability is achieved.

As built or as part of a building permit – module A1-A5

From a legal perspective, the climate declaration can be asked for as part of the building permit or 'as built' and part of the final part of the building permit process, or required to be reported on both occasions. When a limit value is required, it will force the market to make several GWP calculations in the early design in order to evaluate if the limit values will be fulfilled as built or not; if so, to take action so that the limit value is fulfilled. A validation, which will confirm that the GWP value calculated from the building permit is fulfilled as built, should be part of the supervision. It is worth noting that from a legal perspective, it should be enough to only ask for the climate declaration as built. It is only the construction stage that can be evaluated as built and the remaining parts of the life cycle will aways be scenario-based.

A1-A3 Product stage

The GWP result from the product stage will be found on generic data that is to be used, as required by the regulators. All countries that are part of the evaluation have specified what data shall be used (see section Common approach for definition of typical cradle-to-gate values'). Generic national representative GWP data on at least high-volume construction products must be advised (typically 80% of GWP-GHG A1-5) and publicly available for free and collected in a GWP database.

In order to have a GWP indicator result that reflects the actual building as built, there is a need to use a significantly high amount of specific GWP data on resources used during the construction stage. The new EPBD directive stresses (Annex I): "Where product-specific regulations for energy-related products adopted under Regulation 2009/125/EC include specific product information requirements for the purpose of the calculation of energy performance and life cycle GWP under this Directive, national calculation methods shall not require additional information". It is likely that the intention with this text is that there will be no place for an individual country to require additional requirements on the product level to be used for a building climate declaration. In the new EPBD as such, there is no indication of a certain amount of specific data that is required for the GWP indicator to make the result for module A1-3 as specific and representative as possible. It is likely that such requirement is possible to be defined in the delegated act in 2025 if the Construction Products Regulation (CPR) will be in force and would make such requirements possible. Thereby, the ongoing work in the CPR Acquis process is important and considered in this report.

A4 Transport to the building site

A4 includes the transport of materials, products, equipment, and services to the site. This includes all transport from the factory gate to the construction site, including the return journeys, intermediate storage, and distribution. It also includes the impacts and aspects related to losses due to the transport (EN 15978, EN 15804).

In the Swedish database, a generic transport scenario is defined for each individual building material that typically consists of one last mile and then an additional distance to the average manufacturer. To simplify the approach and improve the comparison across different materials, this last transport leg is always given as a recalculated value for an "equivalent" lorry transport. When the declaration is reported for as built, it is possible to use the actual transport (if proof is provided).

There are two approaches used in Finland. The first is a calculation via the mode of transport, mass and distance, using the GWP indicators for ships, trains, trailers, etc. (kg CO_2e/tonne km) in the database. The second is a proxy method where A4 is simplified to a default GWP figure per m^2 building. This GWP figure is based on statistical data and earlier research results. In the updated climate declaration representing 'as built', one could either use specific data for A4 calculation or utilise the table values.

Although A4 is currently excluded in the Danish legislation, a published supporting report [26] recommends to include A4-5 that currently is not accounted for in the construction stage.

In the Norwegian climate declaration, a simplified approach is also applied where the transport within Norway is assumed to be 300 km to the construction site, except for concrete that is set to 50 km. For imported construction materials, transports to Norway should be added. For specific materials that have an EPD (as built), the transport value from the EPD can be used but with an adjusted transport distance: As an alternative to

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26. https://vbn.aau.dk/da/publications/ressourceforbrug-p%C3%A5-byggepladsen-klimap%C3%A5virkning-af-bygningers-ud

the EPD and for specific calculations, a transport calculator on the website lca.no can be used. In this GWP calculator, lorry transport is defined by a Euro 5 truck 16 - 32 tons with a 50% filling rate as the default, but GWP calculations can also be performed with actual transport distances and modes of transport.

In prEN 15978, it is noted by referring to EN 15941 that "... the transport and installation scenarios proposed at the building level do not follow those given in EPD, the scenarios for the construction of the building take precedence over the product or system specific data provided in EPD which are adapted or the impacts and aspects are calculated accordingly using other data, ...".

The goal with the CPR Acquis process and its new approach for EPDs is that they shall create a basis for information on a construction product level that, if possible, the EPD-based scenario information can be reused on the building or any construction works level, or at least partly.

A common set of parameters is therefore needed to digitalise and increase the transparency for transport scenarios used in the GWP calculations and the building declaration. One should observe that this parametrisation approach can be used in combination of any of these simplified approaches listed above. A transport scenario normally consists of several transportation legs and a default value is typically defined by the regulators - if not, in the future EPD based on the CPR Acquis process. We therefore assume that in an EPD, several so-called 100% scenario will be reported. It is suggested here that each individual transport scenario alternative is named, documented what it is representative for, and reported for 100 km, and all its underlying transport legs are communicated in the digital version of the EPD (ISO 22057 is currently developed to allow this digitalisation).

To support this development is a parametrisation and 100% scenario approach, which is developed here. This approach follows EN 15804 (as defined in Table 6) and its transparency in reporting, except that the energy use given per litre of fuel is obsolete since it not a generic approach. Instead, the energy use is suggested to be given as MJ per ton and km. The generic approach is then to specify the energy use resulting from the vehicle type, utilisation ratio, empty returns, and detour factor. This is then combined with an energy ware, and typically reported as CO_2e emitted Well-to-Wheel/Wake (WtW) per MJ of energy ware used.

Named 100% scenario (1:n)	**Name of the specific 100% scenario and text description on its representative**
Parameters divided in each transport leg (1:n)	**Explanation and potential unit**
Transport leg	Its name as given by the practitioner
Leg type	Default list: last mile, manufacturer to site, warehouse to site, manufacture to terminal, terminal to site, terminal to warehouse, terminal to site
Distance	One way [km]
Vehicle type	Default list: train, lorry, car, train, boat, flight
Energy use, based on	[MJ/ton km] 3)
Utilisation ratio	[-]
Empty return	0/1 yes/no
Detour factor	[-] typically 1.05 as the default, and describes that the nearest distance is in practice not reached
Energy ware type	Default list: i.e. different type of diesel, petrol, electricity, gas, oil, jet kerosene
GWP WtW	Default list [kg CO2e/MJ] for all alternative energy wares

Table 6 Suggested parameters used for a defined and named 100% transport alternative to be reported as part of module A4 and potentially C2 in an LCA or EPD. These parameters produce additional information compared to Table 10 in EN 15804, thereby partly replacing and expanding these parameters.

The current WtW data in existing databases often originates from LCA calculations and their generic databases, and this WtW data is also used when developing EPDs. Future developments should harmonise how such GWP WtW data for EPDs will be the same for transport calculations for life cycle GWP building calculations in all its modules. In the future, it must be decided if the whole transport system and its infrastructure also should be accounted for in the GWP WtW indicator result. If so, there is a need to develop common, publicly available data.[27] Or should one only account for the vehicle's impact and delete the infrastructure part to avoid double accounting?

GLEC is a recommended existing European data source to use for methodology settings. The methodology used for transport should, in the future, be found on ISO 14083:2023. Generic European transport scenario parameters as 100% scenarios are likely and possible to define via (cPCR) as a European average. It should be noticed that there is an ongoing project based on the ISO 14083:2023 framework, which aims to establish a common set of data sources and LCA data needed to launch a harmonised way of handling transport in this context. It is hopeful the outcome from this project can be referred to in the future CPR Acquis EPDs.

It is concluded here that it is not time-consuming to add generic transport figures with a

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27. This kind of LCA data is currently only found in ecoinvent and other references do not cover all GWP sub-indicators).

GWP indicator result per construction material if they are part of the generic data (database) that is required by the regulators to be used.

Furthermore, it shall be specified for any material or product, the type of transport used, distances travelled, capacity of utilisation and fuel type, as well as the consumption required for their movement to and from the building's site.

European level
It is recommended that A4 is a mandatory module. It is concluded here that it is not time-consuming to add generic transport figures with a GWP indicator result per construction product type if they are part of the mandatory generic construction product GWP database for A1-3, as advised by the regulators.

EPD support: In an EPD, it is possible to define commonly applicable mix- scenarios for A4 for different European regions and/or countries. Such harmonised and regulated information from an EPD can replace the generic data from a public database. Nevertheless, in the future, it is likely that at least part of the transport parameters can be replaced by specific data from the actual transport. The parametrisation suggested here, if implemented, will support such developments and result in a more representative GWP indicator result from transportation.

National level
Whenever asked for by a regulator, generic transport data valid for a specific country can be developed to be representative for an individual country and replace European averages or other regionalised data. Such country-specific data must consider the granularity of the generic data required on the European level.

A5 Construction – installation process

The construction – installation process, A5, shall include all construction activities required to complete the building, or part of the building, during the assessment (EN 15978). This can include, if significant and relevant: transport within the site, ground works and landscaping, construction process and installation, temporary works, and waste management. In the expected update to the standard, A5 is divided into the following sub modules (prEN 15978):

- Sub-module A5.1 Pre-construction activities
  - Including demolition/deconstruction of existing buildings or parts thereof, including waste processing and the removal of materials.
- Sub-module A5.2 Construction activities
  - All impacts and aspects related to energy and water use needed to construct the building. This includes, i.e. preparing the site, temporary works on- and off-site, ground works, transport within the site, storage, heating and cooling, installation of materials and products.
- Sub-module A5.3 Waste and waste management
  - Waste and waste management includes the impact from the material use (scope A1-A3 and A4) and waste management (scope C2-C4), all accounted for in A5.3.
- Sub-module A5.4 Transport of construction workers
  - Module used for additional information regarding the transport of workers to and from the site.

The scope and implementation of A5 in legislation differs between the Nordic countries and Estonia. The differences are if all sub-modules are included or not and what is included in each sub module. As of today, no Nordic country nor Estonia requires to divide the result in A5 in sub-modules A5.1 and A5.4, A5.2 and A5.3.

Sub-module A5.1 Pre-construction activities

If the building is a major renovation, it shall, according to EN 15978, be accounted for as a new building, where the construction stage therefore must also account for the demolition/deconstruction of existing buildings or parts. According to the EPBD directive and its climate declaration, it only covers new buildings thus far.

If a new building is built on a plot where an existing building exists, which then needs to be demolished/deconstructed, all activities associated with the demolition/deconstruction will, according to prEN 15978, be accounted for as part of the environmental burden upon the new building.

The fact if it shall be treated as a new building or major renovation when only parts of the building are demolished is decided by how this is classified in a legal context.

European level

A5.1 Pre-construction activities

The EPBD directive mainly accounts for new buildings, but this module is mandatory if there is an existing building on the site that need to be demolished/deconstructed or parts thereof.

Sub-moduleA5.2 Construction activities

Sweden is the only country that has integrated A5 into its legislation currently in force. In Finland, legislation is in place but not in force, whereas this is yet to be determined by Iceland, Estonia, and Denmark. In Sweden, measured data is needed for the construction according to the legislation. Even if the ground works and landscaping are not included in the Swedish scope, they can be included for simplicity. In the recently published report by Kanafani et al. (2023) in Denmark, it is recommended that the energy use shall be based on measured data and include the construction site, as well as temporary storage and assembly outside the construction site.

In addition to this, Sweden, Finland, and Denmark have calculated values for the template data[28] for A5. In Sweden, this data cannot be used to fulfil legislation; this seems to be the case in the Danish study as well (Kanafani, Magnes, Garnow, Lindhard, & Balouktsi, 2023). In Finland, they state that the data "should be based either on the national emissions database or on the basis of a generally approved data...", which could possibly include the use of the template data. The template data is:

- Sweden (energy use, excluding ground works)[29]:
    - Buildings excluding single family houses: 17.1 kg CO_2e/m^2
    - Single family houses, high level of prefabrication: 10.3 kg CO_2e/m^2
    - Single family houses, other: 10.8 kg CO_2e/m^2
- Finland (energy use, excluding ground works)[30]:
    - Office buildings: 78 kg CO_2e/m^2
    - Residential buildings: 46 kg CO_2e/m^2
    - School or kindergarten: 60 kg CO_2e/m^2
- Denmark A5 (energy use and waste)[31]:

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[28] The words ***template data*** are used since default generic figures in different groups are reported and the user takes the most relevant alternative. The word is also used for simplified EPDs where the manufacturer can use the most representative manufacturing alternative in respect to its own manufacturing process.

[29] https://www.diva-portal.org/smash/get/diva2:1812831/FULLTEXT01.pdf

[30] Rakentamisen päästötietokanta (co2data.fi)

[31] "Installation processes include the use of electricity, heating energy, fuel and construction waste. Also, transport on and from the site is included. The analysis is based on monitoring data from 52 construction sites and takes the larger expected share of renewable energy in 2025 into account. Construction waste has the largest share in A5 with 38%". BUILD-rapport_2023_14_Ressourceforbrug_p_byggepladsen.pdf (aau.dk).

- All buildings: 50.0 kg CO_2e/m^2
- (1.0 kg $CO_2e/(m^2$ year) calculated over a period of 50 years)

A comparison of the template data is not a straightforward process since they have a different scope. Especially Denmark's value that includes waste, as well as energy. However, the Swedish and Finnish scopes are assumed to be more similar, only including energy use at the construction site but excluding the ground works. It is therefore interesting to see that the values from Sweden and Finland differ significantly.

European level
A5.2 Construction activities
The suggestion is that this is a mandatory module.

Building permit: In the building permit, it is advised to establish European template data for A5.2 as part of the EPBD delegated act that can be used as proxy data. The source data for such template data are based on building types (see Swedish example above).

EPD support when used in a building permit: a European parametrisation scenario could be developed to support a common European approach that is based. Such a simplified approach can be made on the product density and a simple scenario where the product is transported by a front wheeler 5 minutes and lifted by electric craned 10 meters.[32] This default scenario is used for all construction products if the cPCR do not develop a more representative parametrisation scenario.

As built: Metered data from the actual construction site covering all energy wares, etc. and its related GWP impact shall be reported and accounted for in A5.3.

National level
Whenever asked for by a regulator, generic construction activities data valid for a specific country can be developed to be representative for an individual country and replace European average or other regionalised data. Such country-specific data must consider the granularity of the generic data required on the European level.

Sub-module A5.3 Waste and waste management

Waste is included in the Swedish and Norwegian legislation, and generic factors for waste as a percentage of A1-A4 are used for different materials and material groups. However, in Norway, data from EPDs can be used if the module is available.

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[32] This so-called sector approach is used in the IVL EPD generator tool if no specific scenario is defined in the cPCR.

In Finland, generic values are presented for waste on their national database (CO2data.fi) in the same way as in Sweden and Norway. In Denmark, a recently published report states that the actual amounts should be taken from fractions leaving the construction site as waste (Kanafani, Magnes, Garnow, Lindhard, & Balouktsi, 2023). Hence, the emission values that are used for A1-A3 cannot be used for A5. The report also states that the transport of waste will be included in A4 instead of A5 due to simplicity. In Iceland and Estonia, it is yet to be determined how to include waste.

Today no country has included waste management for A5 in their legislation; however, it is proposed to be included in Finland's incoming legislation. In Finland, data "should be based either on the national emissions database or on the basis of a generally approved data…".[33] The recently published report by Kanafani et. al. (2023) in Denmark also recommends to include waste management, where standard emission factors are presented based on waste fraction and weight covering the scope of C2-C4.[34]

European level
A5.3 Waste and waste management
The suggestion is that this is a mandatory module.

Building permit: It is concluded here that it is not time-consuming to add generic waste figures and waste handling scenarios with a GWP indicator result per construction product type if they are part of the mandatory generic construction product data A1-3, as advised by the regulators, which is why it is recommended to be developed. It is likely that such wastage figures from the construction process could be defined as part of the EPBD directive delegated act and used as the default if the country-specific default is unavailable.

EPD support/simplified approach: It is recommended to define a common European waste factor per cPCR developed.

As built: It is very time-consuming and thereby costly to follow up on the actual waste generated at the construction site. It is therefore recommended, as the first option, to use the amount of construction products delivered to the construction object and combine this with the default wastage figure found in the default database. The metered data can always replace such default figures if proof can be provided.

National level
Whenever asked for by a regulator, generic waste and waste management data valid for a specific country can be developed to be representative for an individual country and replace European averages or other regionalised data. Such

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33. Decree of the Ministry of the Environment – on the climate declaration of building, 30 sept 2022, Ministry of the environment, Department of Built Environment. Matti Kuittinen.
34. Ressourceforbrug på byggepladsen: Klimapåvirkning af bygningers udførelsesfase (Kanafani, Magnes, Garnow, Lindhard, & Balouktsi, 2023).

country-specific data must consider the granularity of the generic data required on the European level.

Sub-module A5.4 Transport of construction workers

The current LCA and EPD praxis is that this kind of externality shall not be considered as part of a building's burden, hence why the recommendation is that this is not a mandatory sub-moule to account for.

European level
A5.4 Transport of construction workers
This burden is to the current praxis assumed to be outside the burden related to a building, hence why it is recommended to be voluntary information, and if reported, it shall be reported separately.

Therefore, the recommendation is that this is a non-mandatory module.

National level

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Module B1 Use

Sub-modules for B1 Use

In prEN 15978, B1 is being divided into the following sub modules:

- **B1.1** for materials, the assessment of emissions from construction products to outdoor air, soil, ground- and surface-water should be based – among other sources of information – on the results of tests and measurements (e.g. blowing agents from insulation, VOCs from surface finishes, and carbonation from materials containing CaO absorbing CO2).
- **B1.2** for "operational emissions", the assessment of fugitive emissions of refrigerants from building-integrated technical systems. For fugitive emissions from non-integrated equipment (e.g. plug-in equipment, such as refrigerators), they should be addressed and reported in sub-module B1.2 as additional information.

Operational GHG removals are also around the corner, EC carbon removal certification.[35] EPBD allows the reporting of temporary sinks (see reporting section). However, the certification system may be combined with EPDs to incorporate such aspects. There will then be a need for such a placeholder in the building climate declaration.

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35. https://climate.ec.europa.eu/eu-action/sustainable-carbon-cycles/carbon-removal-certification_en

The recommendation is to use the same approach as in prEN 15978, which is assumed to be the approach of the delegated act and is hence the suggested method. For reporting the GWP, the two following parts of B1.1 and B1.2 shall be reported:

- B1.1: carbonation from concrete.
- B1.2: emissions of refrigerants from building-integrated technical systems.
- B1.3 Approved GHG removals.

We also notice that in the future, it may be possible to include GHG removals that are approved and verified by the EC carbon removal certification system.

EPD support/simplified approach: It is recommended to define a common European template approach with the most frequent intended use alternatives to be included in the cPCR when relevant.

B1.1 - Carbonation from concrete

The methods of calculating the CO_2 uptake of concrete are included in EN 16757.

Parameters needed to make a building specific calculation on concrete carbonisation are given in Table 7.

Parameters per building element	**Explanation and potential unit**
Reference study period (RSP)	Number of years [years]
Building element type	Its name as given by the practitioner for a concrete building element
Density of building element	[kg/m3]
Amount of concrete	Weight of the concrete in the assessed element [kg]
Concrete strength class	[MPa]
Exposure conditions	Select from: • Outdoor, Exposed to rain • Outdoor, Sheltered from rain • Indoor in dry climate, with cover • Indoor in dry climate, without cover • Indoor in dry climate, in ground
Mineral additions	Select from: • None • Limestone • Silica fume • Fly ash • GGBS
Amount of mineral additions	[weight-%]
Clinker content in cement	[%]
Cement content in concrete	[kg/m3 concrete]

Table 7 Suggested parameters to be used to calculate the carbonatation of concrete in a building context, according to EN 16757, and reported as part of module A4 and potentially C2 in an LCA or EPD.

As the GWP indicator result from B1.1 will generally be relatively small compared to other modules, a simplified harmonised approach is recommended. Such calculations based on EN 16757 are performed here, and the results in a generic average carbonisation GWP indicator that can be used for all of the concrete in a building are set to be conservative. The assumptions made are:[36]

- Reference study period: 50 years
- Concrete strength class: >35 MPa
- Exposure conditions: Indoor dry climate, with cover
- Mineral additions: None
- Clinker content in cement: 95%
- Cement content: 350 kg/m^3 concrete
- Density of building element: 2350 kg/m^3
- Thickness of building element: 300 mm

For B1.1, carbonisation from concrete shall be included, and other pozzolan materials are optional.

A simplified option is recommended with the opportunity to be more specific. To calculate more specific values, the method in EN 16757 shall be followed.

For the simplified options, the recommended Nordic value for B1.1 (carbon dioxide uptake) is:

- 0.002 kg CO_2e /kg concrete (over a 50-year RSP)

  or
- 0.00004 kg CO_2e/kg concrete, year

A specific calculation on carbonation from concretecan be made and used as an option for an individual building, but it shall follow EN 16757 and be found on material characteristics for the specific products used.

B1.2 Emissions of refrigerants

As B1.2 will generally be relatively small compared to other modules, a simplified harmonised approach is recommended.

The recommended value for emissions from the leakage of refrigerants is based on simplified calculations, together with data from studies in Denmark and property owners in Sweden. The suggested value is based on the following assumptions:

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36. Note that the cement amount and type given above shall not be used as a basis for a market representative concrete recipe, but the combination of ordinary Portland clinker (OPC) and the amount used per m^3 is representative for a conservative approach on the carbonation of concrete recipes used in the Nordic.

- Average leakage of refrigerants: 0,25 gram/m^2, year
- GWP for refrigerants: 750 kg CO_2e/kg (this GWP factor is based on the EU limit value from 1 January 2025)

For B1.2, emissions from the leakage of refrigerants shall be included, and other emissions are optional.

A simplified option is recommended with the opportunity to be more specific. How a more specific value should be calculated needs to be decided in the delegated act or by national legislation.

For the simplified options, the recommended Nordic value for B1.2 is:

- Emissions from the leakage of refrigerants: 0.2 kg CO_2e/m^2, year where the area represents the useful area that is heated and/or cooled with compressors that use refrigerants.

EPD support: It is recommended to define a common European template approach on leaching with the most frequent intended use alternatives to be included in the cPCR when relevant.

Decarbonisation scenario for B1

It shall be noticed that the biogenic carbon shall not be part of and multiplied by the decarbonisation (scenario) factor. See section "Selecting GWP indicators" för more information about the decarbonisation scenario for B1.

Module B2-B5 Maintenance, repair, replacement, refurbishment

Upholding running exchange activities versus rebuilding

The use stage B covers the period from the handover of the completed building to the developer until the time when the building reaches its end-of-life (EoL) in stage C. In accordance with EN 15978, this EoL stage for a new building is understood as deconstructed/demolished, or when an existing building is rebuilt, and its performance is improved to the current valid building code (also known as deep renovation/ retrofit).[37]

Rebuilding is, according to EN 15978, assessed in the same manner as a new building (reported in module A1-5), and the partial demolition of the existing building is attributed to the rebuilt building and all reusage if the existing construction is regarded as sank

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[37] Please note that the word "refurbishment" is here only used in the context of individual products or building elements to avoid mixing up with rebuilding activities.

costs. This approach supports circularity and recovers the existing building as much as possible when rebuilt.

A rebuilding that upgrades the building's performance shall be assessed as a new construction stage and therefore, according to EN 15978, assessed in A1-A5. A new service life with a new reference study period and end-of-life scenario shall be defined for the rebuilt building and its forthcoming service life.

Division of different activities and specifications needed

It can sometimes be a problem to select the most appropriate information module to address an upholding process, especially if it should be addressed in B2 Maintenance or B3 Repair. If it is unclearly defined whether the activities belong to B2 or B3, it is suggested that the first alternative shall be used. In prEN 15978, it also states that B2 and B3 can be combined due to the difficulties in separating them. The current state of practice is that repair processes are typically not accounted for. In the future, it should be possible to account for A3 repair if it is mandatory to include it in the cPCR if relevant. Such information can then be based on the repair frequency and other information needed, typically from statistics.

The other common interpretation problem is to understand the meaning of B5 Refurbishment. It is however clear that this type of process is related to the larger building context, rather than an individual building material, product, or element. As different strategies exist on refurbishment, it is suggested that a coordinated upholding processes covering more than one building element shall be accounted for in B5 refurbishment rather than B2 or B4. This could be, e.g. a façade renovation that includes windows, doors, and a partly new wall plaster. The other simplified refurbishment approach is that each building material, product, or element is maintained and replaced without regarding the relevance of combining these activities.

The most common approach regarding the implementation of exchange activities in an LCA based on EN 15978 is by addressing the maintenance or exchange of an individual construction product, and they are reported in B2 and/or B4. Additionally, B3 can be reported separately or may be combined with B2, as stated in prEN 15978.

It is recommended, in the future, to account for A3 repair if it is mandatory to include in the cPCR if relevant. Such information can then be based on the repair frequency and other information needed, typically from statistics.

It is suggested that B5 Refurbishment is more strictly defined to cover the combined upholding exchange activities and process that cover more than one building element. The exchange will be dependent on the scenario setting of a combined renovation as the main strategy for the selected building system. Consequently, if the combined exchange activities are not considered, this module will be reported as a zero for all environmental indicators. If accounted for, the building system part as a combined renovation shall be listed in B5, and these activities shall not be included in B2-B4.

Estimated service life for building component (ESL)

The most common way to handle different upholding activities in B2 to B5 is to give a time-related interval for its appearance. Ideally, these intervals should be dependent on the on-site conditions and different environmental exposures. The problem is that these types of data are often absent and difficult to verify. Therefore, default representative figures are often applied as a proxy. This, instead of the (non-existing) data, is based on more sophisticated methods, such as the factor method (ISO 15686-1, -2, -7 and -8), outlined in EN 15804 (see Appendix A). The factor method allows the handling of (or transferring) the ESL to different local environment conditions and aspects, such as where the material is placed in the building. However, since this is not an operational approach, and very little data is available, we suggest that the ESL shall be representative for the average conditions.

To calculate the number of replacements of the building component (NR), the estimated service life (ESL) for the building component is needed.

A national table of the estimated service life (ESL) for products is recommended to be defined for all construction products. A granularity similar to the CPR Acquis cPCR 'product type' is the most likely approach in the future. Moreover, it suggests that the ESL shall be representative for average conditions.

If the national table of ESL for products does not exist and, in the future, is not found in the CPR Acquis based information or new requirements outlined in the forthcoming EPBD directive delegated act, the ESL can be used from Level(s). The development in those cPCR will likely be relevant for the average European context, hence why national specification may be relevant in the future if regulators ask for more precise data.

For national legislation purposes, the use of company/building-specific service life data is not allowed, as this is impossible to verify. However, if such a system will be developed in the future, this might be optional.

It is recommended to use:

1. advised European default data, typically found in the forthcoming delegated act, which can be replaced by national advised default figures for the ESL.
2. such generic data can always be replaced by data from the EPD if the cPCR includes such information needed to determine a generic and/or specific ESL. If the factor method (ISO 15686-1/2/7) is applied (as asked for in EN 15804), or any other more specific method, it is possible to use specific data.

Number of replacements (NR)

According to prEN 15978, the frequency of replacements are calculated as:

NR(j)=[RSP/ESL(j)]-1 (1)

where

- ESL(j) is the estimated service life for building component j;
- NR(j) is the number of replacements of building component j;
- RSP is the reference study period of the building assessment.

In prEN 15978, there are two approaches suggested to quantify the frequency of an upholding activity:

- Integer number of replacements:
  - For decimal points between 0 and 0.4, the number of replacements is rounded down to the next smaller integer number.
  - For decimal points above 0.5, the number of replacements is rounded up to

the next higher integer number.

- Decimal number of replacements; where the calculated frequency with decimals is used without an adjustment to quantify the number of anticipated replacements.

As stated in prEN 15978, the decimal number approach shall be used when required by national or regional regulations.

The two approaches suggested in prEN 15978 are also suggested and evaluated in a report that includes a default for periodic defined upholding activities to be used for a whole life cycle assessment (Erlandsson Holm 2015). The calculation example in this report indicates that it is possible to find examples for individual building components where the choice of calculation rule is significant. For an entire building, however, there is only a minor difference. In addition to this, the relative importance from B2-B5 is not the most contributing part from a life cycle perspective.

Based on the overall uncertainty in calculations, regarding the result for module B2 to B5, it is therefore suggested to use the decimal number approach.

LCA data and decarbonisation scenario for B2-B5

To assess the B2-B5 information about the resources, LCA data and waste factors are needed. Most of the time, this data will be available from the assessment for the LCA stage A1-A5. In some cases, the necessary data does not exist in existing national databases, e.g. some specific measures in B2.

To use LCA data from A1-A5 can be seen as a conservative way of assessing B2-B5 (business as usual scenario, BAU), as there then will be no product developments that will decrease the climate impact of building materials in the future. To take such development into account a decarbonisation scenario is added. See section "Decarbonisation scenario for B1.2-B5, B7 and C1-C4" for more information about the decarbonisation scenario factors used for B2-B5.

However, if reused components are used in A1-A5, this will be beneficial if the assessment uses the same LCA data in B2-B5. As it is impossible to verify that similar reused components can be used in the future, it is therefore suggested that only new building components are allowed to be used in B2-B5.

LCA data used for A1-A5 shall be used for B2-B5. If new and/or other types of GWP data are needed, it shall be published on a national level.

If reused building components are used in A1-A5, it is not allowed to benefit from this in B2-B5. In the assessment of B2-B5, it shall only include new building components.

Module B6 Operational energy use

The methodology behind the calculated impact of the operational energy use of the building can be divided into three different categories (prEN 15978):

- Sub-modules for operational energy use.
- Approach for building generated energy production.
- Time-related changes related to environmental aspects.

Sub-modules for operational energy use

In prEN 15978, there are some expected changes regarding the categories related to module B6. The expected changes include B6 being divided into the following sub modules:

Sub-categories related to energy use.

- **6.1 (Shall)** Energy use from building integrated systems regulated by the EPBD and its national implementation shall be included; e.g. heating, cooling, ventilation, humidification, dehumidification, domestic hot water and fixed (installed) lighting.
- **6.2 (Should)** Energy use from an unregulated building should be included; e.g. external lighting, elevators, escalators, and other building integrated systems (e.g. security and communication systems.
- **6.3 (May)** Other energy related to the activities of the building user may be included; e.g. plug-in appliances, computers, washing machines, and refrigerators, etc. It is reported separately as additional information.

Today, the division between energy in 6.1, 6.2, and 6.3 is not typically used and may differ between countries.

The recommendation is to use the same approach as in prEN 15978. If not, the EPBD delegated act is contradicted. As a basis, the same assumptions made for the energy declaration shall be reused as scenario settings for the life-cycle GWP result. The approach, as in prEN 15978, is assumed to be the approach of the EPBD delegated act and is hence the suggested method. Sub-category 6.1 is mandatory, 6.2 is mandatory depending on national implementation, and 6.3 is optional. Each sub-category should be reported and documented separately.

In addition:

- If the declaration is performed as part of the building permit, default values for energy use must be used, as already defined in national legislation.
- If declaration is based on 'as built' and measured energy data, the data shall be used and typically normalised, as already defined in national legislation.

Two approaches for building generated energy production

In prEN 15978, an alternative approach for calculating building generated energy production is presented. The different approaches are expected to be divided into Approach A and Approach B, where Approach A is the default approach in line with the current standard En 15978. A short description of the different approaches is shown here:

Approach A: All impacts and aspects regarding the building generated energy is allocated to the building. Hence, exported energy leaving the building will be free of an environmental burden. Any benefits and/or loads from the exported energy is reported in module D.

Approach B: The impacts and aspects regarding the building generated energy is allocated to the building proportionally to the energy that is used by the building. Hence, no benefits from exported energy can be taken credit for in module D.

Approach A is the recommended approach, which is also the default approach in prEN 15978.

Scope of LCA data and time-related changes to environmental aspects

Since the energy system will change over time, future scenarios are applied to the LCA data for the energy use in B6. The approach and studied scenarios are presented in Figure 4, as well as the recommended decarbonisation scenario and its factors.

The expected default in prEN 15978 is to use a national grid mix; however, another approach may be used.

The suggested scenario is a simplified approach to the EU Prime residential scenario. The scenario is applied for all energy wares in B6. However, if a national energy scenario exists, this can be used and reported as additional information. The energy mix used as the default is the national grid mix.

Impact from combined heat and power (CHP)

The prEN 15978 standard regulates the allocation for combined heat and power (CHP), also known as cogeneration. Cogeneration is the use of a heat engine or power station to generate electricity and useful heat simultaneously. This makes this kind of process unique since the process owner receives an income from the reception of waste and for the energy delivered, which is, in the LCA context, referred to as a multi-input/-outputs process. The process owner typically pays for some fuels, acquires some waste at no cost, and earns an income for those waste flows that is handled with a reception fee. The waste handling as such is always a cost (>0), so the waste cost in the reception is related to a material fee, typically per ton of waste material that is paid to the cogeneration plant owner (and does not account for taxes, etc.). To handle this allocation in an LCA, the plant flows need to virtually be separated in different flow types and allocated separately, according to an allocation approach that is suitable for the respective flow type.

To handle cogeneration, prEN15978 states:

> *"In the case of cogeneration (combined heat and power, CHP) an allocation method to assign the environmental impacts and aspects associated with resource use (primary energy/or fuel input) and the associated emissions (upstream, combustion) to the different energy forms/or carriers generated (thermal energy and electricity) shall be based on EN 15316-4-5."*

EN 15316-4-5 calls this allocation approach 'Benefit sharing method'; another name is alternative production since this is partly a co-generation process, and the efficiency used when only producing and electricity respectively is used to attribute the impact to the outcoming emissions. This allocation requirement from EN 15316-4-5 conflicts with the fundamental requirement in EN 15804, where the inherent properties cannot be allocated away. This is the result of the 'Benefit sharing method' if it is applied for the inputs. However, this can be solved by using the 'energy allocation' approach for primary energy/or fuel inputs separately, and using the 'Benefit sharing method' for the outputs. By using the energy allocation method (the same approach as in national statistics), it means that the efficiency follows natural laws like input energy, which is then always larger than the energy output (and the difference is the losses). It shall be noticed that this split allocation solution does not need to be considered if the GWP is only asked for in the LCA calculations, but it must be considered if, for instance, the energy use indicators are reported or asked for.

According to EN 15804, if a material waste flow that is used as an energy carrier in a cogeneration plant meets the End of Waste (EoW) criteria, the combustion is classified as energy recovery if – to start with – a thermal energy efficiency is greater than 65% for the combustion process. In this case, the energy recovery is accounted for as 'Materials for energy recovery (MER)' in kg per declared unit and reported in module C3. If it is less than 65%, it is defined as incineration and accounted for in C4. If the energy from that process is used by the market, it is reported in C4 as Exported Electric Energy (EEE) and Exported Thermal Energy (ETE) in MJ per declared unit. In the first case, the emissions/outputs from the process is allocated downstream, and in the latter case, upstream to the process that generated the waste flow.

Materials that have not reached the End-of-Waste state prior to incineration, e.g. due to containing hazardous substances, do not qualify for energy recovery (e.g. C3); therefore, any emissions resulting from their disposal or incineration are always, in this case, assigned to module C4 and reported as described above if the energy is exported.

Another EoW criteria listed in EN 15804 states that: "A market or demand, identified e.g., by a positive economic value, exists for such a recovered material, product or construction element". In the interpretation of the meaning of this statement, it is crucial how the meaning of the output/recovered material has a market shall be interpreted. We can here notice two schools:

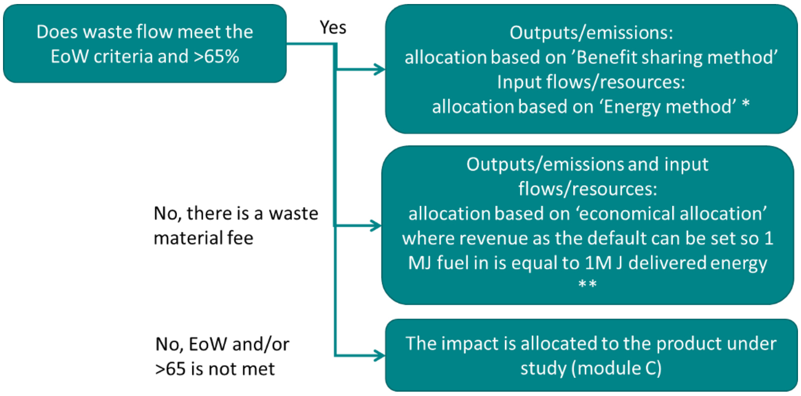
→ **School A**: The waste generator may pay to get rid of the waste, but this is overruled if a market exists for the energy generated (and above 65%). The cogeneration owner typically gets paid for the generated energy that constitute the output. In other words, if there is a fee for the reception of the waste, it is, in fact, not part of the EoW criteria, but that there exists a market for the output that then generates an income.

→ **School B:** This interpretation adds to the main text defining the EoW criteria in EN 15804; an additional requirement that: " ...(the material reaches end of waste before incineration)..." is part of the EoW criteria. To be clear, it shall be noted that this is not stated elsewhere in the standard beside in the informative (i.e. non-mandatory) Annex D. If this aspect is added to the EoW criteria, one can consider waste (that is related with a reception fee) still being a waste at the moment it is combusted and will therefore be allocated to the upstream system. In other words, if the waste generator pays to get rid of the waste, it shall then be regarded as incineration and always be reported in module C4, even if the energy exported has a market and fulfils the thermal 65% efficiency requirement.

Based on the first sentence given in Annex D: "In case of different interpretations between the annex and the text of the standard, it is the text of the standard which prevails on the information in this annex.", we can conclude that School B is in conflict with the main text in the standard, hence why School A must be used.

What is thus far not considered is the fact that waste flows associated with a reception fee constitute a multi-input/-outputs process. An economical allocation in such a multi-input/output process is the only alternative in the context of LCA, since their contribution to the revenue is the only common allocation basis for waste and the delivered energy flows. A rough estimation is that the district heat facilities generally obtain half of their income/revenue from waste fees and the other half from the energy sold. Essentially, this multi-input/-output economical allocation approach generates a split between the waste generator and the energy sold.

A criticism of economical allocation in general is that it is market dependent, and the value can therefore fluctuate over time for the very same site. Therefore, a regulator can also state that this kind of economical allocation shall be based on a fixed value, say 50/50 or any other split, which shall be applied and should be updated regularly in any steering document, like in so-called Product Category Rules (PCR) or in a legislative context in any delegated act.



* In order to follow the approach "inherent properties cannot be allocated away"
** Other default figures can be regulated nationally and updated regularly

Figure 6 Decision tree combined for separate allocations on different type of waste flows in a combined heat and power (CHP) plant.

Per the outcome of interpreting prEN 15978 and taking basic prerequisites from EN 15804 about what cannot be allocated away, the allocation in any cogeneration plant must divide the waste flows in two waste categories and perform an allocation individually. The multi-input/-outputs process introduced here supports the circularity and PPP since there is a split of the burden downstream and upstream, implying that both parties share the burden and gain from potential improvements.

European level

The allocation for cogeneration differs from flows that contribute to the cogeneration revenue and other input waste flows, and it must be allocated separately as follows:

1. **Input waste flow that does not contribute to the cogeneration revenue**: It is recommended to follow prEN 15978, using the 'Benefit sharing method' for cogeneration process emissions and the ''energy' allocation approach' for the input energy carrier.
2. **Input waste flow that contributes to the cogeneration revenue**: It is recommended to use a multi-input/-output allocation approach, whereas the inherent energy in the input flow (as default) can be set to be equal to the energy delivered, meaning that 1 MJ net calorific value of inputs is equal to 1 MJ delivered energy to the net.

National level

Whenever asked for another economical allocation factor for case 2, than a generic European representative allocation factor (1 MJ in:1 MJ out) can be defined nationally.

Module B7 Operational water use

The boundary for module B7 includes the impacts and aspects of the operational water use. Operational water use entails the consumption (net use) of freshwater resources. Its environmental impacts are caused by the processes for the water input (upstream) and the wastewater output (downstream).

Note that:

- The impacts and aspects associated with any water-related energy use within the building and its site are included in module B6.
- The impacts and aspects due to material usage for any water-related technical system in the building during the use stage are covered in modules B1 – B5.
- Water usage for cleaning the building and its components are included in module B2, when possible, to separate it from the overall water usage.

In prEN 15978, B7 is being divided into the following sub modules:

- **B7.1 (Shall):** Covering water demand and wastewater disposal by essential building integrated systems; e.g. water for sanitation, heating, cooling, ventilation, humidification systems, and irrigation of building integrated landscape areas, green roofs, and green walls.
- **B7.2 (Should):** Covering water demand and wastewater disposal by other building integrated systems; e.g. swimming pools and saunas.
- **B7.3 (May):** Covering water demand and wastewater disposal by non-building integrated systems; e.g. dishwashers, washing machines, and washing cars. It is reported separately as additional information.

It is noticed that the division of water use between 7.1, 7.2, and 7.3 is not typically used today and may differ between countries.

The recommendation is to use the same approach as in prEN 15978, which is assumed to be the approach of the delegated act and is hence the suggested method.

Sub-category 7.1 is mandatory, 7.2 is mandatory depending on national implementation, and 7.3 is optional. Each sub-category should be reported and documented separately.If this is not, on a national level, the current practice to divide into these sub-categories,an overall GWP indicator can be used and reported as a total of B7.1-B7.3.

GWP data for B7

GWP data is needed for processes regarding the water input (upstream) and the wastewater output (downstream). As of today, this data is not part of any LCA database in the Nordic countries.

It is recommended that European common figures can be used as part of the delegated act that can be used if national data does not exist. If national regulations do not provide GWP data for the water input nor wastewater output, Nordic default values can be developed and used. These GWP values can be replaced by EPD data related to the actual water supply or waste-water treatment, or other specific data in line with the EN 15804 methodology.

Suggested GWP data if more specific data are missing:

- Water input (upstream): 0,08 kg CO_2e /m^3
- Wastewater output (downstream): 0,3 kg CO_2e /m^3

The suggested value for the water input is a mean value from two freshwater plants in Sweden and with a conservative approach. The suggested value for the wastewater output is a mean value from six sewage water treatment plants in Sweden and with a conservative approach.

Water demand

The water demand for the assessed building is needed for assessing B7. Setting a universal level of water demand for all Nordic countries has proven to be challenging due to the lack of comprehensive and reliable data sources. Therefore, addressing the water demand must be approached at a national level.

It is recommended that the water demand is set on a national level for a relevant number of reference-building (e.g. litres of water per person and year for housing, offices, and schools).

Decarbonisation scenario for B7

See Figure 4 for more information about the decarbonisation scenario for B7.

Module B8 Other building-related building activities

According to prEN 15978:

"The assessment of module B8 is optional. When carried out it shall be reported separately as additional information and its scope/activities reported shall be clearly disclosed to avoid confusion.

The boundary for module B8 covers impacts and aspects of the users' activities associated with the building's intended use during its normal operation, that are not relating to energy and water use addressed in modules B1 – B7."

It is recommended that B8 is optional and if it is included by any national legislation, it shall be based on national level requirements.

Module C1-C4 End of life

The end-of-life stages calculation consists of two parts: the first is the actual activity taking place in the sub-modules based on GWP data for current processes, and the second is the application of a decarbonisation scenario (factor). To handle the uncertainty, as well as the complexity in calculating something happening 50 years in the future, a parameterised approach is suggested for the activity occurring in each sub-module. The decarbonisation scenario is then applied to all processes and their GWP impact based on data for the current situation from each module C1 to C4.

A waste stream has to be classified in the waste handling process if it reaches the end-of-waste criteria or not (see EN 15804 paragraph D.3.3).[38] If not, all impact shall according to EN 15804 be reported in module C4. For waste that fulfils end-of-life criteria and recovered, the impacts related to waste processing for material recovery (recycled and reused) shall be reported in C3. If combustion is made with a thermal energy recovery greater than 60% the impact will then be attributed to the downstream system (i.e. no combustion impact in C3 but and reported material for energy recovery in C3). If efficiency is less than 60% impact from combustion will be reported in C4 (and potential energy utilised will be reported as exported energy). Impact from landfill is always

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[38] It is noted that the accounting rules from EN 15804 is currently not fully followed an all EPDs and in Ökobaudat, why data for module C1 to C4 from these sources must be used with care. Current national generic databases that referred to these sources should therefore consider updating, if needed, to be in line with EN 15804.

reported in C4. Moreover, according to EN 15643:2021 it shall be noticed that backfilling is not regarded as recycling, and the impact shall be reported in C4 (and no credit accounted for in module D).

These accounting rules from EN 15804 are currently not followed in all EPDs and in Ökobaudat, so data for module C1 to C4 from these sources must be used with care. Current national generic databases that referred to these sources should therefore consider updating the data to be in line with EN 15804.

A 'material' decarbonisation scenario is applied for all processes in C1-C4. The recommended decarbonisation scenario is a simplified approach to the EU Prime 'Total GHG emissions, excl. international excl. LULUCF'. For details on the recommended Future scenarios for decarbonisation in modules B and C . Apply same methodology settings for energy recovery in C3 and C4 as used in B6, with the difference that in stage C is a decarbonisation scenario applicable for 'materials' used.

Module C1 Deconstruction/Demolition

A parameterised approach is sought for module C1, as it is a simplified method that can be altered to the specific characteristics of the building. Such specific characteristics are, i.e. the number of floors and material composition. An example of a parameterised approach is presented by Erlandsson and Pettersson (2015, p. 28), which can serve as inspiration for the development of an EC common scenario. The parameterised approach from the report is based on the following parameters:

- Energy use and energy carrier per floor area,
- Energy use and energy carrier based on kg material type in the construction, and
- Extra energy use and energy carrier based on the number of floors.

Looking at the Nordic countries, only Finland has values published on their national website for LCA data for the construction sector. However, it consists of template data, which is based on little background information represented by only concreate construction. The template data is published on the CO2data.fi website.[39]

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39. Demolition process R01.01.pdf (co2data.fi)

A parameterised approach is suggested:

- C1: Parameterisation using European Commission default values per material group, including energy use per building floor area, energy use based on the kg material type in the construction, extra energy use based on the number of floors over 6 m.
- EPD support: The same Parameterisation can be used in EPDs and then directly used for the input to the building level.

Module C2 Transport of demolition waste

A parameterised approach is recommended to have the ability to change the calculation in order to fit the location of the building, as well as national conditions. A parameterised approach is also used by Finland,[40] which is the only country covered by this report with a suggested method published for C2.

The parameterisation in this report is suggested as follows:

- Energy use for a diesel-driven lorry [MJ/ (ton km)]
- GWP data for diesel WtW
- European average distance
    - i.e. 50 km or
    - per material category, that can be overruled by national additions, or
    - potentially specific distances

A parameterised approach is suggested:

- C2: Parameterisation (km, fuel type, vehicle type, etc.) using the national default per product type (see A4).
- It is recommended that the delegated act specifies a European (one figure) average distance as 50 km, or different distances per material category, that can be overruled by national additions or potentially specific distances.
- EPD support: In an EPD, it is possible to publish several scenarios for C2 for different European regions and/or countries.

Module C3 Waste processing and C4 Disposal of waste

The current data for C3 and C4 in EPDs offers little or no transparency. It therefore becomes impossible to use these values when calculating the C3-C4 of a building. This is

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[40] Demolition process R01.01.pdf (co2data.fi)

on account of the fact that no assurance of its accuracy for the actual location and country can be made. In Denmark and Finland, the generic data for C3 and C4 is presented. In Denmark, Ökobaudat and EPDs are used to define GWP data for waste handling, whereas in Finland, EPDs are the most common source of information. For future EPD development, this problem is handled in the CPR Acquis process, and they suggest the so called 100% approach to solve this waste scenario matter and to create flexibility and transparency when waste handling is reported in a EPD, so that it can be used in a modular way as input data on the construction works level.

Where little or no transparency can be found in the Danish database, this cannot be said for Finland. Just as in Denmark, values are presented without transparency for specific products; however, the Finnish database CO2data.fi also presents parameterised values. The parameterised values are 100% scenarios for different material groups, meaning that values for, i.e. gypsum, are presented as 100% material recycling and 100% landfill. The CO2data.fi also includes assumed amounts for specific products to be reused or sent to material recycling, energy recycling, or the landfill; for instance, 15% of gypsum is assumed to go to material recycling, whereas 85% goes to the landfill.

With today's developments, it is assumed that EPDs will become more transparent, publishing 100% scenarios in the future for different waste handling options. With this kind of data available, together with national-based scenarios for waste handling options for each material group, a parameterised approach is possible. The outcome of 100% scenario, to improve and support waste handling on the construction works level, is summarised below:

A parameterised approach is suggested:

- C3/C4: Parameterisation should be defined that can be used to develop 100 % scenarios on different waste treatment options, where the parameterisation of the waste treatments scenario is based on a European average or more representative national scenario.
- Based on the parametrisation methodology above, European ready-made 100% scenarios can be published in the EPBD delegated act, representing the European average.
- EPD support: 100% scenario data can be supplied by EPDs that then must include the relevant 100% reported separately and defined in the PCR. Those scenarios can be generalised as 100%.
    - reuse,
    - material recycling
    - landfill or losses, inorganic materials
    - landfill, organic materials (anaerobic degradation)
    - losses, organic materials (aerobic degradation)
    - combustion of non-renewable energy carriers
    - combustion of renewable energy carriers
- To support the calculation of combustion, a generic GWP database should then be expanded with energy indicators 1) Non renewable primary energy resources used as materials and 2) Renewable primary energy resources used as raw materials. That inventory data will then be used to calculate the amount of energy carrier that is combustible for all construction products. Moreover, to calculate emissions from anaerobic degradation the mandatory figure on amount of biogenic carbon stored in the product can be used as input for those calculations.

Module D

In the EPBD climate declaration, it is required that a life-cycle GWP indicator shall be reported, which covers stages A to C, the full lifecycle of the building. Module D is supplementary information and outside the system boundary of the building, where we assume that module D will not be part of the mandatory climate reporting.

It shall be noticed that the importance of module D based on a decarbonisation scenario relative, using a scenario as "business as usual", will mean that its relative importance is decreased. If we achieve the zero emission target, the figures in module D will be zero.

A development is made in prEN 15978, where the D-module is now divided into subcategories:

- D1 Material recovery
    - D1.1 reuse,
    - D.2 recycling
    - D1.3 energy recovery
- D2 Exported utilities

The scenario for the D-module shall be in line with the scenario in the C-stage, as well as comply with the same allocation approach as in the rest of the assessment, meaning that the allocation approach A shall be used. Today, the use of EPD data for module D is often not transparent enough to be used in an assessment. In the future, a 100 % scenario in module C3/C4, suggested by the CPR Acquis for materials and national waste scenarios, is recommended to be used and could simplify the calculation of sub module D1 in particular.

National level
It is optional to include module D if no EU directive/delegated act is in place covering this; a calculation method can be decided upon in the national legislation based on EN 15978/EN 15804. If included, the method should:

- D1: have scenario settings for D1 that is in line with the scenario in the end-of-life stage, module C.
- D2: use the allocation approach A as in the rest of the assessment.

4. Interoperability of data

Interoperability is defined as the ability to access and process data from multiple sources without losing meaning and subsequently integrate the data in question for mapping, visualisation, and other forms of representation and analysis. In this report, two topics are selected, namely:

1. Machine-readable EPD and LCA data that are essential for the digital communication of LCA and EPD results.
2. A common classification system of buildings that support comparability across countries in the building element level. When the result is reported with a high granularity level, a classification that includes building element types, such reported LCA results are then also applicable for digital supervision.

Machine readable EPD and LCA data adopted to BIM

The transfer of any construction object information in the construction process needs standardised machine-readable structures and formats to ensure an efficient and secure flow of information. In the future, with the new Construction product regulation (CPR), we will likely handle this with standardised data templates in the form of jointly agreed and documented properties that are relevant to a product or any construction system. Data templates will likely be used for the declaration of technical performance, as well as the suggested mandatory EPD related to the forthcoming CPR. A data template may cover any property related to a construction object. The data template approach is designed to be used in Building Information Modelling (BIM).

It is likely that, besides the context of other essential requirements and the future Declaration of Performance or Declaration of Conformity, the data template approach will be used for additional (non-regulated) properties asked for by the market as a basis for digital communication. To complement the regulated essential requirements with a more extended list of properties, several initiatives are now running to establish common properties for individual products based on data templates in parallel with regulatory initiatives and nationally established PDT organisations. We will also see the same development with such system data templates (SDT) to handle common properties for construction objects.

The goal with this part of the project is to establish a common definition based on JSON to communicate any data template or sheet based in it. The same format will be reused to create a stand-alone file for a data sheet and the basis for a standardised API. Furthermore, the new ISO 23387 will include an XML based format for communication on data templates; in the future, there will be a need for a uniform mapping between the TD JSON developed here and the XML defined in the new ISO 23387.

European level

Our recommendation for a common digital format for any construction object for digital communication is that it shall be based on the data template approach (ISO 23386, ISO 23387, and ISO 12006-3), which is the new approach that includes the concept of a data dictionary and links property-based information to any construction object. A data template can be used to define a common set of requirements, form the basis for generic properties for a construction object, which will be replaced with the actual (specific) properties when it is in the context 'as built'. This so-called data template is developed to communicate information for any kind of construction objects and designed to be used in BIM.

In the implementation of these data template standards, there is currently an urgent need for a common file format to support communication and interconnectivity between different domains. To support this development is a common JSON specification, developed based on ISO 12006-3 and the future updated ISO 23387. This so-called DT JSON will then be implemented to handle properties for any specific product group and its so-called product data template. The data template can also be defined for any other kind of construction object and referred to as a system data template (SDT). It is also possible to establish a horizontal set of properties that is information used across products, construction objects, or systems based on the same data template approach.

This DT JSON will then be implemented for EPD and LCA following ISO 22057, and then ready to be implemented by the program operators that publish EPDs and the tools that developed these EPDs. It is likely that this is part of the same technical solution that will be launched for Digital Product Passports. Concerning environmental information for products based on EPD and LCA results, it will be made machine-readable based on the standard ISO 22057. To be in line with the product category rules for construction products (EN 15804) and buildings (EN 15978), it is required that the ILCD nomenclature must be followed. ISO 22057 is designed to follow EN 15804 and the ILCD nomenclature is demanded.

We observe that different regulations already have adopted ISO 22057 when digital EPD/LCA information is asked for. The PDT format ISO 22057 is suggested in the EU Taxonomy delegated act as a basis for the digital logbook to be established for a building, in order to collect and report EPD-based information on request. ISO 22057 is also the suggested format for EPDs or Digital Product Passports for construction products, according to the ongoing CPR Acquis process. One of the benefits of using ISO 22057 is that it is part of the BIM standards already applied, and the PDT-defined properties are connected to a common data dictionary that also includes a library of classes, relations, and units. The PDT approach can be used as logical models for any construction data software from 3D object libraries (CAD), product data catalogues (PIM), and to any building information model (BIM) tools.

National level
On a national level, additional indicators may be introduced and added to the EPD or climate declaration, such as the indicator GWP-GHG, and this indicator is already defined in the PDT for ISO 22057.

GWP-GHG is a modular GWP indicator that makes the LCA result comparable module by module and is used in the Finnish and Swedish LCA databases. GWP-GHG is asked for in Sweden when, for example, a limit value is suggested for the construction stage, module A1-5. In the programme operators EPD International and EPD Norway, it is mandatory to report GWP-GHG for construction products. The indicator GWP-GHG includes all greenhouse gases except the uptake and emission of biogenic carbon in the product itself and its packaging material. These uptakes and emissions are always zero over the life cycle. GWP-GHG is a supplementary indicator to GWP_{total}. GWP_{total} as the GWP indicator restricts the comparison between individual modules. If only a whole life cycle (A to C) is reported, the result will be the same for GWP-GHG and GWP_{total}. See the section 'Selecting GWP indicators' concerning more information about GWP indicators.

What is a data template?

A recognised way to support innovation and cost-effective solutions is to start with performance-based constructions. In the same way, authorities can contribute to innovative thinking and material-neutral solutions by setting performance-based requirements in laws and regulations for construction. Today, the construction industry, to a great extent, has performance-based requirements in European building legislation. To achieve performance-based construction, there must be a common system for managing properties at different levels from the construction work to parts of buildings, building elements, components, and products.

In the digital world, a building consists of several different construction objects. Regardless of which construction object it is, its properties must meet the prescribed performance that can be defined using a data template. These requirements can then be matched against a generic or specific solution or product selection. A data template is a set of defined properties for a given type of construction object. A data template, when it has been filled with a generic or specific solution, is referred to as a data sheet.

The problem we generally see with digitisation today is a broken digital flow of information between different actors during a building's life cycle. When it comes to reporting product properties for objects, the challenge seen today is different competing systems dealing with product information, with different ways of defining properties, and varying quality and documentation (see Figure 7 below). The systems exist today mainly because nowadays, material suppliers need to report product properties in different ways to all these different commercial systems dealing with product information, which is extremely resource-intensive and counteracts coordination.

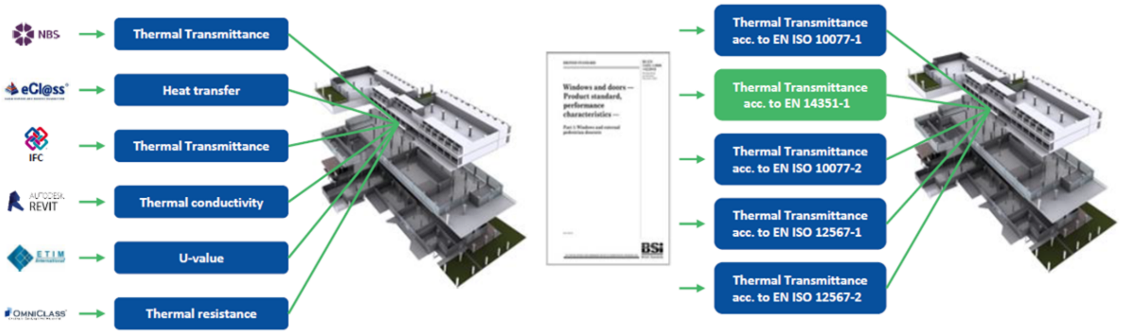

Figure 7 The same property of a window is named and defined differently, depending on the system used, where the concept of data templates would handle these with a common defined property (figure source: Cobuilder).

With the data template setup, the construction material supplier produces their product information once – one data drop – and it can then be used for all other systems or directly to the customers. It is only the material supplier that can guarantee product performance and not any external organisation/system that collects distributed construction product data, but does not put them to the market. With the digital data template setup, updates can also be made automatically by linking the systems that retrieve the product properties of the suppliers to the original source. Normally, one then chooses to save the version that applies at the time of delivery to the building information model representing 'as built'. By setting up a common set of properties for a construction object based on a data template approach, communication is facilitated between the different sources that publish them and those who will use and interpret these properties.

Different types of data templates

The data template concept is described in a number of standards (ISO 23386, ISO 23387, and ISO 12006-3) that define how data templates should be constructed. These standards are generic in terms of the type of information to be handled. The data templates can be *vertical*, i.e. adapted to a certain type of building components or products and their properties. A data template can also be created for a set of common properties that are valid for all types of structural objects, which then constitutes a *horizontal* data template. An example of this is the data template for an Environmental Product Declaration (EPD), which looks the same regardless of the product or the object for which it is used.

A data template with filled quantities/values for the properties becomes a digital product data sheet. A digital product sheet can theoretically consist of properties from one or more data templates. When searching for product data digitally through a web service (API), a selection of properties from different data templates can be used to get exactly the information one may be looking for. As with all information delivery specifications, the properties can be divided for different so-called purposes. A purpose can be information asked for in the characteristics of a structural design or when ordering the product in the construction phase.

Construction Products Regulation shows the way

EU legislation also sees a need for digitalisation linked to construction products and their properties. Within the framework of the Construction Products Regulation (CPR), work is underway with market players called the CPR Acquis process. The aim is partly to develop a new generation of Technical Declarations of Performance (DoP), and partly to develop the forms for a new mandatory Environmental Product Declaration (EPD) based on the product-specific rules for EPDs of construction products based on EN 15804.[41] From a digitalisation perspective, this work can be seen as a natural continuation of the so-called Smart CE marking of construction products, and of the introduction of data templates as the basis for digital information and product properties.

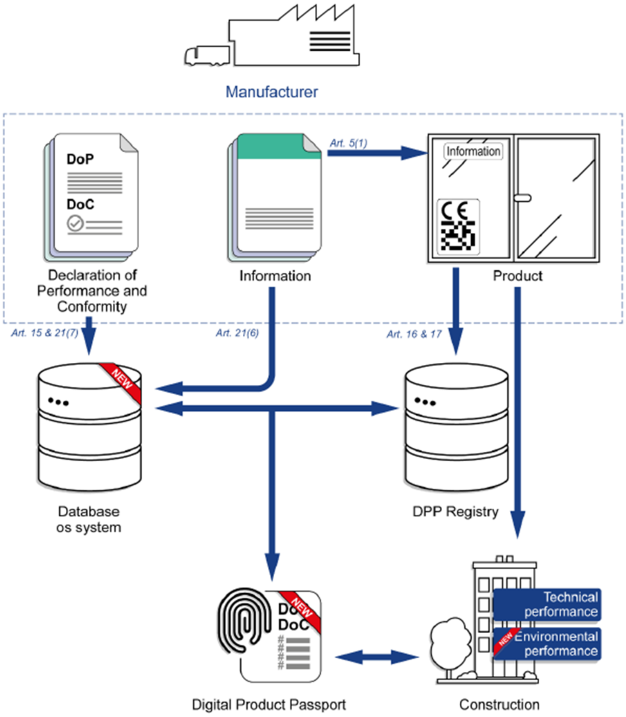

Figure 8 The conceptual structure of digitalised construction product information as part of the CPR Acquis process for future implementation in the forthcoming construction product regulation (figure source, presentation by Oscar Nieto, November 2023).

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41. Sustainability of construction works – Miljödeklarationer – Product-specific rules.

In the CPR Acquis process, the horizontal data template for an EPD, according to ISO 22057,[42] is identified as the most likely choice for an EPD. This will be available for CAD and different information models (BIM). In this way, the CPR and the CPR Acquis process can be seen as a driver of the data template concept. According to the proposal that is currently in place, the requirement for the building material supplier – or rather, the organisation who puts the construction product on the market – will be responsible to point to an internet source (URL) where the performance relationship is available. This is communicated in the CPR Acquis process as a 'system' solution in which the alternative is that a European common database is established, where all products should be published (see Figure 8). The 'system' solution then is very much analogous to the European chemicals legislation REACH, which requires the supplier to make the safety data sheets available, so that customers have access to updated information without the EU having to collect these in a centralised database.

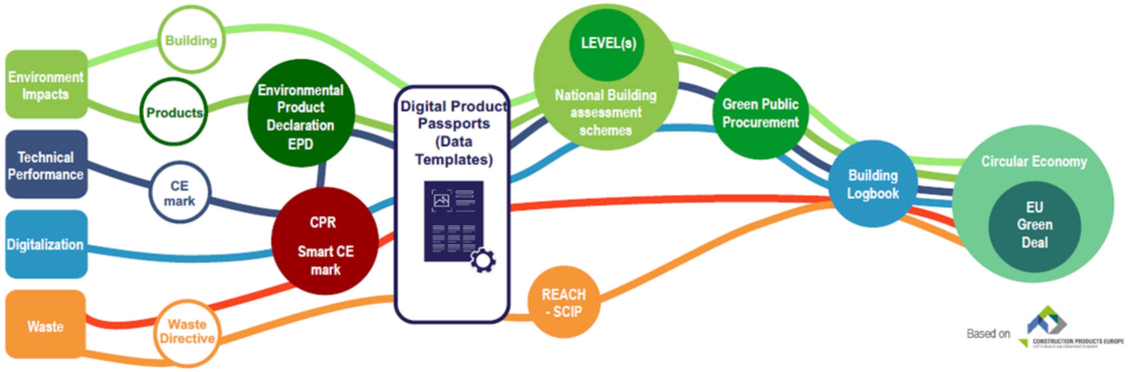

Figure 9 Digitised properties for construction products will be used to support different legislative requirements (figure source, Construction Product Europe).

Thus, it is concluded that within the framework of the current construction product legislation (CPR) and the development that takes place through the Acquis process, a new generation of declarations of performance will be developed based on product data templates. The data template approach will support not only CPR but also other legislation (see Figure 9).

Data templates and data dictionaries

An interesting consequence of developing data templates is that altogether, each individual PDT creates and builds up a subset to a data dictionary, with properties needed for a certain product type (or in general, any construction object). Altogether, these individual properties from all data templates will form the basis of a common European data dictionary. This is where all legally required properties and the standards that define them will be stored. There is a project ongoing dealing with how such databases and other dictionaries could be interconnected.[43] Led by EU DG Grow, the project started in

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42. Sustainability of construction works – Data templates for the use of EPDs for BIM Building Products.
43. The work is done by Tecnalia, UNE and Cobuildet. https://cobuilder.com/en/eu-approach-for-the-digital-product-passport-of-the-construction-industry/

November 2023 and will be finalised by March 2025.

However, the market need for product information is greater than what is contained in the regulated declaration of performance and known as essential requirements. This means that industry associations (or their equivalent) must produce data templates that include more characteristics that are used for different purposes, such as what is required to order a product or what should be included in the dispatch advice (delivery note). These characteristics will likely include national additions. It must therefore be possible to manage them nationally, and a long-term management organisation must therefore also be in place. Currently, Norway is a frontrunner, and two bodies exists (PDT Norway, Cobuilder) that define PDT with national additions. A process initiated by a Smart Built Environment project in Sweden is running, where one of the goals are to establish the foundation of a Swedish organisation type 'PDT Sweden'. In Denmark, Molio is working on establishing data templates for construction elements, but there are no ongoing initiatives for construction products. No data template approach is identified for Finland. In the long run, to maximise the availability of the definitions, a global dictionary, like the buildingSMART Data Dictionary, bSDD, should be used as the central node in a global interconnection between different national data dictionaries.

Data template market values

Examples of market values and benefits generated by the described information structure with standardised data templates and data sheets for product types are given below.

- **A common information structure for many different** markets and systems:
  Data templates and their digital data sheets based on harmonised and European product standards can be used by manufacturers, wholesalers, retailers, and customers in a wide range of markets within Europe and probably a variety of other international markets (as they are based on international standards). The approach is by the potential one-data-drop possibility. The PDT approach will save costs for the material producer, and at the same time, support information that is efficiently communicated throughout the value chain from contractors to property owners and their asset management.
- **Early access to decision information in different phases of, for example, a construction project**
  In the early design stage, data templates can be used to describe the 'recipe' for different construction objects, which can then be inherited down to enterprise product types later in the process. This would likely support an improved design process (see the Danish/Molio example given above). Standardised properties can be compared for products from different suppliers, both from a technical perspective and from an environmental and climate impact perspective. This makes it easier to make choices and calculations, for example, when quantifying for purchasing and the climate impact.
- **Traceable information and data throughout a lifecycle.**
  With standardised data sheets and traceable identities (man and machine) for product types and items, information and data can be included, for example, when

a building is handed over. Building objects in BIM models can be linked to product building objects, and in this way, information and data can be available for decisions and updates throughout the life cycle, for example, for maintenance, repairs, reconstruction. As well as at the end of the life cycle, information and data are also available for circular decisions and activities, even for trade transactions in circular value networks.

A common file format

In the implementation of the data template standards, there is currently an urgent need for a common file format to support communication and interconnectivity between different domains. To support this development is a common JSON specification developed based on ISO 12006-3 and the future updated ISO 23387. This so-called DT JSON will then be implemented to handle properties for any specific product group and its so-called product data template. Data templates can also be defined for any other kind of construction object and then referred to as system data templates (SDT). It is also possible to establish a horizontal set of properties that is information used across products, construction objects, or systems based on the same data template approach. More information on this common DT JSON can be found here:

gitlab.com/bim-alliance/data-lexikon/data-dictionary-schemas/-/tree/main.

The implementation provides well-defined JSON schemas for all the necessary entities from the standards, some additional common "implementation specific" entities, and some useful "default instances" (e.g. a standard set of relationship types).

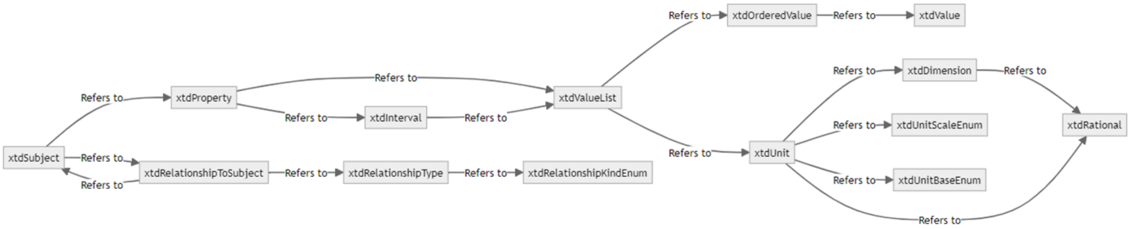

Figure 10 The basic relation between the (construction) object that is called xtdSubject in ISO 12006-3 that is the source of which the property information is linked to.

The standard ISO 23387 provides the rule that apply to a data template established within a data dictionary based on ISO 12006-3:2007. Objects, collections, and relationships are the basic entities of the model in ISO 12006-3:2007. A data template is a superset of this model (since ISO 23387 add entities above ISO 12006-2), providing the concepts and relations needed to describe information about construction objects. It should be noticed that the standard ISO 12006-3 uses other names than ISO 23387, and that there is an update of this later standard (hence, the mapping given in Table 8 will be outdated very soon). A mapping between those current standards for some entities are given in Table 8. Please note that the entities GroupOfProperties and SetOfProperties have similar names but different definitions. The same goes for xtdObject and Object, and it will be elaborated and explained in the forthcoming update of ISO 23387. This updated standard will include a XML-based format for communication on data templates, so in the future, there will be a uniform mapping between the DT JSON developed here and the XML defined in the new ISO 23387.

ISO 23387 names	ISO 12006-3 names
Data template	xtdBag
Reference document	xtdExternalDocument
Construction object	xtdSubject
Group of properties	xtdNest
Generic property	xtdProperty
Specific property	xtdProperty
Quantity	xtdMeasureWithUnit
Unit	xtdUnit
Enumerated type value	xtdValue

Table 8 Naming relations between ISO 23387 and ISO 12006-3.

This DT JSON will then be implemented for EPDs and LCAs in order to follow ISO 22057, and then ready to be implemented by the program operators that publish EPDs and the tools that developed these EPDs. It is likely that this is part of the same technical solution that will be launched for digital product passports. Concerning environmental information for products based on EPD and LCA results, it will be made machine-readable based on the standard ISO 22057. To be in line with the product category rules for construction products (EN 15804) and buildings (EN 15978), it is required that the ILCD nomenclature must be followed. ISO 22057 is designed to follow EN 15804 and the ILCD nomenclature is demanded. More information on this common DT JSON implemented for ISO 22057 can be found here:

gitlab.com/bim-alliance/data-lexikon/data-dictionary-schemas/-/tree/main.

Use of a common classification system in the context of building LCA

Classification in the climate declaration will be used for:

- reporting the GWP result
- defining the inventory scope
- supervision/auditing

A building classification system that is based on a common recognised standard is lacking in the current Product Category Rule (PCR) standard for buildings (EN 15978), as well as in its forthcoming update. The building declaration system Level(s) includes a list of building parts ("shell", "core" and "external"; see Table 3), but this list is only used to describe the scope of the inventory, and not as part of a mandatory common reporting of the environmental indicator result.

Having such a common building classification system in place would greatly benefit the use and comparison of the LCA results between different climate declarations independent of its national origin. Moreover, for thorough and digital authority supervision to be possible, a common method for sufficient classification details is needed, detailed at a suitable level.

European level
Our recommendation for a common classification system for the climate declaration of a building is that it should be based on the IEC/ISO 81346 series of standards. This classification subdivision is used when the climate impact based on the LCA calculations is reported, in combination with information on the information module (from A to D). This approach will guarantee that the climate declaration divided into major building parts can be compared regardless of the country origin. It will contribute to a European common basis of granularity for reporting that will support benchmarking at both building and element levels, see Table 8 and Annex 3. IEC/ISO 81346 is already used in classification systems in Denmark, Sweden, and Eastland as counties related to this report.

National level
The classes of generic building elements defined in IEC/ISO 81346 need to be complemented by more specific types of elements if used as a basis for supervision, e.g. wall constructions using different materials and components. Such granularity is not part of IEC/ISO 81346 and therefore needs to be defined nationally.

To support supervision, the LCA result must, in addition to the overall result divided into building parts, typically be reported per building element type based on a predefined and commonly agreed unit (m, m^2, m^3 pcs). This will allow comparisons in respect to an expected value for the building type assessed. This approach makes it possible to create a key performance indicator for each building element type, which can be used for comparisons between buildings and suitable for supervision.

Moreover, if needed and relevant on a national level, the classes in IEC/ISO 81346 can be translated to and complemented by any national classification systems. Therefore, the building digital logbook must accept different classification systems to be used, since a national system exists that also will be used in parallel in the future.

In the long run, it is recommended that instead of different national classification systems, a free-to-use European classification system based on IEC/ISO 81346 should be established. It should be noticed that a further development is then needed, since the current IEC/ISO 81346 series do not include a granularity for a 'construction element type', where the materials used in a construction element are typically accounted for. Such granularity is essential and there is a need for digitalised cost-effective supervision, since the amount of construction product data that is part of the integrated life-cycle GWP supervision may cover several tens of thousands of data rows.

Parts 2 and 12 of the international standard series IEC/ISO 81346 include classes of building elements: functional systems, technical systems, and components, but not building element types (as described above). These classes can be used for classifying "construction elements", as defined in ISO 12006-2, which is the basic classification standard for the built environment. A classification system based on IEC/ISO 81346 is currently used in Sweden and Norway (CoClass), Denmark (CCS), and the Baltic countries, Poland and Czechia (CCI).

Classification and LCA

The scope of the building LCA and the building elements included is greatly helped by using a classification system. The LCA result is reported per information module, but is often combined with a further granularity by dividing the result attributed to different building elements. Such reporting supports the interpretation of the result. When different technical solutions are evaluated in the design process, it is common practice to compare the climate impact, production cost, and other factors.

When evaluating the LCA result for a building, the most straightforward approach is to compare the result for an individual building element with the expected value. For this, a clear description of the *building element type* is needed. A type has a specified set of properties and property values found in all occurrences of that type.

As an example, in the context of LCA, a type can be a floor construction that fulfils a certain sound insulation class, showing its major material composition, such as made of

CLT and casted concrete on the top. The expected LCA result for a wooden floor system is different than a solid concrete floor that fulfils the same sound insulation class. LCA information on this level can be used to improve the construction. Compared to the LCA in the design process, the digital LCA information that is created for the "as built" background LCA calculation are, at this stage, found of verifiable certificates from the digital trade, namely dispatched advices.[44] In theory, a digital invoice can also serve as a certificate of the amount delivered to a construction works. However, this is unrealistic from a commercial viewpoint.

Note that the number of digital items for the LCA calculation that is based on dispatched advices will increase from a couple of thousands of rows to about 20–40 thousand. If the LCA data is structured combining the building element type and their impact, the regulators can use this information in their supervision. If value limits are introduced in the future, it is important that the authorities can guarantee the law enforcement. Such digitalisation support is currently not on the market, and time is needed to establish such a system.

In order to create comparability on the building element level for supervision (surveillance/auditing) a common predefined reference unit per building element is needed. In practice, the impact in a climate declaration is given for the total amount of respective building elements. So, as supplement information, the amount in m, m^2, m^3, etc. for respective building elements need to be reported. This makes it possible to create a key performance indicator for each building element type to be used for comparison and suitable for supervision. Such digitalisation support is currently not on the market, and time is needed to establish such a system.

The climate impact for the building must therefore be reported per building element type, based on its reference unit. The key performance indicator per building element type can then be calculated per reference unit. The reference unit is a default and commonly agreed unit given per m^3, except for the following building elements (typically according to IFCBuilingElement):

- Windows, doors, curtain walls, and shading devices per m^2
- Chimney per pcs.

To summarise, it seems important that a common classification system is established to support a common knowledge database based on cooperation between countries.

Standardised building classification

The basic standard for the classification of the built environment is *EN ISO 12006-2:2020 Building construction Organization of information about construction works Part 2: Framework for classification*. This standard shows that the built environment can be classified using a series of tables: *spaces*, *construction complexes* (e.g. a housing area),

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[44] A document, delivery note, sent to a customer that states the description, type, and quantity of goods that have been sent to them.

construction entities (e.g. a house), and *construction elements* (e.g. a roof or a window). An element can consist of other elements, thus forming a *system*.

Most or all of these tables can be found in *national classification systems*, e.g. Talo 2000 (Finland), TFM (Norway), SfB (old Swedish system, still used in, e.g. Denmark and the Netherlands), BSAB 96 (Sweden), Omniclass (USA), and Uniclass (GB). These systems are basically "enumerative", sorting objects needed for construction in more or less similar ways: systems, sub-systems, and components.

There is also an *international series of standard* containing tables that can be used as an application of EN ISO 12006-2, namely IEC/ISO 81346. Part 2 of this series contains tables for spaces and "objects" (i.e. "components"); Part 12 contains tables for functional systems and technical systems; Part 10 contains tables for construction complexes and construction entities. All the classes are based on the function of the object.

Part 1 of IEC/ISO 81346 describes a method for identifying individual objects, and for showing four aspects of the object: its function, how it is assembled, where it is located, and what type it is. This method is unique and has been used in the industry—particularly within the field of electrical power—for many years. Classification based on IEC/ISO 81346 has a number of local adaptions: in Sweden and Norway (CoClass), Denmark (CCS), and the Baltic countries, Poland and Czechia (CCI). The use is still fairly small but growing.

For a classification system to be useful, it must have a clear purpose. The Talo system has its primary use for cost calculations. The Swedish BSAB system was developed for technical specifications and is used in the so-called AMA publications for describing technical and other requirements, including the material, on the finished result. The same can be said for SfB, TFM, Omniclass, and Uniclass.

As mentioned, the IEC/ISO 81346 tables have a very different purpose, namely to classify and identify functional objects throughout their entire life cycle. As soon as the need for an object is established, it can be given a class and a unique identity: a *reference designation* (RD). This constant RD will then be supplemented by other properties, based on the current need. These properties can include material, production method, size and weight, type and model, all the way down to the actual product or article used to realise the object. This article may be identified by its GTIN or by some other method.

The generic classes in IEC/ISO 81346, e.g. a wall construction, can be supplemented with constructive *types*, e.g. a wall with a concrete core and plaster board wall covering. In national applications, the 81346 classes and types can be "translated" into the national system.

CAD modelling softwares all have their own method of describing objects. When exported to the standardised IFC format, the software translates its internal object to the IFC equivalent, so that, e.g. a "Beam" becomes an "ifcBeam". Apart from this basic classification, the IFC object carries many properties exported from the CAD software or added afterwards in a IFC editing tool.

Some of these properties—collected in an "ifcPropertySet"—can contain supplementary classification and identification. This way, a complete reference designation, according to IEC/ISO, can be added to each object of interest. It is noteworthy that there may be more than one classification system, and that those systems are often more precise than the IFC elements used.

The unique RD of each object can be used as a common "key" when storing additional data describing the object in other data formats. The different data sources share the same information model of the construction entity. This way, geometrical data from the CAD model can be combined with database sources, together forming a complete description of each object: its size, location, material, environmental impact, cost and so on, possibly to the extent of forming a "digital twin".

To summarise, all classification systems for the built environment have their strength and weaknesses, based on their purpose. The only system designed for the life-cycle stable classification and identification of digital objects is IEC/ISO 81346. Other systems have different roles in specific phases of the construction and asset management process.

Suggested building parts and elements to be used

The draft version of EN 15978 that gives the LCA-based calculation contains an example list of building parts and elements. As an example, this is, in the table below, translated into equivalent CoClass classes or types. The letters in the CoClass are based on the common structure from IEC/ISO 81346. Refer to 'Annex 3: Building part from prEN 15978 mapped with Nordic classifications systems' for an extended mapping of the classification systems.

Building parts	**Building element and processes**		**CoClass class/numbered type** 1 letter = Functional system 2 letters = Constructive system 3 letters = Component	
Pre-construction works	Facilitating works	Temporary/Enabling works		
		Specialist groundworks		
	Work to existing building	Demolition and alterations		
Substructure	Foundations and piles		A20	Foundation
	Basement walls		B31	Cellar wall system
	Retaining walls		B32	Retaining wall system
	Waterproofing		FSG10	Water proofing
	Ground floor construction		C10	Bottom slab system
Super-structure	Frame	Columns	ULD	Column
		Beams	ULE	Beam
		Shear walls	BD	Wall structure
	Upper floors		C20	Mid slab system
	Balconies		C41	Balcony slab system
	Roof	Roof structure	D	Roof system
		Weatherproofing	FSG10 RQA	Water proofing Insulation
	Stairs and ramps		AF AG	Stair construction Ramp construction
Fabric	External envelope	External walls	B10	Exterior wall system
		Windows	QQA	Window
		External doors	QQC	Door
		Shading devices	RQD	Screen
	Internal walls	Internal walls – load bearing	B20	Interior wall system
		Internal walls – non-loadbearing	B20	Interior wall system

Internal doors	QQC	Door		
Finishes	External finishes	Cladding	NCB	Wall covering
		Coatings	FSZ	Coating
	Internal finishes	Wall finishes	FSZ	Coating
		Raised floors	AQ	Floor construction
		Floor finishes	NCC	Flooring
		Ceiling finishes	NCE	Roofing
Building services	Water systems	Hot water distribution	F22	Tap hot water system
		Cold water distribution	F21	Tap cold water system
		Water treatment systems	KC	Cleaning system
		Rainwater systems	G24	Roof water runoff system
	Sewage systems		G11	Wastewater system
	Lighting	Internal lighting	Q11	General lighting system for building space
		External lighting	Q12	General lighting system for outdoors space
	Electricity generation and distribution		K	Electrical system
	Renewable generation systems		K.HG31	Electrical system > Solar electric supply system
	Heating systems		H20	Heating system
	Cooling systems		H10	Cooling system
	Ventilation systems		J	Ventilation system
	Conveying systems		N	Transportation system
	Telecoms and data systems		M	Information and communication system
	Fire protection systems		P10	Fire safety system
	Communication and security installations		P30	Personal safety system

Table 9 Building part outlined in prEN 15978 and its mapping to CoClass that is an example of a classification based on IEC/ISO 81346.

Establishing constructive types of building elements

In order to be useful, classification systems need to have a clear purpose and a consistent principle for sorting objects into classes. For the built environment, ISO 12006-2 stipulates that the classes of construction elements should be defined by *function*, *form* or *position*, where “form” typically means “technical solution”. Examples:

- Function: delimiting a space, providing fresh air, letting in daylight.
- Form: solid, truss construction, aggregated.
- Position: interior, exterior, above, below.

Most of the current systems, e.g. BSAB 96, TFM, and Uniclass, use a combination of the three to define the classes of systems and components. As mentioned, the classes in IEC/ISO 81346 are primarily based on the function of the object. However, in the components table, about half of the 700 classes also show a technical solution.

In CoClass, the *classes* in IEC/ISO 81346 are supplemented by a large number of *types*. No distinct difference between a class and a type can be defined. A type simply has *at least one additional.*

Annex 1: Common approaches regarding the GWPs of different greenhouse gases

Tarja Häkkinen

Indicators in EPD for building products EN 15804

This section discusses the common approaches regarding the GWPs of different greenhouse gases, considering that the EPDs formulated at different timepoints have applied different values. Other environmental indicators defined in EN 15804 are handled and commented on in the next section related to the CPR Acquis process.

The EPDs published in different databases can be based on either of the two versions of the standard European standard EN 15804. EN 15804:2012+A1:2013 says[45] that the global warming potential (GWP) shall be calculated based on the GWP for a 100-year time horizon as in IPCC: Climate Change 2007[46] (AR4). However, the current version of EN 15804 + A2 2019 refers[47] to the IPCC 2013 (AR5). The GWP values for a 100-year time horizon for greenhouse gases somewhat differ in accordance with AR4 and AR5 for carbon dioxide, methane, and nitrogen oxide. At this stage, many EPDs that follow the previous version are still available.

According to EN 15804 A2 (2019), the GWP indicators are defined as follows:

GWP-fossil - This indicator accounts for the GWP from greenhouse gas emissions and removals to any media originating from the oxidation or reduction of fossil fuels or materials containing fossil carbon through their transformation or degradation (e.g. combustion, incineration, landfilling, etc.). This indicator also accounts for the GWP from GHG emissions, e.g. from peat and calcination, as well as GHG removals, e.g. from the carbonation of cement-based materials and lime. The indicator also includes the emission of laughing gas (N_2O) from renewable sources.

GWP-biogenic - All biogenic emissions of carbon dioxide (CO_2), carbon monoxide (CO), and methane (CH_4) from different processes are included, as well as biogenic carbon stored in the product and, potentially, its packaging material. This stored carbon accounts for the sequestration (uptake) of CO_2 into biomass from all sources except native forests. Harvesting wood from native forests and its emitted GHG is treated as a fossil emission, including its origin, from the stored biogenic carbon in the product.

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45. Annex C Normative. Table C.8 Sources for life-cycle impact assessment (LCIA) models
46. The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment
47. Annex C. Normative. Table C1

Biogenic carbon stored in the product or its packaging must be balanced out over the life cycle when the material is recycled or energy recovered to fulfil the requirement in EN 15804 that inherent properties cannot be allocated away. Therefore, GWP-biogenic also accounts for the GWP from the transfers of any biogenic carbon from previous product systems into the product system under study. This indicator also covers biogenic emissions to air from biomass from all sources except native forests due to oxidation or degradation (e.g. combustion, solid waste disposal). It also covers all transfers of biogenic carbon from the biomass from all sources, except native forests, into subsequent product systems in the form of biogenic CO_2. The amount of CO_2 in the product or packaging material from the biomass at the point of complete oxidation results in zero net CO_2 emissions, when biomass carbon is not converted into methane, non-methane volatile organic compounds (NMVOC), or other precursor gases. Note that all other biogenic stored in any other auxiliary material is directly balanced out to support the modularity approach.

GWP-luluc - The indicator accounts for GHG emissions and removals (CO_2, CO, and CH_4) originating from changes in the defined carbon stocks caused by land use and land-use changes associated with the declared/functional unit. This indicator includes biogenic carbon exchanges resulting, e.g. from deforestation or other soil activities (including soil carbon emissions). Calculation rules for GWP-luluc shall follow the latest available version of the PEF Guidance document. For native forests, all related CO_2 emissions are included and modelled under this sub-category. The CO_2 uptake related to the carbon content of biomass entering the product system from native forests is set to zero. Any biomass-based net increase in carbon stocks, including soil carbon uptake (accumulation), shall not be considered in GWP-luluc and is set to zero. Soil carbon storage may be included as additional environmental information when proof is provided. NOTE: For example, proof of soil carbon storage is provided when legislation provides modelling requirements for the sector, such as the EU greenhouse gas accounting rules from 2013 (Decision 529/2013/EU), which indicate carbon stock accounting. GWP-luluc shall be included in the GWP-total. If the contribution of GWP-luluc is < 5% of the GWP-total over the declared modules, excluding module D, GWP-luluc may be provided, as an indicator not declared.

Climate indicator

The GWP is the main indicator in CO2data. The database defines the GWP values for products, services, and systems, covering all modules of the life cycle. CO2data includes three GWP indicators: Global Warming Potential fossil fuels (GWP-fossil), Global Warming Potential land use and land-use change (GWP-luluc), and Global Warming Potential biogenic (GWP-biogenic). However, the typical values for GWP-biogenic and GWP-luluc are mainly assumed as zero values based on the following adopted approaches:

- Based on the review of the environmental declarations, wood products have a low GWP-biogenic value when carbon dioxide that is binding to the growing wood and is released in the C module of the product are not considered. In Finland, in the manufacture of wood products in sawmills, the burning of wood-based fuel does not produce methane, but some carbon monoxide (emission factor of 1.57) is induced. The released nitrous oxide is attributed to fossil emissions. Thus, the GWP-biogenic share caused by wood-based fuels is largely compensated to zero within the A module, and it can be left out of consideration in the typical values of the emission database. Also, the GWP-biogenic values, which are caused by, e.g. packaging materials, are typically minimal compared to the GWP-fossil value. In summary, it was concluded that GWP-biogenic can be ignored without making a significant assessment error when choosing typical values, except for the carbon bound to and released from sawn timber.

- The sum of GWP-biogenic values in modules A and C in environmental declarations for sawn timber is usually zero or almost zero. According to the standard, the procedure is such that the value of bound CO_2 is negative in the A1 module, and the value of CO_2 is positive when the same carbon is then released from the system either during combustion or when the product moves from one product system to the next. CO2data database defines this value based on the product's carbon content, which is calculated as CO_2. The same value is considered in module A as negative and again in module C as positive (i.e. emission). The products are also assumed to be made from timber harvested from a sustainably managed forest. GWP-biogenic values are not multiplied by a conservative factor.
- Regarding other materials and based on a small review of environmental declarations, GWP-biogenic emission values are low. The typical order of magnitude is smaller than 2% compared to GWP-fossil. The current version of the database does not consider GWP-biogenic emissions for any materials other than wood, but those are marked as zero.
- The GWP-luluc values of construction products, as presented in environmental product declarations, are also minimal compared to the GWP-fossil values. In general, construction materials and fossil fuel inputs contribute with an insignificant share to land use impacts in the life cycle of Finnish buildings, as mineral and fossil raw materials and fuels have low embodied land use needs (Häkkinen et al., 2013). Thus, the values are now ignored in the typical values and marked as zero.

The GWP-luluc indicator covers greenhouse gas emissions and removals (CO_2, CO, and CH_4) resulting from changes in carbon stocks caused by land use and land-use changes related to the functional unit under consideration. The indicator includes biogenic carbon changes that result from, e.g. the loss of forests or other soil-related changes, including soil carbon emissions. The calculation of GWP-luluc follows the latest version of the PEF Guidance document[48]. Accordingly, the category includes biogenic carbon exchanges from deforestation, road construction, or other soil activities (including soil carbon emissions). For products based on wood from native forests, all related CO_2 emissions are included and modelled under this sub-category (including connected soil emissions, products derived from native forests, and residues), while their CO_2 uptake is excluded.

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48. Fazio, S., Zampori, L., & Schryver, A. (2020). *Guide for EF compliant data sets. JRC Technical report.* Retrieved from https://eplca.jrc.ec.europa.eu/permalink/Guide_EF_DATA.pdf. p. 35.

The principles for dealing with biogenic carbon substantially affect the emission data of wood products. According to the product category rules defined by the Finnish EPD operator (RTS PCR (Method for the formulation of building products' EPDs following the principles of SF EN 15804 2019. RTS EPD WG PT 18 22.4.2022):

- The carbon bound to the organic material is reported as a negative GWP-biogenic value in section A1 if the product's raw material comes from a sustainably managed forest. If this biological raw material is used for energy production in manufacturing the product, the resulting CO_2 emission is reported as a positive GWP-biogenic value in section A3.
- If the product's raw material does not come from a sustainably managed forest, no GWP-biogenic information is reported in section A1. If this organic raw material is used for energy production in manufacturing the product, the resulting CO_2 emission is reported as a positive GWP-luluc value in section A3.

The same principle has been adopted for the CO2data database. It considers the carbon uptake for products originating from sustainably managed forests and assumes this is the case in Finland, especially based on the statistics that show that the living standing trees in the Finnish forests are still increasing. However, the current interpretation of sustainable forestry criteria does not consider the effect of harvesting levels on the net carbon sink. According to The Finnish Climate Change Panel's (Seppälä et al., 2022) report, increasing levels of harvesting have decreased the carbon sink for decades. Calculation rules and principles regarding land use, forestry, and wood-related emissions require more research and discussion.

Annex 2: Considerations for the use of carbon data

Tarja Häkkinen

The proposal for the new regulation on climate declarations in Finland requires that all life cycle modules A, B, and C be considered in calculating the carbon footprint. It also requires calculating the so-called carbon handprint (i.e., nearly the same benefits beyond the life cycle [module D]). Climate declaration is naturally calculated using the GWP indicator. However, considering decarbonisation also causes some problems in this context; thus, energy and material resources could be reasonable additional indicators.

The assessment of climate impacts aims to support a low-carbon future. Naturally, the rules of assessment should also support this goal. The life cycle methodology ensures the consideration of all phases while the focus needs to be on today's emissions because of the urgency of the climate measures.

The methodology for assessing sustainable buildings should reflect reality correctly and support decision-making toward low-carbon choices. The consideration of decarbonisation of energy probably describes the future well. However, this approach provides less support to efforts toward zero-energy building. The consideration of decarbonisation in the manufacturing industry would probably describe the future well but would correspondingly create less pressure for the industry to hasten the implementation of solutions for the low-carbon industry.

Because of this dilemma, the suitability of the GWP (fossil) indicator to describe potential benefits is questionable. Being able to assess and consider the future benefits and problems of different selections is important; however, it is unreasonable to make these comparisons using an indicator that deals with emissions that should be almost zero 50 years from now. Although the current measures – including limit values for buildings' emissions – will hopefully end GWP (fossil) emissions, there will quite probably be a shortage of available material and energy resources.

Although GWP (fossil) is currently the key indicator, the role and significance of other key indicators should be considered. The importance of indicators that describe the use of material and energy resources, GWP(luluc), and GWP(biogenic) need to be discussed and emphasised.

As a conclusion of the discussion, indicators that describe the consumption of energy and materials resources are important. As the idea of the energy indicator would especially be to reflect the magnitude of the demand for energy, the division for non-renewable and renewable would not be important, although low-energy consumption as such would be. However, regarding materials, considering material types and the origin of materials would be more important.

Embodied and operational GWP and energy indicators

The CO2data database considers all modules, including the D module (benefits beyond the life cycle), and the climate database from Boverket focuses on the A module.

From the life cycle perspective, considering all phases would naturally be recommended. However, considering the GWP impact that will occur several years or 50 years from now is complicated because of the foreseen decarbonisation of energy services and manufacturing processes. This significantly influences operational impacts, end-of-life impacts, and benefits beyond the life cycle. The lack of good-quality data, especially for modules C and D, emphasises the significance of the A module.

The climate database from Boverket provides the GWP values for Swedish electricity and for fuels. The foreseen decarbonisation of electricity is not considered, but the GWP is since these figures are only used for energy use at construction site A5 and shall not be compared with the figure design to be used in B6.

The CO2data defines GWP-fossil values for 100 years for district heating and electricity, considering the decarbonisation calculated based on the foreseen changes because of existing regulations and policies. Both approaches enable the consideration of embodied and operational emissions over a selected period, but the calculation results differ significantly. The Finnish approach probably gives a more realistic picture of the life-cycle impacts. It emphasises the role of product selections and low-carbon product development, while it does not specifically emphasise the meaning of energy efficiency. However, even based on this approach, the energy choices still significantly affect the design's carbon footprint. Based on the results of a recent interview[49] with building and construction practitioners, energy-related choices are still the focus when searching for possibilities for low-carbon building; however, interest in low-carbon concrete solutions has greatly increased.

From the viewpoint of a carbon-neutral society, the rapid development of low-carbon manufacturing processes and the true decarbonisation of energy services are important. The focus of the proposal for the recast energy performance-building directive[50] is the reduction of operational greenhouse gas emissions. Still, steps are taken to address carbon emissions over a building's whole life cycle (see Section X). The European standard EN 15978 (2011) does not define specific rules for considering the decarbonisation of energy services. However, Section 8.3.3 says, "Other specific requirements may have to be considered in the description of the life cycle of the object of assessment". Examples given include regulations and the client's requirements. When the decrease of the GHG emissions of electricity and district heat are based on the nationally agreed policies and regulations, these may be considered part of other specific requirements.

The following table suggests the pros and cons of the various choices to simultaneously

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[49] Häkkinen, T. RAKSE project report

[50] European Commission. Brussels, 15.12.2021 COM(2021) 802 final 2021/0426 (COD) Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the energy performance of buildings (recast). https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021PC0802&from=EN

regulate embodied emissions and operational energy or emissions.

Object of regulation	Pros	Cons
Embodied GHGs and operational / purchased (renewable and non-renewable) energy separately	Perspective extended to embodied emissions	No consideration of GWP of energy choices, although renewability is considered. Investment in renewable energy, such as PV, appears negative from the viewpoint of embodied GHGs.
Embodied GHG and operational GHGs (no decarb.) separately	Perspective extended to embodied emissions. Considers the GWP of energy choices.	Investment in renewable energy, such as PV, appears negative from the viewpoint of embodied GHGs Exaggerates the influence of operational energy on GHGs.
Embodied GHG and operational GHGs (decarb. considered) separately	Perspective extended to embodied emissions. Considers the GWP of energy choices. Provides a realistic outcome of the total GHGs.	Does not provide high pressure for very low-energy solutions because of the foreseen decarbonisation of electricity and district heat. However, decreased demand would be important to realise the policy targets.
Embodied GHG and operational GHGs (no decarb.) together	Perspective extended to embodied emissions. Considers the GWP of energy choices. Helps find optimised solutions regarding materials and energy use.	Exaggerates the influence of operational energy on GHGs. Thus, solutions that appear optimum are not actually the best. Combined calculation may weaken the concrete understanding of the calculation result.
Embodied GHG and operational GHGs (decarb. considered) together	Perspective extended to embodied emissions. Considers the GWP of energy choices. Provides a realistic outcome of the total GHGs. Allows finding optimised solutions regarding materials and energy use.	Does not provide high pressure for very low-energy solutions because of the foreseen decarbonisation of electricity and district heat. However, decreased demand would be important to realise the policy targets. Combined complicated calculation may weaken the concrete understanding of the calculation result.

Table 1 Pros and cons of different approaches to regulating the environmental impacts of building materials and energy compared to a situation where only energy use is the object of regulation.

Annex 3: Building part from prEN 15978 mapped with Nordic classifications systems

Klas Eckerberg, Tommi Kaartinen, Allan Schiøtz, Trine Dyrstad Pettersen

prEN 15978 Sustainability of construction work. Assessment of the environmental performance of buildings. Calculation method.			**IEC/ISO 81346** With notes describing division to the Danish CCS		**CoClass Sweden**			**Finland: Talo2000 (Building), LVI2010 (HVAC), S2010 (Electrical)**			**IFC ISO 16739:2024**				**ICMS 3rd edition, November 2021**		**NS 3451 Norway**	
Building parts	**Building element and processes**		1 letter = Functional system a) 2 letters = Technical system b) 3 letters = Component c)		**CoClass class/numbered type** 1 letter = Functional system 2 letters = Constructive system 3 letters = Component		Comments			Comments	IFC Entity	IFC PredefinedType (koodistot .suomi.fi)	IFC Properties	Comments				
Pre-construction works	Facilitating works	Temporary/ Enabling works	-	-				1)		1) Talo2000 includes classes for project management, design, supervision, construction, and maintenance, but they do not match the categories of the EN 15978 standard.	IfcTask 2)	STARTUP		2) An IfcTask may be assigned a Work Breakdown Structure (WBS) code from a published external structure or company standard. As well as being used to designate the code, the classification structure also enables the source of the work breakdown structure classification to be identified.	2.01.	Demolition, site preparation, and formation	21	Site and foundation
		Specialist groundworks	-	-				1)	-		IfcTask 2)	CONSTRUCTION			2.01.	Demolition, site preparation, and formation		
	Work to existing building	Demolition and alterations	-	-				1)	-		IfcTask 2) IfcTask 2)	DEMOLITION ADJUSTMENT			2.01.	Demolition, site preparation, and formation	-	
Substructure	Foundations and piles		A	Ground system	A20	Foundation		121 1121	Foundations Piles		IfcFooting IfcPile (IfcDeepFoundation)	FOOTING_BEAM, PAD_FOOTING, STRIP_FOOTING		IfcDeepFoundation is a supertype of IfcPile, so it may not be necessary.	2.02.	Substructure	215 216	Pilar foundations Foundations
	Basement walls		B	Wall system	B31	Cellar wall system		1212	Enclosure walls		IfcWall	SOLIDWALL			2.02.	Substructure	231	Bearing walls
	Retaining walls		B	Wall system	B32	Retaining wall system		1153	Retaining walls		IfcWall	RETAINING WALL			2.02.	Substructure	231	Bearing walls

Waterproofing			FSG	Protective seal	FSG10	Waterproofing	12124	Thermal insulation		IfcCovering	MEMBRANE		IfcMembrane is not an IFC class. It is defined by the IfcCovering and PredefinedType MEMBRANE.	2.03.	Substructure	231	Bearing walls
Ground floor construction			C	Slab system	C10	Bottom slab system	122	Ground floors		IfcSlab	BASESLAB	Pset_Slab Common.Load-bearing = TRUE		2.03.	Substructure	252	Bottom slab system
Super-structure	Frame	Columns	ULD	Column	ULD	Column	1233	Columns		IfcColumn	COLUMN	Pset_Column Common.Load-bearing = TRUE		2.03.	Structure	223	Columns
		Beams	ULE	Beam	ULE	Beam	1234	Beams		IfcBeam	BEAM	Pset_Beam Common.Load-bearing = TRUE		2.03.	Structure	222	Beams
		Shear walls	BD	Wall structure	BD	Wall structure	1232	Bearing walls	No distinction is made between load-bearing and shear walls in Talo2000.	IfcWall	SHEAR	Pset_Wall Common.Load-bearing = TRUE		2.03.	Structure	231	Bearing walls
	Upper floors		C	Slab system	C20	Mid slab system	1235	Inter-mediate floors		IfcSlab IfcBeam	FLOOR HOLLOWCORE	Pset_Slab Common.Load-bearing = TRUE Pset_Beam Common.Load-bearing = TRUE		2.03.	Structure	251	Slab system
	Balconies		C	Slab system	C41	Balcony slab system	1251	Balconies		IfcElement Assembly - IfcSlab - IfcWall - IfcRailing - IfcRailing - IfcCurtain Wall	 FLOOR PARAPET GUARDRAIL HANDRAIL			2.03.	Structure	284	Balconies
	Roof	Roof structure	D	Roof system	D	Roof system	1261	Roof substruc-tures		IfcRoof	* Shape of the roof			2.03.	Structure	261	Roof structure
		Weather-proofing	FSG RQA	Protective seal Insulation	FSG10 RQA	Water-proofing Insulation	1263	Roofings		IfcCovering	ROOFING		IfcMembrane is not an IFC class. It is defined by the IfcCovering and PredefinedType MEMBRANE.	2.03.	Structure	262	Roofing

Stairs and ramps			AF AG	Stair construction Ramp construction	AF AG	Stair construction Ramp construction	1237	Structural frame stairs	IfcStair IfcRamp IfcSlab	LANDING			2.03.	Structure	281 282	Internal stairs External stairs	
Fabric	External envelope	External walls	B	Wall system	B10	Exterior wall system	1241	External walls	IfcWall	SOLIDWALL	Pset_Slab Common.Is External = TRUE		2.04.	Architectural works | non-structural works	231 232	External bearing and non-bearing walls	
		Windows	QQA	Window	QQA	Window	1242	Windows	IfcWindow	WINDOW, LIGHTDOME, SKYLIGHT	Pset_Window Common.Is External = TRUE		2.04.	Architectural works | non-structural works	2341	Windows	
		External doors	QQC	Door	QQC	Door	1243	External doors	IfcDoor	DOOR, TRAPDOOR	Pset_Door Common.Is External = TRUE		2.04.	Architectural works | non-structural works	2342	External doors	
		Shading devices	RQD	Screen	RQD	Screen	1244	Facade attachments	IfcShading Device	SHUTTER	Pset_Shading Device Common.Is External = TRUE		2.04.	Architectural works | non-structural works	237	Solar screen	
	Internal walls	Internal walls – load-bearing	B	Wall system	B20	Interior wall system	1232	Bearing walls	IfcWall	PARTITIONING, SHEAR	Pset_Wall Common.Is External = FALSE Pset_Wall Common.Load-bearing = TRUE	To identify load-bearing and non-load-bearing interior walls, the IsExternel and LoadBearing properties must be set.	2.03.	Structure	241	Internal load-bearing walls	
		Internal walls – non-load-bearing	B	Wall system	B20	Interior wall system	1311	Partitions	IfcWall	PARTITIONING, SHEAR	Pset_Wall Common.Is External = FALSE Pset_Wall Common.Load-bearing = FALSE	To identify load-bearing and non-load-bearing interior walls, the IsExternel and load-bearing properties must be set.	2.04.	Architectural works | non-structural works	242	Internal non-load-bearing walls	
		Internal doors	QQC	Door	QQC	Door	1315	Internal doors	IfcDoor	DOOR	Pset_Door Common.Is External = FALSE		2.04.	Architectural works | non-structural works	2442	Internal doors	

Finishes	External finishes	Cladding	NCB	Wall covering	NCB	Wall covering	12414	Sheating		IfcCovering	CLADDING	Pset_Covering Common.Is External = TRUE	2.04.	Architectural works | non-structural works	235	External cladding and sheating
		Coatings	FSA FSB	Plaster paint	FSZ	Coating	12414	Sheating		IfcCovering	COPING	Pset_Covering Common.Is External = TRUE	2.04.	Architectural works | non-structural works	235	External cladding and sheating
	Internal finishes	Wall finishes	FSA FSB	Plaster paint	FSZ	Coating	13261	Wall finishing		IfcCovering	COPING	Pset_Covering Common.Is External = FALSE	2.04.	Architectural works | non-structural works	236	Internal sheating
		Raised floors	BF	Floor structure	AQ	Floor construction	1321	Floor surface elements		IfcSlab	FLOOR	Pset_Covering Common.Is External = FALSE	2.04.	Architectural works | non-structural works	253 254	Floor construction
		Floor finishes	NCC	Flooring	NCC	Flooring	1322	Floorings		IfcCovering	FLOORING	Pset_Covering Common.Is External = FALSE	2.04.	Architectural works | non-structural works	255	Floorings
		Ceiling finishes	NCE	Roofing	NCE	Roofing	1324	Ceiling finishings		IfcCovering	CEILING	Pset_Covering Common.Is External = FALSE	2.04.	Architectural works | non-structural works	256 257	Ceilings
Building services	Water systems	Hot water distribution	F	Water and fluid system	F22	Tap hot water system	212	Water and sewerage systems	LVI2010	Ifc Distribution System	DOMESTIC HOTWATER		2.05.	Services and equipment	312	Water and sewerage systems
		Cold water distribution	F	Water and fluid system	F21	Tap cold water system	212	Water and sewerage systems	LVI2010	Ifc Distribution System	DOMESTIC COLDWATER		2.05.	Services and equipment	312	Water and sewerage systems
		Water treatment systems	KC	Filter system	KC	Filter system	212	Water and sewerage systems	LVI2010	Ifc Distribution System	WASTEWATER		2.05.	Services and equipment	312	Water and sewerage systems

Rainwater systems		G	Drainage and waste system	G24	Roof water runoff system	212	Regional sections for water and sewerage systems	LVI2010	IfcDistribution System	RAINWATER	2.06.	Surface and underground drainage	217	Drainage
Sewage systems		G	Drainage and waste system	G11	Wastewater system	212	Water and sewerage systems	LVI2010	IfcDistribution System	SEWAGE	2.05.	Services and equipment	312	Water and sewerage systems
Lighting	Internal lighting	Q	Lighting system	Q11	General lighting system for building space	S251	Internal lighting system	S2010	IfcElectricalCircuit	LIGHTING	2.05.	Services and equipment	442	Internal lighting system
	External lighting	Q	Lighting system	Q12	General lighting system for outdoor space	S252	External lighting system	S2010	IfcElectricalCircuit	LIGHTING	2.05.	Services and equipment	744	External lighting system
Electricity generation and distribution		K	Electrical system	K	Electrical system	S212	Electricity generation systems	S2010	IfcDistribution System	POWER GENERATION	2.05.	Services and equipment	411	Electrical system
Renewable generation systems		K.HG	Electrical system > Electrical power supply system	K.HG31	Electrical system > Solar electric supply system	S212	Electricity generation systems	S2010	IfcDistribution System	POWER GENERATION	2.05.	Services and equipment	471	Electrical system > Solar electric supply system
Heating systems		H	Cooling and heating system	H20	Heating system	211	Heating systems	LVI2010	IfcDistribution System	HEATING	2.05.	Services and equipment	325 356 45	Heating systems
Cooling systems		H	Cooling and heating system	H10	Cooling system	214	Cooling systems	LVI2010	IfcDistribution System		2.05.	Services and equipment	353 356	Cooling systems
Ventilation systems		J	Ventilation system	J	Ventilation system	213	Ventilation systems	LVI2010	IfcDistribution System	VENTILATION	2.05.	Services and equipment	36	Ventilation systems
Conveying systems		N	Transportation system	N	Transportation system	S222	Main distribution system	S2010	IfcDistribution System	CONVEYING	2.05.	Services and equipment		
Telecoms and data systems		M	Information and communication system	M	Information and communication system	T1	Communication and information network systems	S2010	IfcDistribution System	FIXED TRANSMISSION NETWORK	2.05.	Services and equipment	5	Communication and information network systems

Fire protection systems	P.PA	Security and safety system > Fire protection system	P10	Fire safety system	T6	Fire safety systems	S2010	IfcDistribution System	FIREPROTECTION	2.0	Services and equipment	33	Fire safety systems
Communication and security installations	M	Information and communication system	P30	Personal safety system	T5	Security systems	S2010	IfcDistribution System	SECURITY	2.0	Services and equipment	54	Security systems
		a) ISO 81346-12:2019, Table A.1 b) ISO 81346-12:2019, Table A.2 c) EN IEC 81346-2:2019, Table 2											

Annex 4: Carbon stock and sink data of trees in urban areas in the context of building climate reporting

Alam Ashraful[51], Erlandsson Martin[52], Karlsson Per Erik[53], Mattsson Eskil[54], Miettinen Heli[55], Mänttäri Miia[56], Silvenius Frans[57] and Tuhkanen Eeva-Maria[58]

Summary

There is a need to add vegetation data to Nordic construction databases, as the carbon sequestration capacity of trees and other vegetation may play an important role in urban area carbon balance estimates. This report aims to produce suitable and usable life cycle and carbon stock change estimates for urban trees for the greenhouse gas (GHG) emission databases used for construction. This report also assessed how different operational scenarios increase or decrease the carbon sink urban trees produce.

Carbon sequestration of trees and even commonly used tree species depends on local conditions. This report aims to produce an example of practice for a limited area. The data used in this report are urban tree data collected in the i-Tree projects in southern Finland and Sweden. The calculation method and results of the report can be used as an example to calculate results in other countries or regions.

An assessment for three scenarios was produced, considering the changes for an individual tree if it is planted, removed, or remained in the construction area. The estimates considered the biogenic carbon sequestration and the life cycle GHG emissions from nursery production, planting, maintenance, and tree removal over a 50-year time period, representing a default building service life.

The results show that over a 50-year period, the amount of carbon sequestered by trees is significantly higher than greenhouse gas (GHG) emissions from planting, maintaining, or removing a tree. Conversely, soil composition is the main determinant of life cycle GHG emissions.

The highest carbon sink is achieved when existing trees are not cut and remain in the area during construction. Removing trees results in the highest GHG emissions but can be partly compensated by planting new trees and creating a new carbon sink. However, the

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[51] Natural Resources Institute Finland (Luke)
[52] IVL Swedish Environmental Research Institute
[53] IVL Swedish Environmental Research Institute
[54] IVL Swedish Environmental Research Institute
[55] Natural Resources Institute Finland (Luke)
[56] Natural Resources Institute Finland (Luke)
[57] Natural Resources Institute Finland (Luke)
[58] Natural Resources Institute Finland (Luke)

results in this report are gross simplifications based on assumptions and should be interpreted as indicative figures.

Introduction

The importance of green areas in an urban environment

Urban trees and vegetation offer crucial ecosystem services, including carbon storage. The changes in the carbon stocks in the biomass of living trees may constitute a significant number of the changes in the carbon stocks of urban areas, including living vegetation and changes in carbon stocks of dead biomass and soil. Therefore, information on carbon stock and greenhouse gas (GHG) data of the green areas of the built environment, such as yards, parks, and street trees, needs to be added to the Nordic construction databases used for building reporting and certification. These databases are based on the Life Cycle Assessment (LCA) methodology, where the contribution to climate impacts is transformed into a Global Warming Potential (GWP) indicator result.

The importance of urban green spaces as part of meeting the goals of carbon neutrality and carbon negativity encourages considering the role of green spaces in the context of the LCA of buildings. The effects of greenhouse gas (GHG) balance for land use from vegetation have significant implications for urban areas as a potential carbon sink. Assessments of the GHG balance from land use in urban areas enable the possibility of including the carbon sink in forests and soil in strategic climate work and the general planning process (Lindahl & Lundblad, 2022).

The carbon sequestration potential of green areas in an urban environment and their capacity of green spaces to offset fossil fuel emissions in cities can be significant. For example, in the Stockholm municipality, the carbon sink in forests and soil was estimated to be -35 kt CO_2e per year, corresponding to slightly below 2 t CO_2e per hectare per year (Lindahl & Lundblad, 2022). Compared to the carbon sequestration of approximately 23 million hectares of productive forests in Sweden, the forests sequester about 32 000 kt CO_2 per year, i.e., about 1.4 t CO_2e per hectare per year (Swedish Environmental Protection Agency, 2022). Absorption of carbon dioxide by the living biomass of trees accounted for most of the carbon sink compared to another type of planting and species (Erlandsson et al., 2022).

A modelling study (Havu et al., 2024) shows that urban green spaces sequester 5.9 t CO_2 annually in Helsinki. However, the greatest sequestration potential was found in urban city forests, where the sequestration reached up to 11 t CO_2 per year. Thus, urban green spaces can offset 7 % of the anthropogenic emissions of Helsinki (Havu et al., 2024). A few other studies in the United States and Southern Europe confirm the role of green spaces in offsetting emissions, with urban green spaces vegetation sequestering 2%–6% of fossil fuel emissions (Hardiman et al., 2017; Vaccari et al., 2013).

The high carbon sequestration capacity of urban green spaces encourages the inclusion of vegetation in climate planning. In the City of Malmö in Sweden, a carbon budget that includes vegetation is established (Råberg, 2022). This carbon budget is used to set goals for different GHG sources for 2030; in that context, different pathways are outlined to achieve these climate goals, as Figure 1 illustrates.

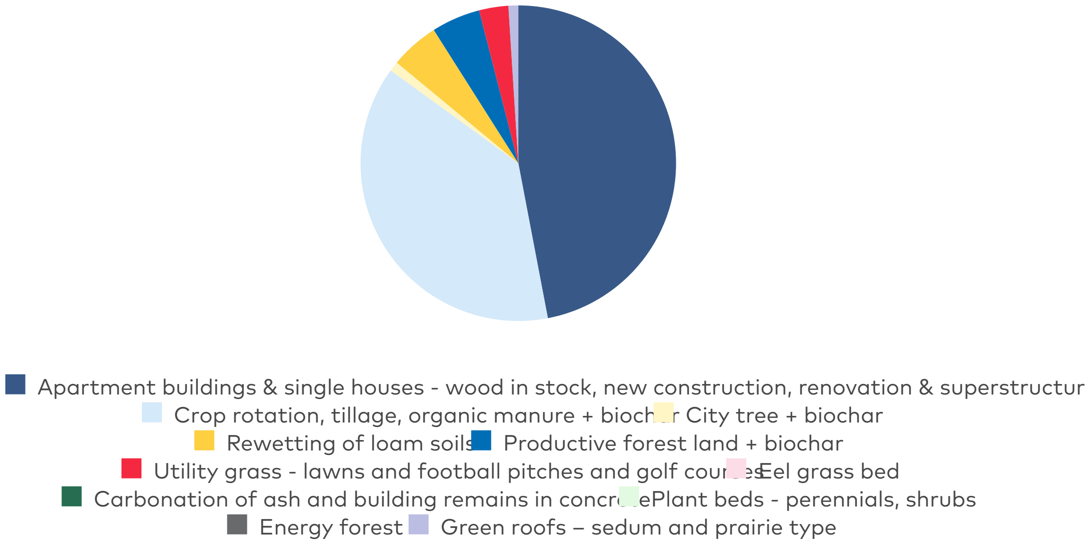


Figure 1 The various categories' share of the total potential for increased carbon storage by 2030. The opportunities are highest in housing construction and crop cultivation in Malmö's conditions (Råberg, 2022).

The work done in Malmö concludes that several possibilities exist to increase carbon storage and annual carbon sequestration and achieve several other benefits simultaneously. The main result of the analysis is that the greatest potential for increased carbon sequestration is in the construction sector and crop production by 2030. These two categories account for 85% of the increased potential from 2022 to 2030 (Figure 1).

The Nordic countries are working on regional carbon neutrality ahead of the European Union's goals. For example, Finland aims to be carbon neutral by 2035 and is developing a set of policies, including legislation for low-carbon construction. Also, the Nordic declaration on low-carbon construction by Nordic ministers for construction and housing set a goal for the built environment. It is noticed that vegetation is not part of any regulated climate declaration for buildings in the Nordic countries, but it is likely that in accordance with the new Energy Performance of Buildings Directive (EPBD), reporting carbon sinks in the construction or on the building is possible.

Even if no climate declaration requires it, it can always be reported as supplementary information. Numerous challenges appear when urban green spaces are accounted for with a building's LCA and its surrounding area. An example of vegetation's contribution to a building and its surrounding vegetation is described in (webpage link the Fælledby project). In this case study, vegetation is compared to different parts of a building's climate impact over the life cycle, as Figure 2 shows. The calculation is performed by Henning Larsen architectural firm and includes carbon sequestration for vegetation using the ClimatePositiveDesign database for "The North Growth Zone" (webpage link Urban Forestry Network). The proposed scenario has a carbon footprint for buildings and infrastructure of 8.9 kg CO_2 m^{-2} $year^{-1}$, but the carbon sequestration of trees and non-mowed lawns reduces it by 0.35 kg CO_2 m^{-2} $year^{-1}$, i.e., 4 % of the total life cycle impact.

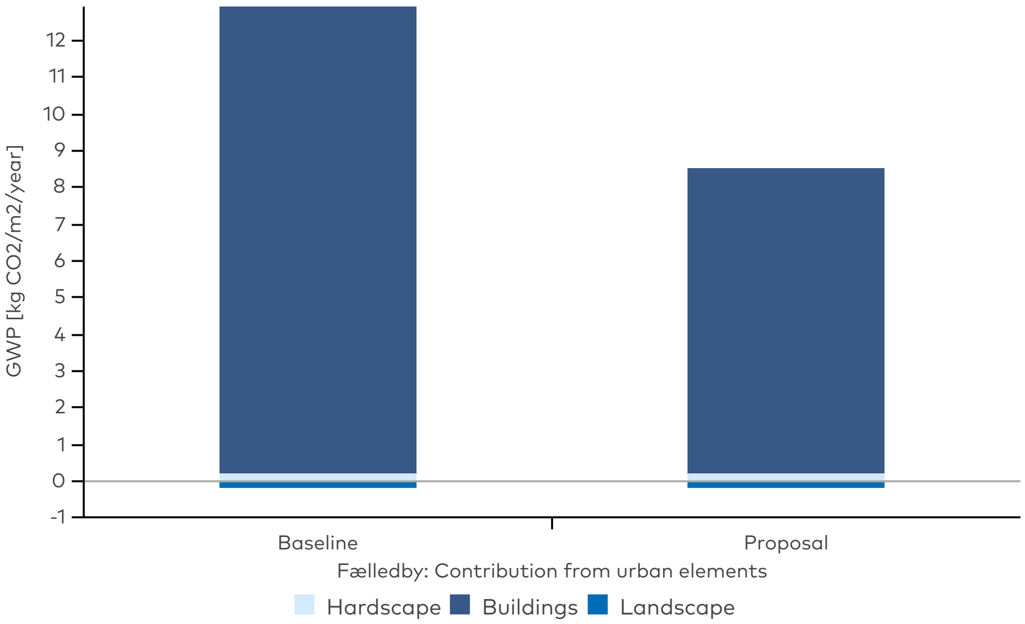


Figure 2 Climate declaration of the Faelledby building where the impact is divided into building parts; hardscape and landscape. The landscape includes trees and roof sedum (Hermansdorfer et al., 2023).

The Fælledby project example calculation of the biogenic carbon sequestration potential of vegetation shows that trees are, by far, the biggest contributor to any carbon sink effect. All other urban vegetation is negligible or sometimes even increases the overall carbon footprint, e.g. intensive green roofs, due to maintenance-related emissions (Hermansdorfer, 2024).

Harmonisation of life cycle assessment methodology

In the declaration, Denmark, Finland, Iceland, Norway, and Sweden agreed to collaborate on a common life cycle assessment (LCA) approach to buildings. One challenge that is discussed more often is harmonising the LCA methodology since different regulations and standards have different rules for calculating the life cycle impact assessment. A survey conducted in the Nordic Climate Forum by the Swedish Life Cycle Center (2019) showed that over 90% of the respondents (100 participants) would like to have a harmonised methodology, including a common Nordic database for a built environment.

On the possibility of including a vegetation stock change in building a life cycle assessment

Biogenic carbon accounted for in Environmental Product Declarations

In the context of reporting the environmental performance of products are so-called Environmental Product Declarations (EPD), which are launched and commonly used. EPD are for business-to-business and business-to-costumer communication and internationally standardised in ISO 14025. Compared to a traditional life cycle assessment (LCA), EPDs are divided into different information modules that can be added to a full life cycle if such data are reported. In many applications, only the cradle-to-gate data (A1-3) is used from EPD in an LCA calculation; the other information modules are just illustrative examples of what a full life cycle can look like.

EPD for construction products is suggested to be mandatorily reported for any product that falls within the forthcoming constructing product regulation (CPR) and for new buildings, according to the new Energy Performance Declaration Directive (EPBD) to be launched in 2024. This kind of communication product is based on an attributional LCA, meaning the results, like statistics, shall, in theory, be able to add up the environmental impact from, e.g. all new buildings based on the LCA result A1-5; the sum will be the same as in national statistics for new buildings, i.e. if a life cycle approach was used in the statistics. The product category rules for building follow EN 15804 and adds regulations on all aspects needed for a building and its life cycle. Notably, the prEN15978 includes "Vegetation and soft landscaping" as a potential building element of external works.

The current impact assessment of climate impact in EPD used for construction products and buildings (EN 15804 and ISO 15978) is not strictly scientifically adopted. The impact assessment of the Global Warming Potential (GWP) is based on well-established scientific characterisation factors, which are based on radiative forcing that have been integrated for over 100 years. However, the problem in EPD is that this impact category, the GWP, is also complemented with a physical life cycle inventory flow of biogenic carbon that is added to the GWP indicator based on the so-called 1 kg biogenic CO_2 that is equal to -/+1 kg CO_2e, where the "e" transforms it to an impact assessment result. The photosynthesis and, thereby, the sequestration of carbon dioxide is accounted as -1 kg CO_2e; when released as emission or recycled into a new product system at the end of its life, it is the same amount of carbon as in an emission of +1 kg CO_2e.

According to EN 15804 and EN 15978, this GWP-biogenic indicator accounts for GHG gases arising from biogenic carbon and the carbon stored in the assessed product and its packaging material. However, the general calculation rule says that such inherent properties as biogenic carbon in a material cannot be allocated away. The calculation rule implies that the 'real GWP indicators' based on radiative forcing are added with the biogenic carbon stored in the product and its packaging. This -1/+1 kg CO_2e calculation rule is in the calculation rules combined with the fact that the sum of biogenic carbon in the product and its packaging material shall always be zero when summed over the entire life cycle (from A to C). If not, an error was made in the calculation and needs to be corrected.

Altogether, this means the modular approach in EN 15804 and EN 15978, where the result can be compared module by module, is lost. A GWP indicator that includes an accounting of this physical flow of biogenic carbon can only be compared if a full life cycle is considered since this biogenic carbon is then balanced out. In EPD International and EPD Norway, an indicator referred to as GWP-GHG, respectively, GWP-IOBC, is introduced; all biogenic GHG emissions are accounted for except biogenic carbon stored in the product or its packaging material that is directly balanced out. GWP-GHG is used in Finland and Sweden, for example. In Sweden, this is required to make a limit value possible where the construction stage (A1-5) defines the current climate declaration and suggested future limit value.

Biogenic carbon accounted for forestry and vegetation in EPD

There is no explicit method for accounting for vegetation in an EPD, but specifications are given for forestry, which must be considered in this context. Complementary Product Category Rules (cPCR) for wood and wood-based products are defined in the standard (EN 16485) that complements the core PCR for all construction products and services, as established in EN 15804. The calculation rule is, in brief, that biogenic carbon from non-native sources/forests is accounted for based on the -1/+1 kg CO_2e calculation rule and reported to the GWP-biogenic indicator, meaning the sum is always zero over the life cycle (i.e. carbon dioxide neutral), while harvest wood from native forests is considered fossil where the -1 kg CO_2e from sequestration is unaccounted for and reported as an impact of 1 kg CO_2 from non-sustainable sources and is equal to 1 kg CO_2e in the GWP-luluc indicator. This means that wood from non-sustainable forests has no sequestration accounted for, so the CO_2 emitted will be accounted for as if they were fossils.

Also, specifications concerning the accounting of LULUC (Land Use and Land-Use Change) can be found in the EN 15804 standard:

"Any biomass-based net increase in carbon stocks, including soil carbon uptake (accumulation), shall not be considered in GWP-luluc and is set to zero. Soil carbon storage may be included as additional environmental information when proof is provided."

Altogether, it is recognised that carbon sink and stock changes from vegetation must be reported separately in an EPD. Therefore, the approach here is to report the biogenic carbon sink and stock changes to GWP-luluc as a separate indicator. Supporting processes for nursery, planting, and gardening are also accounted for separately and mostly contribute to GWP-fossil. The climate impact indicator that needs to be declared by the Energy Performance Directive is named 'life-cycle GWP' and is equal to the GWP-total, consisting of the sum of GWP-fossil, GWP-biogenic, and GWP-luluc.

Factors influencing carbon sequestration and storage in urban trees

Trees absorb carbon dioxide (CO_2) from the atmosphere through photosynthesis and convert it into organic carbon. The carbon is then stored in tree components: the wood, leaves, bark, and roots (Thomas & Martin, 2012). This process of capturing carbon dioxide is known as carbon sequestration. Several factors influence the ability of urban trees to sequester and store carbon, each playing a role in determining the effectiveness of trees to act as carbon sinks. These factors include the species of the tree, age and size of the tree, and tree health and maintenance (Nowak et al., 2013). The local climate, length of the growing season, soil quality, and urban environmental stressors also affect the trees' capability to absorb carbon (Toochi, 2018; Czaja et al., 2020).

Tree species affect carbon storage and sequestration due to variations in photosynthetic rate, growth rate, longevity, wood density, and other physiological characteristics (Tootchi, 2018). Among these factors, the photosynthetic rate directly affects a tree's ability to produce energy for growth and development. Trees typically have different growth rates at different stages of their life cycle. Young trees often have a rapid growth rate – a phase of vigorous carbon absorption – which slows down as they reach maturity (Litvak et al., 2003; Toochi, 2018; Smith et al., 2019). The growth rate can also vary yearly depending on environmental conditions (Rossi et al., 2006).

The longer a tree lives, the more carbon it can store throughout its lifetime. An urban environment can be harsh for a tree to grow, leading to shorter life expectancies than those in a natural environment. The lifespan of street trees is often considerably shorter than that of trees in parks. The Finnish Tree Care Association has estimated the life expectancy of urban trees in Finland (personal communication). Common tree species known for their longevity include the Scots pine (*Pinus sylvestris*), English oak (*Quercus robur*), common lime (*Tilia* x *europaea*), and European ash (*Fraxinus excelsior*). In contrast, species with shorter lifespans, such as the grey alder (*Alnus incana*) and rowan (*Sorbus aucuparia*), generally accumulate less carbon during their lifetimes.

Local environmental conditions also influence trees' effectiveness in absorbing carbon. Each tree species typically thrives within a specific range of these conditions. Specialist species often have narrow tolerance ranges and may struggle to compete effectively outside of these, especially in extreme conditions like deep shade or drought. In addition to light and water, the availability of nutrients can also constrain tree growth. Climate factors, such as temperature and rainfall, directly impact tree growth and carbon uptake. The most common environmental stressors for trees in an urban environment include limited soil volume, drought, compacted soil, air pollution, and lack of oxygen to the roots – all of which can adversely affect a tree's health and its capacity for carbon absorption (Czaja et al., 2020). Urban trees are also prone to damage in connection with transportation and vandalism (Czaja et al., 2020).

Additionally, the maintenance of urban trees influences their ability to sequester and store carbon (Vogt et al., 2015). Healthy and well-maintained trees can absorb and store more carbon over their lifespan than neglected trees. Regular maintenance, especially adequate watering during the rooting phase and extended drought periods, as well as appropriate pruning, is critical to keep trees healthy and extend their lifespan.

Objectives of this report

This report aims to create a simplified life cycle carbon balance approach and provide example data to account for the carbon balance of the living biomass in individual trees in an LCA or EPD for a whole life cycle building climate declaration. Besides the carbon stock change, this article lists the GWP indicator results for the processes or activities needed for vegetation, with a special focus on large trees. Another objective is to use example data for urban trees based on the latest research from available reporting from ongoing i-Tree projects for selected cities from Finland (Helsinki, Turku, Tampere) and Sweden (Malmö, Gothenburg, Umeå). Besides LCA scenarios and data, two different approaches for urban tree carbon sink and stock calculation are presented: Approach 1 assesses the changes in the carbon stock resulting from the individual urban trees that are felled, retained, and planted in the construction area over a 50-year period and produces generalised values for the construction emission database combined with life cycle assessment results; 2) Approach 2 provides species-specific equations to support quantifying carbon sequestration of the living biomass by trees.

Materials and methods

i-Tree source data

Carbon sequestration and storage in urban trees were estimated using the i-Tree Eco software (v.6.0.32) and its Forecast model. I-Tree Eco uses peer-reviewed model equations based on long-term research to estimate the ecological benefits of urban trees, including carbon sequestration and carbon storage. It considers various factors such as species, size, local environmental conditions, and growth patterns to provide these estimates. Key outputs include estimations of the urban forest's composition, biomass, and the ecosystem services it provides, such as air pollution removal, carbon storage, and carbon sequestration. The Forecast model, an extension of i-Tree Eco, enables long-term projections of these benefits. It simulates future growth and the development of urban trees under various management and environmental scenarios. Nowak (2021) described the methods for the calculations.

Biomass equations, combined with growth models, can predict how a tree's biomass and carbon storage capacity will change over time. The biomass equations used in the i-Tree Eco software (Table 1) are similar to other commonly used biomass equations. Since no specific biomass equations exist for urban trees, i-Tree uses forest-derived equations as proxies. These equations from forest trees should provide reasonable estimates for urban trees, although some differences will likely exist. If no species-specific biomass equations are available, i-Tree uses an average from equations of the same genus. If genus-level equations are also unavailable, the software then uses the average from the next phylogenetic level. For a detailed explanation of the model, see Nowak (2021).

Species	Equation	A	B	C	D	E	F
Picea abies	$Y=A+Bx+C^2X+-D^3x+E^4x+F^5x$	10	-1.3638	0.4216	0.0041	-3E-05	1E-07
Pinus sylvestris	$Y=A+Bx+C^2X+-D^3x+E^4x+F^5x$	1.5	-0.8569	0.3074	0.003	-3E-05	1E-07
Populus spp.	$Y=e^{(A + B * Ln(X) + (C/2))}$	-2.28909	2.44837	0.01442			
Prunus serotina	$Y=e^{(A + B * Ln(X) + (C/2))}$	-2.00442	2.44771	0.03475			
Quercus rubra	$Y=e^{(A + B * Ln(X) + (C/2))}$	-2.07550	2.42949	0.07839			

Table 1 Example equations for calculating the total dry weight biomass of individual trees of different species. x = DBH in cm; Y= total tree dry weight biomass in kg

Parameters for forecasting change in carbon stocks

In Approach 1, the Forecast model from the i-Tree Eco software was used to predict how carbon sequestration and stock for urban trees would develop over time in Finland. The modelling was restricted to Southern Finland, as no weather data were available in the i-Tree Eco for any cities in Northern or Eastern Finland. In the analysis comparing the same set of tree species and conditions in Helsinki, Turku, and Tampere, no significant differences were found in the carbon sequestration and storage capabilities of urban trees across these cities. Notably, the species selection for Northern Finland would be much more limited, and there would be differences in the trees' abilities for storage and sequestration as they would sequester and store somewhat less carbon than trees in Southern Finland. For the final results, data from Turku was chosen for this study as it represented a median between Helsinki and Tampere.

The 30 most common urban tree species identified from the tree databases of the cities of Helsinki and Turku were selected for the simulation. Different health and light conditions were used to more accurately model the actual conditions (see examples in Figure 3). For each species, three health conditions were defined: excellent, good, and fair. According to i-Tree, 'excellent' means no dieback, 'good' indicates a 1%–10% dieback, and 'fair' indicates a 10%–25% dieback in the crown. The simulation also included the growth of these species under various lighting conditions, ranging from complete shade, where the crown receives no direct sunlight, to fully open spaces, where the crown is exposed to direct sunlight from all sides. Altogether, 18 individual trees grown under different environmental conditions were modelled for each species. The carbon storage and sequestration values for each species are averages of these results.

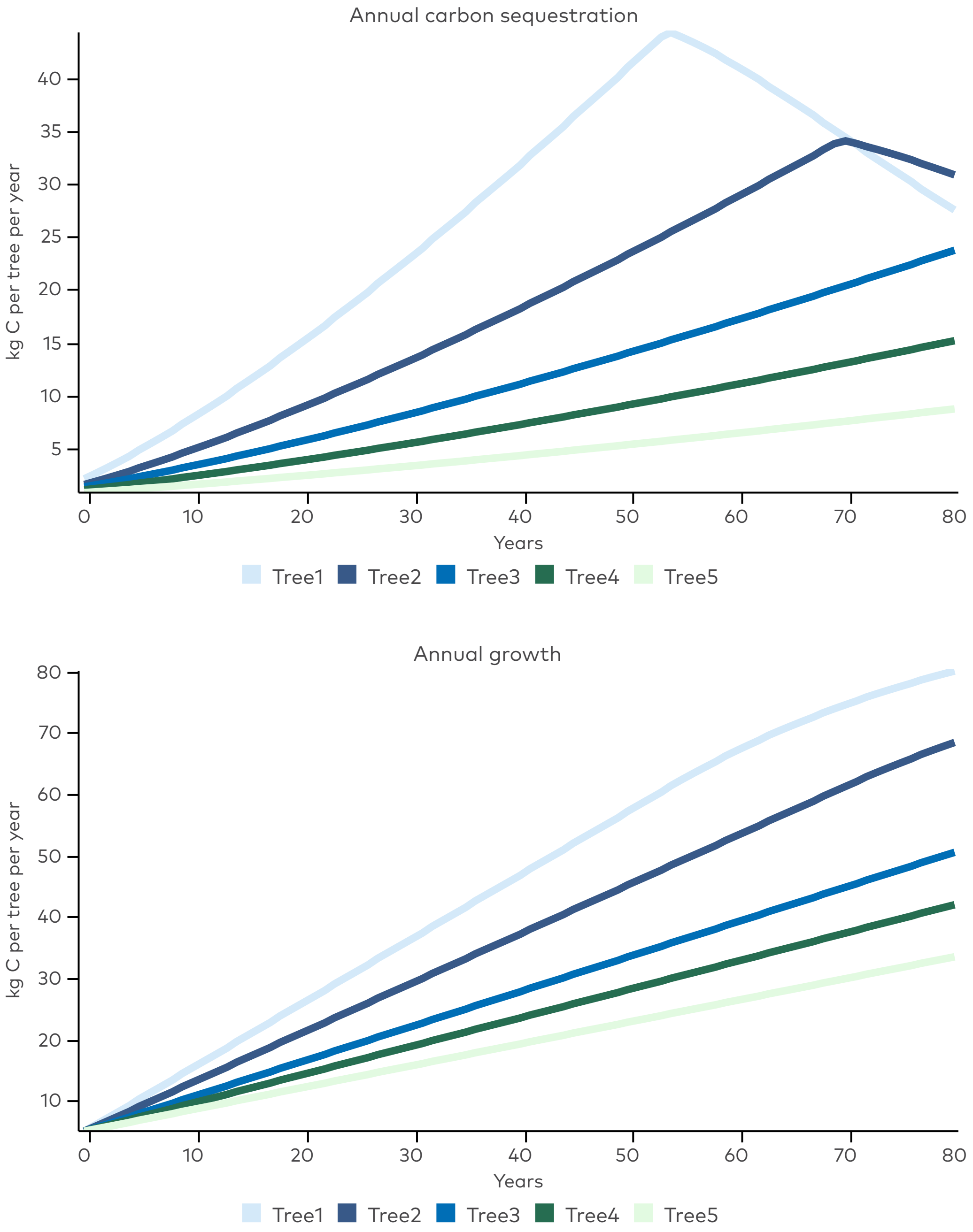


Figure 3 Examples of how varying health and light conditions affect the annual growth and carbon sequestration of Norway maple trees over their lifetime as modeled with i-Tree. Tree1, in excellent canopy health, receives light from all directions. Tree2, with fair canopy health, also receives light from all directions. Tree3 has good canopy health and receives light from three directions. Tree4, despite being in excellent health, is in complete shade. Tree5, with fair canopy health, is similarly in complete shade.

The Forecast model in i-Tree Eco is limited to predicting tree growth up to 100 years. Since some trees live longer, running two consecutive simulations was necessary. The first simulation predicted the growth for the initial 100 years after planting. The second simulation continued from where the first one ended, covering the following 100 years.

This approach helped calculate carbon storage accumulation for trees older than 100 years. The maximum age estimate for each species considers the expected lifespan of a tree planted in appropriate urban environments. This approach aims to provide a realistic average lifespan, excluding exceptionally short or long lifespans.

One objective was to create a simplified life cycle carbon balance for individual trees for the Finnish Emissions database. This data was expected to be represented as a single, generalised value. However, grouping tree species into very general but representative and as similar groups as possible proved challenging due to the inherent diversity and variability among different species. One seemingly straightforward method for grouping could have been based on tree species' potential maximum height. This approach would have been easily understood by, distinguishing tall tree species from low ones. However, a comparison between the carbon stock and the height of the trees showed that carbon storage is not necessarily dependent on height. Therefore, using height as a criterion for grouping tree species was neither viable nor effective. Other factors considered were growth rate, maximum carbon storage capacity, and botanical groups (broadleaf/conifer). Ultimately, only the botanical groups were used as the criterion for grouping, and the carbon-cycle balance was calculated individually for each of the 30 species.

In Approach 2, the original data for the species-specific equations was obtained from the project i-Tree Sverige (Deak Sjöman & Östberg, 2020) and were sampled in 2018 in three cities in Sweden: Umeå, Malmö, and Gothenburg. Values for tree growth and tree carbon sinks were obtained using the program i-Tree Eco.

The i-Tree tool reports carbon sequestration and storage in kilograms of carbon (kg C). A standard conversion factor of 3.6663 was used to convert this into the weight of carbon dioxide (CO_2). This ratio represents the molecular weight relationship between CO_2 and carbon, allowing for translating sequestered carbon into the corresponding amount of CO_2. Translating i-Tree results from C to CO_2 aligns with global standards for climate reporting.

Possible operational tree scenarios on the construction site

When construction starts on a plot, the trees onsite can be removed or retained; new trees might also be planted. Trees were categorised into three distinct groups – planted trees, remaining trees, and removed trees – to reflect an estimated average potential change in tree cover to facilitate decision-making based on a simplified approach regarding trees on construction sites. This classification helps calculate their net carbon balance at different stages, which is essential for understanding their total contribution to carbon sequestration and storage.

Planted Trees. This category includes all new trees that were planted on a plot after construction work has been completed. Strategic planting of new trees is essential for maintaining and increasing the carbon storage potential of urban areas, especially if any trees were removed during construction. This category focuses on the carbon sequestration potential from the planting until age 50.

Urban tree planting sizes vary depending on the species and purpose of planting. Based on information from Finnish cities for this study, broadleaf yard trees have a trunk circumference of 10–12 cm (DBH: 3.2–3.8 cm) at the breast height, park trees 14–20 cm (DBH: 4.5–6.4 cm), and street trees 18–24 cm (DBH: 5.7–7.6 cm) when planted. In exceptional cases, street trees can be even larger. Conifers, which are usually planted smaller than broadleaf trees, are sized by height rather than circumference. Typical planting sizes for conifers are 120–150 cm for yard trees and 175–300 cm for park and street trees. Since most of the planted trees are broadleaf, the initial planting size for the model was set to a diameter of 5 cm at breast height, reflecting the average size used in urban tree planting in Finland.

First, the current carbon storage and sequestration rates of planted trees were modelled. To determine how much carbon, on average, each species is expected to sequester, the increase in carbon storage over the 50-year period was calculated. This total increase was then divided by 50, giving the average annual rate of carbon sequestration for each species.

Remaining trees. The category consists of trees that were on a plot before construction started and were not removed during construction. The ages and sizes of the remaining trees can vary greatly, leading to large variations in the trees' carbon stocks. The trees were divided into several size classes based on their diameter at breast height (DBH), with the average carbon storage calculated for each class to achieve more precise estimates of carbon storage and sequestration for database end-users. The remaining trees were expected to grow for the next 50 years or until they reached their species-specific maximum lifespan. A tree's maximum DBH, and, consequently, its carbon storage capacity, was linked to its lifespan. Thus, if the DBH indicated a tree had reached its full size and maximum carbon storage capacity, the carbon storage size was not projected to increase further. The difference between the projected carbon storage in 50 years and the current carbon storage was determined and then divided by 50 to calculate the average annual gain in carbon sequestration over 50 years.

Removed Trees. The category includes trees that were cut down during construction. Removing trees for construction projects can significantly impact carbon stock and sequestration potential in urban areas. When felled, the stored carbon might be released back into the atmosphere, either quickly when used for energy or over a longer period through wood product usage or natural decomposition. The emission from the decay of below-ground parts after removal has not been quantified in this study. Also, its potential to sequester carbon in the future is lost, meaning the beneficial impact the tree would have had on reducing atmospheric carbon levels over its remaining lifespan is missed.

Like the trees that remain on site, removed trees can vary greatly in age and size, leading to different amounts of carbon stored in biomass. For more accurate estimates of carbon storage, these trees were categorised into several size classes based on their DBH, and the average carbon storage for each size class was calculated. For the database, the current carbon stock of trees was projected to be what it would be in 50 years. This total carbon stock was then used to calculate the annual loss in carbon stock by dividing it over the 50-year period.

Data collection for the life cycle assessment

For the life cycle inventory (LCI), extensive data were collected from a variety of sources. Information on the composition of the commonly used soil substrate and tree maintenance measures was collected from the authorities in Helsinki, Turku, and Tampere (personal communication). Secondary sources, e.g. published literature, were also used where appropriate. Tree data were needed to calculate volumes and the dry matter of tree trunks and other biomass components. These data were obtained from the i-Tree model simulation for the most typical urban tree species grown in Southern Finland. Various background data, e.g. energy, waste disposal, and transport, were included in the calculation and taken from the Ecoinvent 3.7 LCI database, which contains regional energy and material mix data.

Global warming potential process data based on life cycle assessment

The calculation was based on various assumptions about typical urban tree-related patterns.

Seeding production in nursery. Seeding production in the nursery includes seedlings grown in a greenhouse gas chamber, use of fertilisers (e.g. lime, peat, ammonium, potassium, phosphorus), and a polypropylene pot for seedlings. Electricity and heat needed for the activity are included. Table 2 details the use of fertilisers, electricity, and heat needed.

Substrate and soil preparation for planting. The planting of urban trees was assumed to be carried out by an excavator, digging a so-called planting pit with dimensions of 2 m x 2 m x 0.8 m, or 3.2 m^3, and using a spacing lane with a width of 3 m and the planting of large trees 10 m distance apart. For the growth base, a minimum substrate required is 25 m^3 of soil for the street tree, including 1 m^3 of peat for the park and street trees. The growth base is a mixture that uses 100–200 mm excavated local granite (ca. 70 volume %) as a support structure and 25% of soil substrate comprised of 15% biocarbon and 10% infrasoil. Ready-made growth bases are used. The most common brands used are Inframulta or Puutarhamulta from TerraWise. Bark or wood chips are spread around the planted seedling in a 10 cm layer; after planting, 1 m^2 of wood chips are added once every five years. The growth base mix used in this study fulfils the requirements of the Finnish Association of Landscape Industries (VYL) and General Quality Requirements for Construction (InfraRYL).

Planting and maintenance. Fertilising and liming are done when the area is founded with the growth base mix. Fertilising (e.g. lime and dolomite-lime) and maintenance (e.g. pruning and trimming) are done during a tree's development. Pruning is done every 3–5 years, and work includes 30–45 minutes per young tree to 90 minutes per mature tree.

Harvesting. Trees are harvested at year 50, and harvesting is done by a typical harvester used in Finland. The harvested wood is transported to a factory about 50 km away. The harvested wood is dried (naturally), chipped using a wood chipper, and is used for energy; the amount of avoided emission generated is also calculated, but no option for long-lasting wood products is included in this study.

Leaf treatment. Leaf treatment is done to produce compost using the windrow composting process. The fuel and electricity needed for the process is 3 L diesel and 0.2 kWh of electricity per mg (or tonne) of fresh leaf (Andersen et al., 2010). The estimated average weight of fresh leaf is 25 kg dry matter for a broad-leaved tree and 21 kg dry matter for coniferous trees (data from i-Tree modelling). In the calculation, the moisture content is assumed to be 70% (Andersen et al., 2010), and the emission factor is 50 kg CO_2e per mg of fresh leaves (Amlinger & Peyr, 2008). The system boundaries do not include the collection and transportation of waste leaves to downstream processes nor the substitution benefit of other composting materials.

Calculation of Global Warming Potential (GWP)

The life cycle impact assessment (GWP100) calculation is done separately for street trees and park trees in urban areas in Finland. For the modelling and calculating of the Global Warming Potential (GWP), the LCA software SimaPro version 9.2 was used by using the method GWP100 v1.02 (IPCC, 2021).

The GWP, commonly called the 'carbon footprint' (CF), assesses the potential impact of different gaseous emissions on climate change (IPCC, 2021). In this method, the potential impact of one kilogram of greenhouse gas is compared to the potential impact of one kilogram of CO_2, resulting in kg CO_2-equivalents (kg CO_2e). This prediction uses a multiplier based on heat-trapping capability and atmospheric reactivity of various contributing gases over time. The International Panel on Climate Change (IPCC) uses several time horizons (20, 100, 500), but the most widely used is a 100-year, as we did in our calculation. An example of the CO_2 equivalence index can be seen below, where 1 kg CO_2, 1 kg CH_4, and 1 kg N_2O is:

CO_2 equivalent kg = CO_2 kg + (CH_4 kg x 27) + (N_2O kg x 273) = 301 kg CO_2e

System boundary and functional unit

A single park or street tree is used as a functional unit. The average volume of a tree is estimated to be ca. 1 m^3. The schematic diagram (Figure 4) shows the system boundary and the time horizon is 50 years. The calculation starts from seedling production in the nursery and proceeds through transporting, planting, and maintenance measures, and finally, harvesting and transportation to the yard of the power plant for energy generation. Freshly harvested wood is transported, dried naturally, and chipped at the plant. In addition, leaves in harvested trees are utilised to produce compost using the windrow composing process. The carbon and other greenhouse gases (kg CO_2e) emitted during the life cycle are included in the calculation by consuming fuel, electricity, and other necessary means. Ultimately, heat generated from the harvested wood is credited.

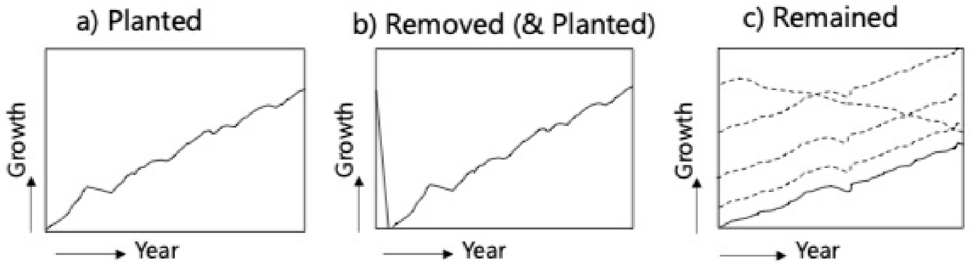


Figure 4 Diagram of system boundary showing tree growth over a 50-year time period for three used scenarios in this study: a) Newly planted trees, b) Trees removed from the site, and new seedlings are planted, c) Remaining trees on site

The calculation was carried out for three different scenarios, which were considered when calculating the carbon sink of trees for a 50-year time period according to Approach 1 (Chapter 3.1.). These scenarios are 1) planting a new seedling in the construction area, 2) removing trees from the construction area, or 3) leaving the trees in the construction area without cutting them during construction (Figure 4; also look at Chapter 2.3.). From the life-cycle assessment (LCA) perspective, the calculation for a newly planted tree (Figure 4a) is done, including the end-of-life phase of harvested trees. These results can be utilised in scenarios where trees are harvested and a new seedling is planted the same year, as Figure 4b shows. However, the emissions value for the remaining trees may vary considerably since trees are at various ages of their life. Estimating a single value is challenging from a life cycle methodological perspective if the age and dimension of each tree are unknown, because remaining trees may need specific maintenance measures depending on their life phase. In this calculation, we assumed the remaining tree is age 20 and was harvested at the end of the calculation period.

Results

Life cycle assessment for different scenarios

Seedling production

Table 2 shows the total carbon footprint of seedling production in the nursery, corresponding to 5 kg CO_2e per seedling. The major emissions (4.3 kg CO_2e) are sourced from using peat, heating of infrastructure, and electricity. Fertilisation emitted is 0.45 kg CO_2e per seedling (Table 2).

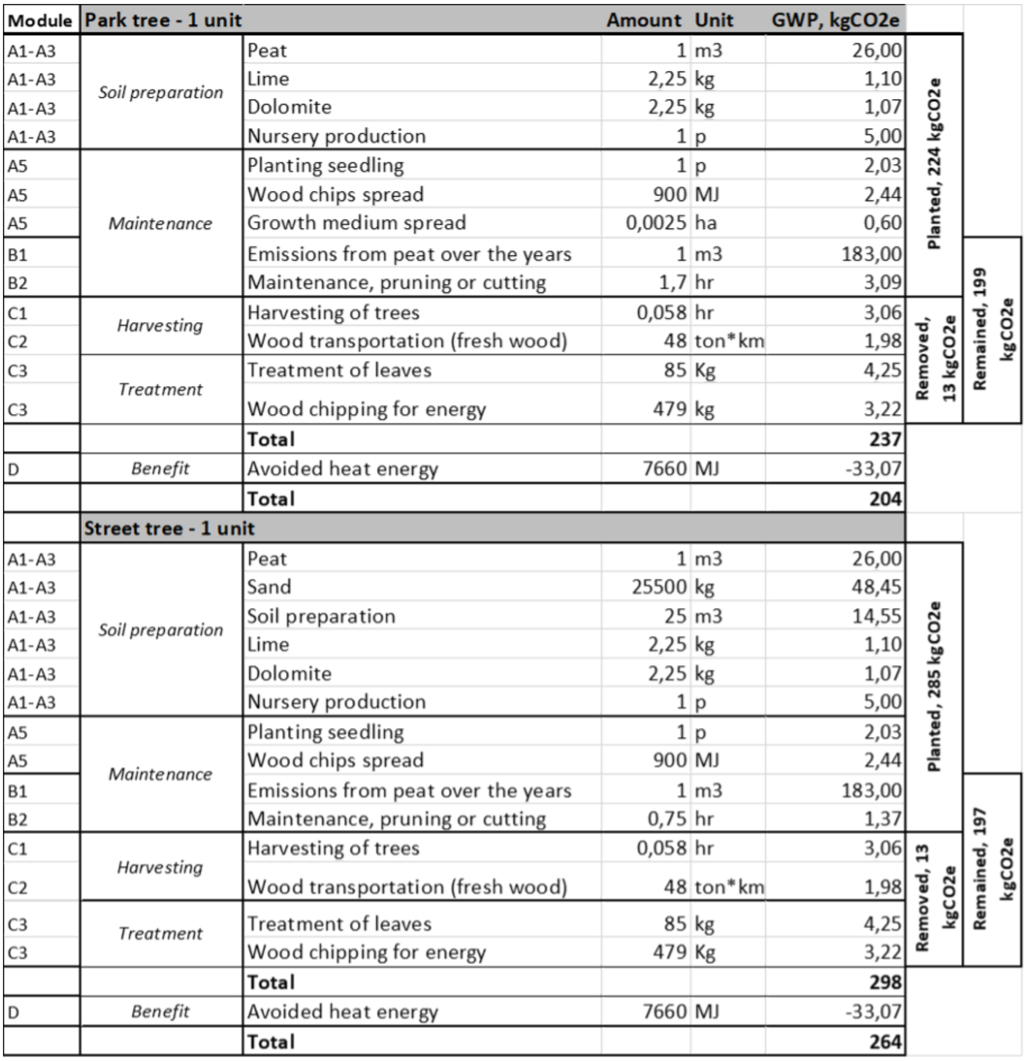
Nursery seedling- 1 unit	Amount	Unit	GWP, kg CO_2e
Polypropylene pot for seedling	1	pc	0.1440
Lime	0.06	kg	0.0292
Peat	7	l	1.2110
Ammonium nitrate, as N	0.007	kg	0.0540
Potassium chloride, as K2O	0.116	kg	0.0430
Dolomite lime	0.0158	kg	0.0075
Dolomite, at plant	0.0158	kg	0.0004
Nitrogen fertilisation (direct emission) as N2O	0.007	kg	0.0300
Nitrogen fertilisation (indirect emission) as N2O	0.007	kg	0.0068
Single superphosphate, as P2O5	0.0732	kg	0.1547
Potassium chloride, as K2O	0.0943	kg	0.0348
Tree seedling production, in unheated greenhouse	1	p	0.0341
Electricity, medium voltage	3	kWh	1.3476
Heat energy	21.3	MJ	1.8178
Total			**5.0021**

Table 2 Global warming potential (kg CO_2e) of nursery seedlings

Park and street tree

Total emissions over the 50-year are estimated at 237 kg CO_2e for a park tree and 298 kg CO_2e for a street tree (Table 3). This value corresponds to the life of the tree from seedling production until final harvest at year 50. The process emissions for energy generated from the harvested tree was 33 kg CO_2e with a volume of 1 m^3 (equal to the dry mass 500 kg m^{-3}). If this value is assumed to be avoiding heat from fossil energy sources, the total emission is reduced to 204 kg CO_2e for the park tree and 264 kg CO_2e for the street tree (Table 3). It should be noted that neither the PCR rules EN 15804 nor EN 159768 accept attributional LCA, where substitution effects are accounted for during the life cycle of the assessed product or system. These figures are only given for additional information.

Table 3 also shows the emission values separately for different tree scenarios at the construction site. The values ranged 224-285 kg CO_2e for the planted, 13 kg CO_2e for the removed, and 197-199 kg CO_2e for the remaining trees. These are indicative values, and careful consideration should be taken using the data since they are based on various assumptions and Finnish conditions. In addition, a comparison between the different scenarios may be incorrect due to differences in the time horizon. For example, in the case of removed trees, the emissions happen during the one year, while emissions for planted trees are considered in the 50-year time period.



Module	Park tree - 1 unit		Amount	Unit	GWP, kgCO2e		
A1-A3	*Soil preparation*	Peat	1	m3	26,00	Planted, 224 kgCO2e	
A1-A3		Lime	2,25	kg	1,10		
A1-A3		Dolomite	2,25	kg	1,07		
A1-A3		Nursery production	1	p	5,00		
A5	*Maintenance*	Planting seedling	1	p	2,03		
A5		Wood chips spread	900	MJ	2,44		
A5		Growth medium spread	0,0025	ha	0,60		
B1		Emissions from peat over the years	1	m3	183,00		Remained, 199 kgCO2e
B2		Maintenance, pruning or cutting	1,7	hr	3,09		
C1	*Harvesting*	Harvesting of trees	0,058	hr	3,06	Removed, 13 kgCO2e	
C2		Wood transportation (fresh wood)	48	ton*km	1,98		
C3	*Treatment*	Treatment of leaves	85	Kg	4,25		
C3		Wood chipping for energy	479	kg	3,22		
		Total			**237**		
D	*Benefit*	Avoided heat energy	7660	MJ	-33,07		
		Total			**204**		
	Street tree - 1 unit						
A1-A3	*Soil preparation*	Peat	1	m3	26,00	Planted, 285 kgCO2e	
A1-A3		Sand	25500	kg	48,45		
A1-A3		Soil preparation	25	m3	14,55		
A1-A3		Lime	2,25	kg	1,10		
A1-A3		Dolomite	2,25	kg	1,07		
A1-A3		Nursery production	1	p	5,00		
A5	*Maintenance*	Planting seedling	1	p	2,03		
A5		Wood chips spread	900	MJ	2,44		
B1		Emissions from peat over the years	1	m3	183,00		Remained, 197 kgCO2e
B2		Maintenance, pruning or cutting	0,75	hr	1,37		
C1	*Harvesting*	Harvesting of trees	0,058	hr	3,06	Removed, 13 kgCO2e	
C2		Wood transportation (fresh wood)	48	ton*km	1,98		
C3	*Treatment*	Treatment of leaves	85	kg	4,25		
C3		Wood chipping for energy	479	Kg	3,22		
		Total			**298**		
D	*Benefit*	Avoided heat energy	7660	MJ	-33,07		
		Total			**264**		

Table 3 Global warming potential (kg CO_2e) of a park tree (A) and a street tree (B) over the 50-year lifespan. The values are added for planted, remained and removed trees, and allocated for modules according to EN 15804 and ISO 14025. Transportation of raw materials to the site (A5) is excluded due to low emissions values.

Carbon stock change estimates for different scenarios

Approach 1. Carbon stock change estimates for different scenarios

Planted trees

Planted trees showed significant variations in carbon sequestration and storage capabilities across different species over a period of 50 years after planting (Figure 5). Species-specific characteristics such as life expectancy and growth rate are key factors affecting how much carbon trees can sequester in 50 years.

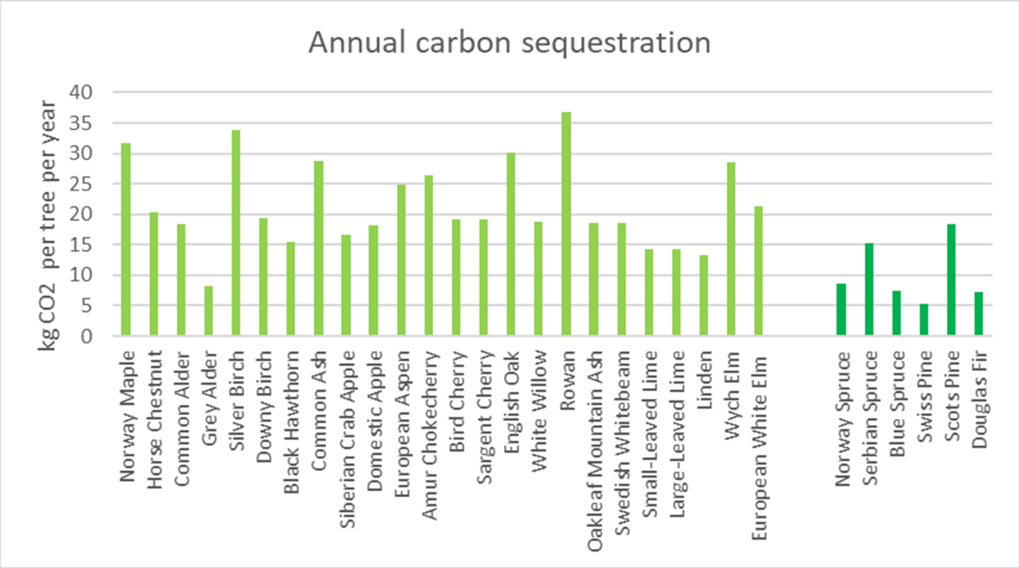


Figure 5 Annual CO_2 sequestration (kg CO_2) for individual trees varies widely across species. Light green indicates broadleaf trees; dark green indicates conifer trees

Some of the most efficient species in carbon sequestration during the first 50 years after planting were the Norway maple (*Acer platanoides*), silver birch (*Betula pendula*), and rowan (*Sorbus aucuparia*) (Table 4). These species stored an average of 430–500 kg of carbon over 50 years, giving an average annual carbon sequestration of around 9–10 kg C. In contrast, the grey alder, which has one of the lowest sequestration capacities, sequestered only about 110 kg C over 50 years, with an average annual carbon sequestration of only 2 kg C.

Broadleaf species	**Scientific name**	**Life expectancy in years**	**Predicted carbon storage in kg of C**	**Average annual carbon sequestration in kg of C**	**Predicted carbon storage in kg of CO_2**	**Average annual carbon sequestration in kg CO_2**
Norway Maple	*Acer platanoides*	100	432	9	1584	32
Horse Chestnut	*Aesculus hippocastanum*	80	278	6	1018	20
Common Alder	*Alnus glutinosa*	90	250	5	918	18
Grey Alder	*Alnus incana*	40	113	2	415	8
Silver Birch	*Betula pendula*	90	462	9	1695	34
Downy Birch	*Betula pubescens*	80	263	5	964	19
Black Hawthorn	*Crataegus douglasii*	70	210	4	771	15
European Ash	*Fraxinus excelsior*	150	391	8	1434	29
Siberian Crab Apple	*Malus baccata*	80	227	5	831	17
Domestic Apple	*Malus domestica*	80	247	5	905	18
European Aspen	*Populus tremula*	70	340	7	1245	25
Amur Chokecherry	*Prunus maackii*	60	359	7	1317	26
Bird Cherry	*Prunus padus*	60	262	5	962	19
Sargent Cherry	*Prunus sargentii*	60	262	5	962	19
English Oak	*Quercus robur*	200	411	8	1506	30
White Willow	*Salix alba*	70	257	5	942	19
Rowan	*Sorbus aucuparia*	50	502	10	1841	37
Oakleaf Mountain Ash	*Hedlundia hybrida*	70	254	5	930	19
Swedish Whitebeam	*Scandosorbus intermedia*	70	254	5	930	19
Small-Leaved Lime	*Tilia cordata*	*170*	194	4	710	14
Large-Leaved Lime	*Tilia platyphyllos*	*170*	194	4	710	14
Linden	*Tilia x europaea*	*170*	181	4	662	13

Wych Elm	*Ulmus glabra*	*140*	389	8	1428	29
European White Elm	*Ulmus laevis*	*140*	290	6	1062	21
Conifer species						
Norway Spruce	*Picea abies*	100	118	2	434	9
Serbian Spruce	*Picea omorika*	100	208	4	762	15
Blue Spruce	*Picea pungens*	70	102	2	375	8
Swiss Pine	*Pinus cembra*	80	72	1	265	5
Scots Pine	*Pinus sylvestris*	250	251	5	919	18
Douglas Fir	*Pseudotsuga menziesii*	100	99	2	363	7
Average broadleaf species		98	293	6	1073	21
Average conifer species		117	142	3	519	10
Average all species		102	262	5	962	19

Table 4 Projected increase in carbon stock for various tree species over a 50-year period starting from planting. Figures are given per tree.

Broadleaf species generally showed a higher capacity to store and sequester carbon than conifer species (Figure 5). Scots Pine (*Pinus sylvestris*) was the most efficient among the conifers, achieving a carbon storage of 251 kg by year 50, with an annual uptake of 5 kg – equivalent to 18 kg of CO_2. In contrast, Swiss pine (*Pinus cembra*) had the lowest carbon storage among conifers, totalling 72 kg, and sequestered an average of 1 kg of carbon (equivalent to 5 kg of CO_2) annually.

Planting new trees can help offset the carbon loss from removed trees. Adding new trees ensures the urban area's overall carbon sequestration and storage capacity are maintained or increased. Notably, however, to maintain the carbon stock, more new trees need to be planted than trees need to be removed because some of these new trees may die or be removed before they mature. Also, the carbon sequestration potential of young trees (e.g. 0–20 years) is rather low compared to maturing trees (e.g. age 30–40).

Remaining trees

The results for the remaining trees reflected their carbon stock and sequestration potential, considering their current size, as indicated by diameter at breast height (DBH), and projected growth over the next 50 years. These trees are spared from being cut down during construction, allowing them to continue growing and contributing to carbon storage for the duration of their natural life cycle or until their removal. With remaining trees, a life cycle's impact on carbon storage became evident.

Typically, younger, vigorously growing trees have higher carbon sequestration rates because they rapidly build biomass as they grow. However, older trees have more biomass, meaning they have a larger structure (trunk, branches, leaves, roots) to store carbon. Even if the growth rate, relative to their size and age, slows down, the overall amount of carbon they sequester annually can still be substantial because of their size. For instance, the English oak demonstrated a significant carbon storage capacity, largely due to its long lifespan. It showed a robust increase in carbon storage when it grows larger, with mature trees (60–80 cm DBH) predicted to store, on average, up to 2612 kg of carbon by the 50th year for now, with the annual sequestration rate being 22 kg of carbon or 81 kg of CO_2.

Broadleaf	Current DBH class	Current carbon storage	Predicted carbon storage in kg C	Average annual carbon sequestration in kg of C	Predicted carbon storage in kg CO_2	Average annual carbon sequestration in kg CO_2
Norway Maple	1-20	43	680	13	2492	47
Acer platanoides	20-40	292	1242	19	4555	70
	40-60	929	1460	11	5354	39
	60-80	1398	1460	1	5354	5
Horse Chestnut	1-20	40	495	9	1814	33
Aesculus hippocastanum	20-40	309	758	9	2778	33
	40-60	668	758	2	2778	7
Common Alder	1-20	31	358	7	1314	24
Alnus glutinosa	20-40	170	587	8	2153	31
	40-60	458	628	3	2303	12
Grey Alder	1-20	32	113	2	415	6
Alnus incana	20-40	104	113	0,2	415	1
Silver Birch	1-20	36	742	14	2722	52
Betula pendula	20-40	291	1545	25	5663	92
	40-60	1015	1719	14	6303	52
	60-80	1636	1719	2	6303	6
Downy Birch	1-20	36	472	9	1729	32
Betula pubescens	20-40	293	706	8	2589	30
	40-60	639	706	1	2589	5
Black Hawthorn	1-20	33	294	5	1076	19
Crataegus douglasii	20-40	210	335	3	1230	9
European Ash	1-20	37	603	11	2212	42
Fraxinus excelsior	20-40	253	1279	21	4688	75

	40-60	804	2171	27	7960	100
	60-80	1738	2949	24	10815	89
	80+	2664	3007	7	11026	25
Siberian Crab Apple	1-20	36	327	6	1199	21
Malus baccata	20-40	260	417	3	1528	12
Domestic Apple	1-20	39	356	6	1306	23
Malus domestica	20-40	283	454	3	1664	13
European Aspen	1-20	26	536	10	1967	37
Populus tremula	20-40	213	694	10	2544	35
	40-60	550	694	3	2544	11
Amur Chokecherry	1-20	51	482	9	1769	32
Prunus maackii	20-40	302	507	4	1859	15
Bird Cherry	1-20	42	322	6	1181	21
Prunus padus	20-40	223	334	2	1223	8
Sargent Cherry	1-20	51	834	16	3056	57
Prunus sargentii	20-40	396	890	10	3262	36
	40-60	828	890	1	3262	4
English Oak	1-20	53	597	11	2189	40
Quercus robur	20-40	279	1150	17	4218	64
	40-60	766	1836	21	6731	78
	60-80	1507	2612	22	9578	81
	80+	2442	2930	10	10742	36
White Willow	1-20	20	406	8	1488	28
Salix alba	20-40	161	525	7	1925	27
	40-60	416	525	2	1925	8

Rowan	1-20	40	481	9	1762	32
Sorbus aucuparia	20-40	273	481	4	1762	15
Oakleaf Mountain Ash	1-20	40	351	6	1288	23
Hedlundia hybrida	20-40	254	397	3	1456	11
Swedish Whitebeam	1-20	40	351	6	1288	23
Scandosorbus intermedia	20-40	254	397	3	1456	11
Small-Leaved Lime	1-20	29	337	6	1236	23
Tilia cordata	20-40	214	832	12	3050	45
	40-60	705	1654	19	6066	70
	60-80	1538	2206	13	8089	49
	80+	2125	2211	2	8106	6
Large-Leaved Lime	1-20	29	337	6	1236	23
Tilia platyphyllos	20-40	214	832	12	3050	45
	40-60	705	1654	19	6066	70
	60-80	1538	2206	13	8089	49
	80+	2125	2211	2	8106	6
Linden	1-20	27	314	6	1153	21
Tilia x europaea	20-40	199	778	12	2853	42
	40-60	660	1543	18	5657	65
	60-80	1434	2057	12	7543	46
	80+	1982	2062	2	7559	6
Wych Elm	1-20	33	615	12	2256	43
Ulmus glabra	20-40	248	1357	22	4976	81
	40-60	833	2387	31	8753	114

	60-80	1870	2986	22	10948	82
	80+	2747	2987	5	10952	18
European White Elm	1-20	33	368	7	1348	25
Ulmus laevis	20-40	266	527	5	1933	19
	40-60	543	611	1	2241	5
Conifer						
Norway Spruce	1-20	39	231	4	849	14
Picea abies	20-40	236	415	4	1521	13
Serbian Spruce	1-20	35	347	6	1273	23
Picea omorika	20-40	226	714	10	2618	36
	40-60	585	774	4	2839	14
Blue Spruce	1-20	33	164	3	601	10
Picea pungens	20-40	129	183	1	672	4
Swiss Pine	1-20	21	139	2	509	9
Pinus cembra	20-40	111	178	1	651	5
Scots Pine	1-20	26	374	7	1372	26
Pinus sylvestris	20-40	165	741	12	2716	42
	40-60	486	1186	14	4350	51
	60-80	973	1698	15	6228	53
	80+	1569	2202	13	8074	46
Douglas Fir	1-20	12	178	3	652	12
Pseudotsuge menziesii	20-40	110	378	5	1386	20
	40-60	309	410	2	1503	7

Average broadleaf species	445	848	8	3111	30
Average conifer species	226	471	5	1729	18
Average all species	401	773	7	2834	27

Table 5 The results for remaining trees reflected their carbon storage and sequestration potential

Removed trees

The results highlight the impact of tree removal on carbon stock and sequestration across various stages of tree maturity. Initially, the immediate impact was assessed based on the direct loss of carbon stored within the trees at the time of removal. For example, for young trees (classified within a diameter at breast height [DBH] range of 1–20 cm), the immediate carbon stock losses were quantified as 43 kg for the Norway maple, 37 kg for European ash, and 53 kg for English oak. When losses are distributed over a 50-year time period, the annual losses are around 1 kg of carbon for each species. The impact is much larger for older, larger trees within a DBH class of 60–80 cm, where the carbon stock losses are substantially higher, recorded at 929 kg for Norway maple, 1738 kg for European ash, and 1507 kg for English oak. The annual losses would be 19 kg for Norway maple, 35 kg for European ash, and 30 kg for English oak. These figures underscore the considerable amount of carbon stored in mature trees and the significant impact their removal has on the carbon balance.

Expanding the analysis to include the long-term effects, which account for the potential carbon sequestration these trees would have contributed had they not been removed, reveals even bigger losses. The example trees show expected decreases in current carbon storage and future carbon capture potential for the young trees, totalling 680 kg for Norway maple, 603 kg for European ash, and 597 kg for English oak. That is, annually, 14 kg of carbon for Norway maple, 12 kg for European ash, and 12 kg for English oak. The impact is more significant for mature trees, with anticipated sequestration losses of 1460 kg for Norway maple, 2949 kg for European ash, and 2612 kg for English oak. Annually, this would mean a loss of 29 kg of carbon for Norway maple, 59 kg for European ash, and 52 kg for English oak. These figures underscore the considerable amount of carbon stored in mature trees and the significant impact their removal could have on the carbon balance.

				Loss based on current storage				Loss based on future storage			
Broadleaf	**Current DBH class**	**Current carbon storage**	**Predicted carbon storage in 50 years**	**Carbon storage lost in kg C**	**Annual carbon sequestration lost kg C**	**Annual carbon sequestration lost kg CO_2**	**Annual carbon sequestration lost kg CO_2**	**Carbon storage lost in kg C**	**Average carbon storage during 50 years in kg C**	**Carbon storage lost in kg of CO_2**	**Average carbon storage during 50 years in kg CO_2**
Norway Maple	1-20	43	680	-43	-1	-158	-3	-680	-14	-2492	-50
Acer platanoides	20-40	292	1242	-292	-6	-1072	-21	-1242	-25	-4555	-91
	40-60	929	1460	-929	-19	-3406	-68	-1460	-29	-5354	-107
	60-80	1398	1460	-1398	-28	-5126	-103	-1460	-29	-5354	-107
Horse Chestnut	1-20	40	495	-40	-1	-146	-3	-495	-10	-1814	-36
Aesculus hippocastanum	20-40	309	758	-309	-6	-1133	-23	-758	-15	-2778	-56
	40-60	668	758	-668	-13	-2449	-49	-758	-15	-2778	-56
Common Alder	1-20	31	358	-31	-1	-114	-2	-358	-7	-1314	-26
Alnus glutinosa	20-40	170	587	-170	-3	-622	-12	-587	-12	-2153	-43
	40-60	458	628	-458	-9	-1680	-34	-628	-13	-2303	-46
Grey Alder	1-20	32	113	-32	-1	-119	-2	-113	-2	-415	-8
Alnus incana	20-40	104	113	-104	-2	-381	-8	-113	-2	-415	-8
Silver Birch	1-20	36	742	-36	-1	-133	-3	-742	-15	-2722	-54
Betula pendula	20-40	291	1545	-291	-6	-1066	-21	-1545	-31	-5663	-113
	40-60	1015	1719	-1015	-20	-3723	-74	-1719	-34	-6303	-126
	60-80	1636	1719	-1636	-33	-5999	-120	-1719	-34	-6303	-126
Downy Birch	1-20	36	472	-36	-1	-133	-3	-472	-9	-1729	-35
Betula pubescens	20-40	293	706	-293	-6	-1076	-22	-706	-14	-2589	-52
	40-60	639	706	-639	-13	-2345	-47	-706	-14	-2589	-52
Black Hawthorn	1-20	33	294	-33	-1	-122	-2	-294	-6	-1076	-22
Crataegus douglasii	20-40	210	335	-210	-4	-771	-15	-335	-7	-1230	-25

European Ash	1-20	37	603	-37	-1	-135	-3	-603	-12	-2212	-44
Fraxinus excelsior	20-40	253	1279	-253	-5	-928	-19	-1279	-26	-4688	-94
	40-60	804	2171	-804	-16	-2947	-59	-2171	-43	-7960	-159
	60-80	1738	2949	-1738	-35	-6372	-127	-2949	-59	-10815	-216
	80+	2664	3007	-2664	-53	-9769	-195	-3007	-60	-11026	-221
Siberian Crab Apple	1-20	36	327	-36	-1	-131	-3	-327	-7	-1199	-24
Malus baccata	20-40	260	417	-260	-5	-952	-19	-417	-8	-1528	-31
Domestic Apple	1-20	39	356	-39	-1	-143	-3	-356	-7	-1306	-26
Malus domestica	20-40	283	454	-283	-6	-1038	-21	-454	-9	-1664	-33
European Aspen	1-20	26	536	-26	-1	-97	-2	-536	-11	-1967	-39
Populus tremula	20-40	213	694	-213	-4	-782	-16	-694	-14	-2544	-51
	40-60	550	694	-550	-11	-2016	-40	-694	-14	-2544	-51
Amur Chokecherry	1-20	51	482	-51	-1	-186	-4	-482	-10	-1769	-35
Prunus maackii	20-40	302	507	-302	-6	-1107	-22	-507	-10	-1859	-37
Bird Cherry	1-20	42	322	-42	-1	-153	-3	-322	-6	-1181	-24
Prunus padus	20-40	223	334	-223	-4	-818	-16	-334	-7	-1223	-24
Sargent Cherry	1-20	51	834	-51	-1	-187	-4	-834	-17	-3056	-61
Prunus sargentii	20-40	396	890	-396	-8	-1451	-29	-890	-18	-3262	-65
	40-60	828	890	-828	-17	-3038	-61	-890	-18	-3262	-65
English Oak	1-20	53	597	-53	-1	-193	-4	-597	-12	-2189	-44
Quercus robur	20-40	279	1150	-279	-6	-1023	-20	-1150	-23	-4218	-84
	40-60	766	1836	-766	-15	-2808	-56	-1836	-37	-6731	-135
	60-80	1507	2612	-1507	-30	-5524	-110	-2612	-52	-9578	-192
	80+	2442	2930	-2442	-49	-8953	-179	-2930	-59	-10742	-215

White Willow	1-20	20	406	-20	0	-73	-1	-406	-8	-1488	-30
Salix alba	20-40	161	525	-161	-3	-592	-12	-525	-11	-1925	-39
	40-60	416	525	-416	-8	-1525	-31	-525	-11	-1925	-39
Rowan	1-20	40	481	-40	-1	-148	-3	-481	-10	-1762	-35
Sorbus aucuparia	20-40	273	481	-273	-5	-999	-20	-481	-10	-1762	-35
Oakleaf Mountain Ash	1-20	40	351	-40	-1	-146	-3	-351	-7	-1288	-26
Hedlundia hybrida	20-40	254	397	-254	-5	-930	-19	-397	-8	-1456	-29
Swedish Whitebeam	1-20	40	351	-40	-1	-146	-3	-351	-7	-1288	-26
Scandosorbus intermedia	20-40	254	397	-254	-5	-930	-19	-397	-8	-1456	-29
Small-Leaved Lime	1-20	29	337	-29	-1	-106	-2	-337	-7	-1236	-25
Tilia cordata	20-40	214	832	-214	-4	-784	-16	-832	-17	-3050	-61
	40-60	705	1654	-705	-14	-2585	-52	-1654	-33	-6066	-121
	60-80	1538	2206	-1538	-31	-5640	-113	-2206	-44	-8089	-162
	80+	2125	2211	-2125	-43	-7793	-156	-2211	-44	-8106	-162
Large-Leaved Lime	1-20	29	337	-29	-1	-106	-2	-337	-7	-1236	-25
Tilia platyphyllos	20-40	214	832	-214	-4	-784	-16	-832	-17	-3050	-61
	40-60	705	1654	-705	-14	-2585	-52	-1654	-33	-6066	-121
	60-80	1538	2206	-1538	-31	-5640	-113	-2206	-44	-8089	-162
	80+	2125	2211	-2125	-43	-7793	-156	-2211	-44	-8106	-162
Linden	1-20	27	314	-27	-1	-99	-2	-314	-6	-1153	-23
Tilia x europaea	20-40	199	778	-199	-4	-731	-15	-778	-16	-2853	-57
	40-60	660	1543	-660	-13	-2419	-48	-1543	-31	-5657	-113
	60-80	1434	2057	-1434	-29	-5259	-105	-2057	-41	-7543	-151

	80+	1982	2062	-1982	-40	-7267	-145	-2062	-41	-7559	-151
Wych Elm	1-20	33	615	-33	-1	-120	-2	-615	-12	-2256	-45
Ulmus glabra	20-40	248	1357	-248	-5	-908	-18	-1357	-27	-4976	-100
	40-60	833	2387	-833	-17	-3053	-61	-2387	-48	-8753	-175
	60-80	1870	2986	-1870	-37	-6857	-137	-2986	-60	-10948	-219
	80+	2747	2987	-2747	-55	-10074	-201	-2987	-60	-10952	-219
European White Elm	1-20	33	368	-33	-1	-120	-2	-368	-7	-1348	-27
Ulmus laevis	20-40	266	527	-266	-5	-976	-20	-527	-11	-1933	-39
	40-60	543	611	-543	-11	-1993	-40	-611	-12	-2241	-45
Conifer											
Norway Spruce	1-20	39	231	-39	-1	-144	-3	-231	-5	-849	-17
Picea abies	20-40	236	415	-236	-5	-864	-17	-415	-8	-1521	-30
Serbian Spruce	1-20	35	347	-35	-1	-128	-3	-347	-7	-1273	-25
Picea omorika	20-40	226	714	-226	-5	-830	-17	-714	-14	-2618	-52
	40-60	585	774	-585	-12	-2146	-43	-774	-15	-2839	-57
Blue Spruce	1-20	33	164	-33	-1	-121	-2	-164	-3	-601	-12
Picea pungens	20-40	129	183	-129	-3	-473	-9	-183	-4	-672	-13
Swiss Pine	1-20	21	139	-21	0	-78	-2	-139	-3	-509	-10
Pinus cembra	20-40	111	178	-111	-2	-407	-8	-178	-4	-651	-13
Scots Pine	1-20	26	374	-26	-1	-94	-2	-374	-7	-1372	-27
Pinus sylvestris	20-40	165	741	-165	-3	-605	-12	-741	-15	-2716	-54
	40-60	486	1186	-486	-10	-1783	-36	-1186	-24	-4350	-87
	60-80	973	1698	-973	-19	-3567	-71	-1698	-34	-6228	-125
	80+	1569	2202	-1569	-31	-5753	-115	-2202	-44	-8074	-161

Douglas Fir	1-20	12	178	-12	0	-43	-1	-178	-4	-652	-13
Pseudotsuge menziesii	20-40	110	378	-110	-2	-404	-8	-378	-8	-1386	-28
	40-60	309	410	-309	-6	-1133	-23	-410	-8	-1503	-30
Average broadleaf species		445	848	-445	-9	-1631	-33	-848	-17	-3111	-62
Average conifer species		226	471	-226	-5	-828	-17	-471	-9	-1729	-35
Average all species		401	773	-401	-8	-1470	-29	-773	-15	-2834	-57

Table 6 The results for removed trees reflected their carbon storage and lost sequestration potential

Implications of the results

Incorporating carbon data related to green areas within the built environment into the 'Emission Database for Construction' is important for evaluating the environmental impacts of urban construction. This database facilitates the use of standardised or comparable values to assess the carbon footprint. By providing access to essential data, such as the emissions associated with tree maintenance practices and the carbon-storing and sequestration capabilities of various tree species, the database supports a more consistent and accurate evaluation of trees' contributions to construction's carbon footprint. However, the challenge is in accurately measuring the dynamic nature of trees' carbon absorption and storage capabilities, considering their growth, health, species diversity, lifecycle changes, etc. As methodologies evolve to better capture these complexities, integrating trees into climate impact calculations could provide a more holistic view of buildings' environmental footprints.

Enhanced data leads to a deeper understanding of construction projects' environmental impact by accounting not only for the emissions associated with building materials and construction processes but for the negative emissions of trees on yards, streets, and parks. This would enable more informed decision-making in urban planning and construction, encouraging the preservation of trees and incorporating green infrastructure in new developments to enhance carbon capture and contribute to climate change mitigation.

The results presented here have significant implications for management and planning in construction and development projects. Planners should consider a tree's carbon sequestration potential over time when making decisions. Older trees with larger biomass can continue sequestering substantial carbon even as their growth rate decreases. Trees with longer lifespans may provide more carbon storage over their lifetimes compared to shorter-lived species. This long-term storage can support a city's carbon reduction goals. Given the carbon sequestration capabilities of mature trees, development plans should prioritise retaining existing trees and incorporating planting new ones as part of the sustainability strategy (Figure 6). When removal is unavoidable, these insights can inform replacement strategies. In replacing removed trees, considering various factors is important, including the tree's growth rate and carbon sequestration potential, to maintain or enhance the urban forest's carbon storage.

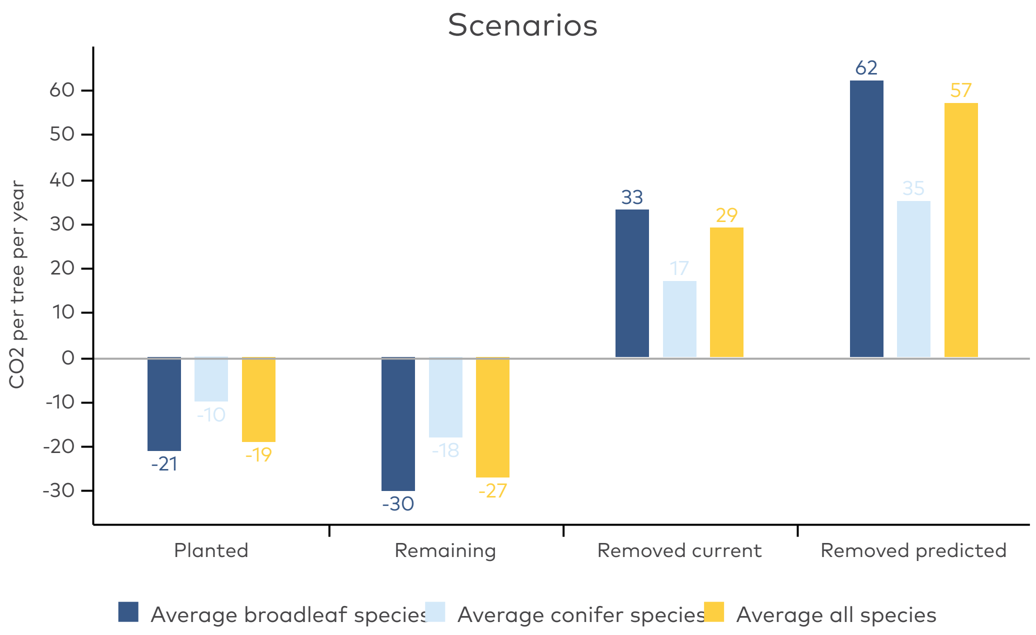


Figure 6 The average annual carbon sequestration data for individual trees of broadleaf (dark blue bars), conifer (light blue bars), and the average of all species (yellow bars) in different scenarios (planted, remaining, removed current, and removed predicted). Here, the negative values refer to carbon sink, and positive values refer to carbon emission.

Choosing species that match the specific site conditions is also essential. Factors like soil type, space, climate, and pest resistance are important. Biodiversity is key to creating a resilient urban forest. Diverse species can better withstand various environmental stresses and contribute to a healthier ecosystem. If a tree is unsuited to its environment, it may die prematurely, and the potential carbon sequestration for the rest of its intended lifespan is lost. Dead trees not only stop sequestering carbon but can start releasing stored carbon back into the atmosphere. Successful tree planting for carbon management depends on selecting the right tree for each location, ensuring health, longevity, effective carbon sequestration, and overall ecosystem resilience.

Approach 2. Species-specific equations

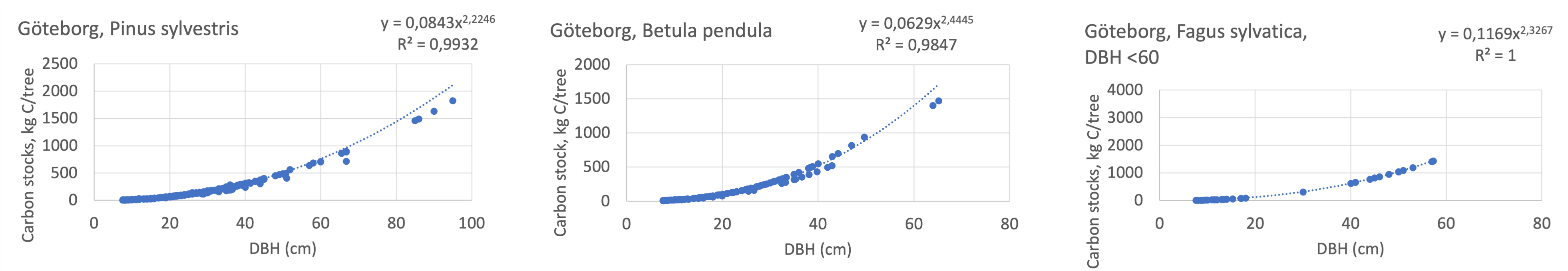
We also explored whether making a more detailed calculation of changes in tree carbon stocks was possible based on the i-Tree data using variables of diameter breast height (DBH), carbon stocks, and carbon sinks. Examples of the plotted relations between DBH and the carbon stocks and carbon sinks are shown for individual tree data for some different common species in Göteborg (Figure 7). It should be noted that the relations between DBH and carbon sinks/stocks should be used only within the DBH limits presented in each figure.

The relationships between DBH and the carbon sinks were relatively linear. However, the estimated intercepts were often negative, indicating a slight tendency for exponential relations. The relationships between DBH and the carbon stocks were clearly exponential, which is to be expected since the stem basal area correlates with the stem radius squared.

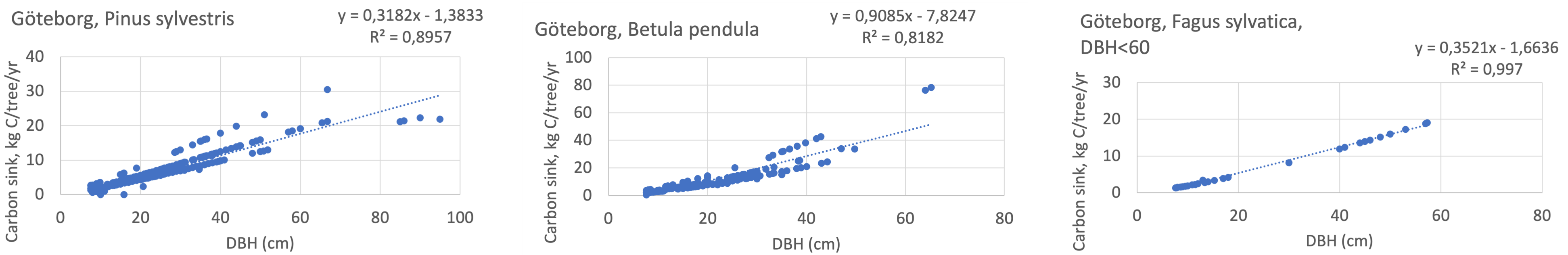
The analysis for *Fagus sylvatica* and *Salix caprea* in Göteborg had to be made separately for small and large trees, separated into DBH <60 cm and DBH >60 cm (Fagus sylvatica shown in Figure 7). Tree growth rates are sometimes expected to increase with age up to an optimum, after which the growth starts decreasing with age.

The results presented for the inventoried tree species were relatively similar between Göteborg, Umeå, and Malmö. Table 7 shows that broadleaf tree species were differentiated into slow- and fast-growing species. Figure 8 shows the relations between DBH, and the carbon sinks are shown for individual tree data for different tree species categories in the urban areas of Göteborg, Umeå, and Malmö. Similarly, Figure 9 shows the relationship between DBH and the carbon stocks.

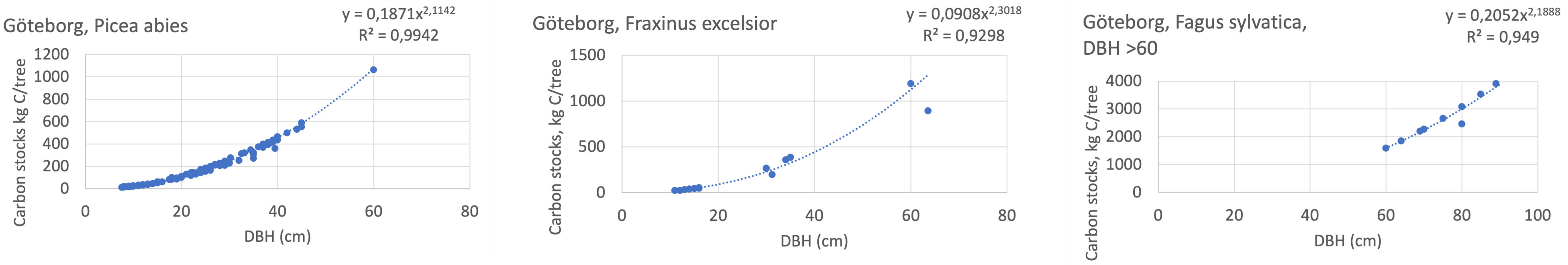
Carbon stocks, kg C/tree



Carbon sinks, kg C/yr/tree



Carbon stocks, kg C/tree



Carbon sinks, kg C/yr/tree

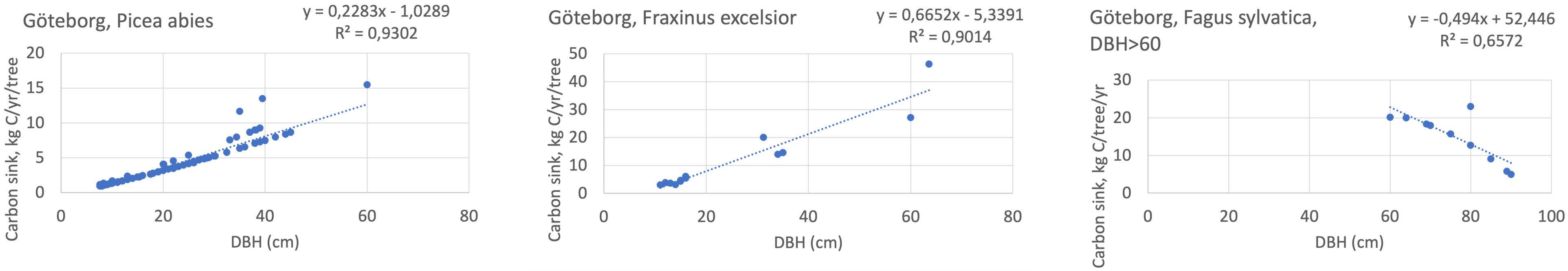


Figure 7 Examples of the calculated relations between DBH and the carbon stocks and carbon sinks are shown for individual tree data for some different common species in the Göteborg region. Upper row, conifers; middle row, broadleaf, fast-growing species; lower row, broadleaf, slow-growing species. The analysis for *Fagus sylvatica* was separated into one, including DBH <60 cm and another, including DBH >60 cm.

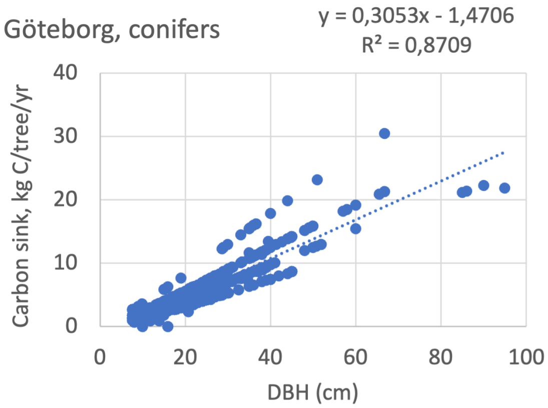
Tree species	Göteborg			Umeå			Malmö			Growth classification
	Carbon sink vs DBH, linear regression			Carbon sink vs DBH, linear regression			Carbon sink vs DBH, linear regression			
	Slope, kg C/ yr/ cm DBH	Intercept, kg C/ yr	R^2	Slope, kg C/ yr/ cm DBH	Intercept, kg C/ yr	R^2	Slope, kg C/ yr/ cm DBH	Intercept, kg C/ yr	R^2	fast = > max sink/2**
Conifers										
Juniperus communis	0.22	-0.6	0.54	-	-	-	-	-	-	slow
Picea abies	0.23	-1.0	0.93	0.26	-1.4	0.90	-	-	-	slow
Pinus sylvestris	0.32	-1.4	0.90	0.38	-1.4	0.81	-	-	-	slow
Broadleaf										
Acer campestre	-	-	-	-	-	-	1.14	-16	0.58	fast
Acer platanoides	0.86	-6.4	0.88	-	-	-	-	-	-	fast
Aesculus hippocastanum	-	-	-	-	-	-	0.75	-5.1	0.99	fast
Alnus glutinosa	0.23	0.43	0.89	-	-	-	-	-	-	slow
Alnus incana	0.10	0.05	0.64	-	-	-	-	-	-	slow
Betula pendula	0.91	-7.8	0.82	-	-	-	-	-	-	fast
Betula pubescens	0.57	-4.4	0.89	0.83*	-8.6	0.88	-	-	-	fast
Corylus avellana	0.21	-0.6	0.71	-	-	-	-	-	-	slow
Fagus sylvatica, DBH<60	0.32	-1.7	0.84	-	-	-	0.64	-5.7	0.99	slow
Fagus sylvatica, DBH>60	-0.49	52.4	0.65	-	-	-	-	-	-	slow
Fraxinus excelsior	0.67	-5.4	0.90	-	-	-	-	-	-	fast
Malus sp	0.79	-4.3	0.99	-	-	-	0.67	-3.1	0.99	Fast***
Populus tremula	0.56	-3.8	0.95	0.82	-6.9	0.94	-	-	-	fast
Prunus sp	0.74	-4.5	0.91	0.67	-3.9	0.92	0.88	-4.6	0.75	fast

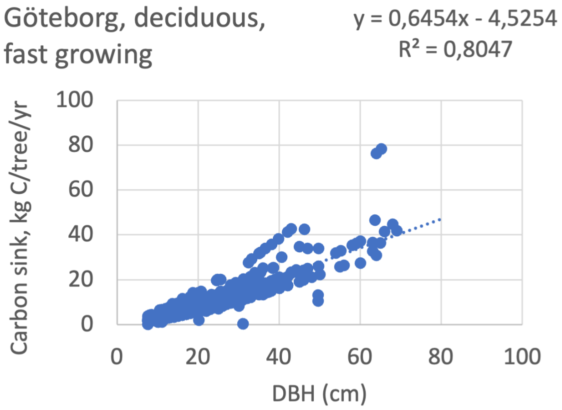
Quercus petraea	0.24	-0.3	0.92	-	-	-	-	-	-	slow
Quercus robur	0.43	-0.3	0.90	-	-	-	0.71	-2.1	0.91	slow
Salix alba	-	-	-	-	-	-	0.57	-4.6	0.99	slow
Salix caprea, DBH<30	0.41	-2.4	0.84	-	-	-	-	-	-	slow
Salix caprea, DBH>30	-0.28	17.1	0.48	-	-	-	-	-	-	slow
Sorbus aucuparia	0.59	-2.5	0.84	0.90	-6.1	0.85	0.76	-2.2	0.99	fast
Tilia cordata	-	-	-	-	-	-	0.53	-3.6	0.99	slow
Tilia europea	-	-	-	-	-	-	0.67	-10.8	0.99	slow
Ulmus glabra	0.58	-4.3	0.81	-	-	-	-	-	-	fast

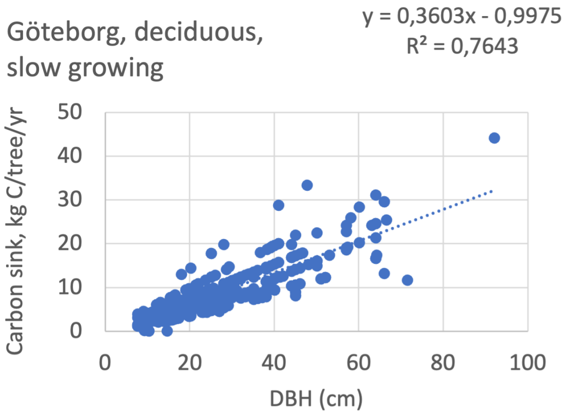
* All *Betula* in Umeå were assumed to be *Betula pubescences.*
** This criterion was assessed separately for each city. This criterion must be valid for all cities where this tree species was present and inventoried to be characterised as fast-growing.
*** Assessed as slow-growing in Malmö.

Table 7 The relationships between stem diameter at breast height (DBH) and the carbon sink rates of different tree species in Göteborg, Umeå, and Malmö. Tree carbon sink rates are classified into conifers and fast- and slow-growing broadleaf species, respectively. Fast-growing broadleaf species are marked with a grey background. For *Fagus sylvatica* and *Salix caprea* in Göteborg, separate calculations were made for trees above and below a DBH threshold of 60 cm. Species were classified as fast-growing when the carbon sink rates exceeded the maximum sink rates at the specific city divided by 2. The maximum sink rates for any tree species were 0.90 kg C/ yr/ cm DBH for Umeå, 0.91 kg C/ yr/ cm DBH for Göteborg, and 1.44 kg C/ yr/ cm DBH for Malmö.

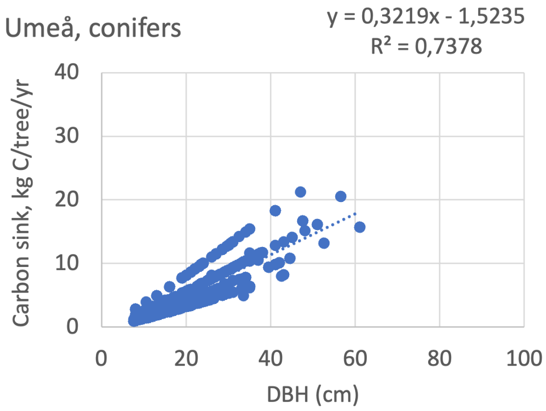
Göteborg

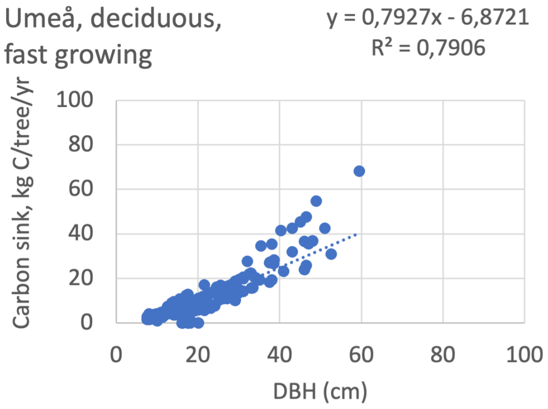






Umeå





Malmö

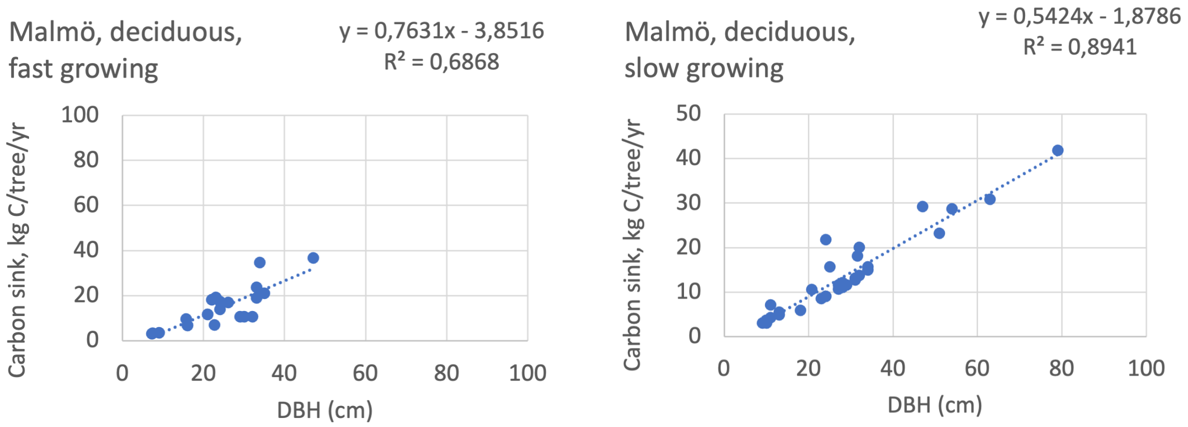
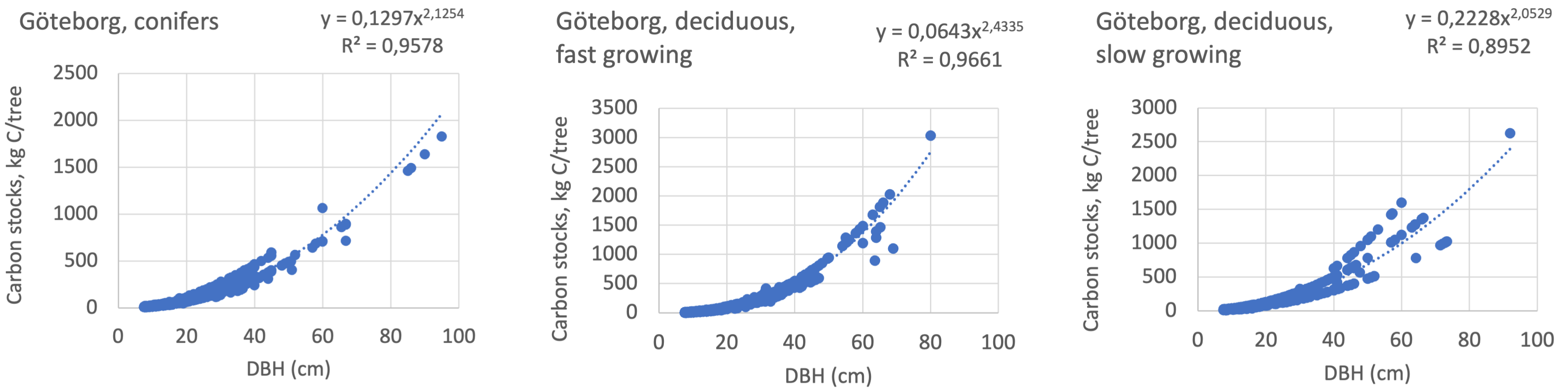
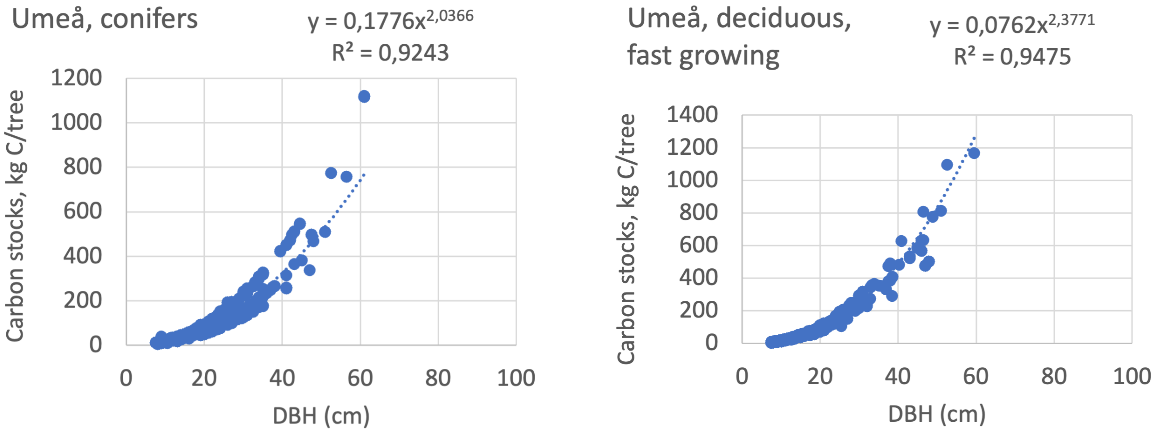


Figure 8 Relations between diameter at breast height (DBH) and the carbon sinks (kg C $tree^{-1}$ $year^{-1}$) are shown for individual tree data for different tree species categories in Göteborg, Umeå, and Malmö's urban areas. Upper row, coniferous tree species; middle row broadleaf, fast-growing species; lower row, broadleaf, fast-growing species. Table 7 shows the category for each tree species. There were no inventories of slow-growing deciduous species in Umeå and no coniferous species in Malmö.

Göteborg



Umeå



Malmö

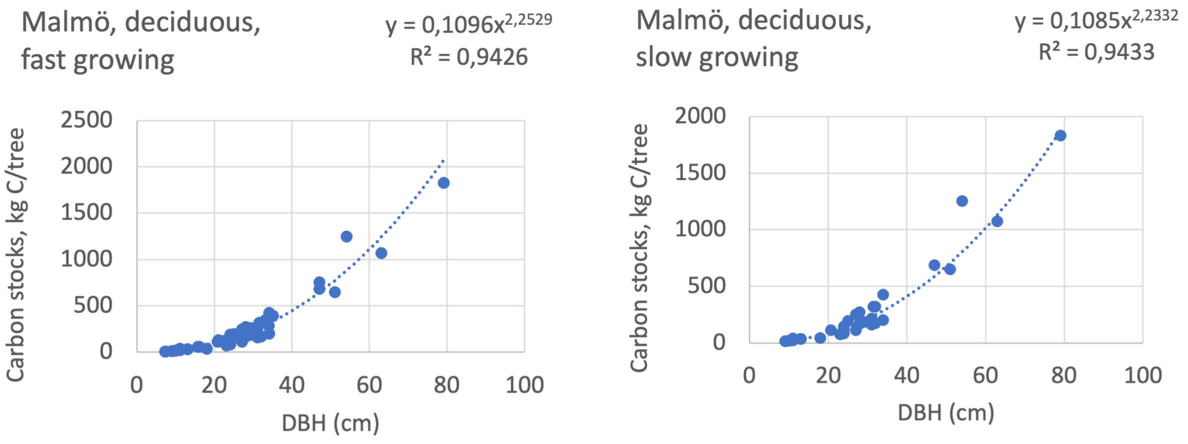


Figure 9 Relations between diameter at breast height (DBH) and the carbon stocks (kg C tree^{-1}) are shown for individual tree data for different tree species categories in Göteborg, Umeå, and Malmö's urban areas. Upper row, coniferous tree species; middle row broadleaf, fast-growing species; lower row, broadleaf, fast-growing species. Table 7 shows the category for each tree species. There were no inventories for slow-growing deciduous species in Umeå and no coniferous species in Malmö.

Values for emission database for construction

Trees or other living vegetation are not included in construction emission databases, and no obligation exists to include them. This report aimed to provide estimates of the types of activities in urban green spaces that contribute to the carbon sink of green spaces and information on the quantitative size of the carbon sink of trees.

The estimates for the emission database for construction (Table 8) shown here are separate mean values for park and street trees and grouped by tree type into broadleaf and conifer tree groups. An assessment for three scenarios was conducted, considering the changes for an individual tree if the tree is planted, removed, or retained in the construction area. Estimates considered the biogenic carbon sequestration and the life cycle emissions from nursery production, planting, maintenance, and tree removal (see table 3 for detailed information).

The results show that over a 50-year period, the amount of carbon sequestered by trees is significantly higher than emissions from nursery, maintenance, or removal, which are included in information of life cycle assessment in Table 8. In addition, the planting of street and park trees and their maintenance differ, resulting in slightly higher GHG emissions for street trees. However, the difference is slight and, in the overall picture, does not greatly impact final estimates. A comparison between groups shows that typically, faster-growing broadleaf types sequester carbon more efficiently than conifers. Notably, the results are rough simplifications and do not consider, e.g. actual growing conditions, actual tree size or tree species, and factors that significantly affect the growth and actual carbon sequestration capacity of an individual tree.

			Biogenic carbon sink	Life cycle assessment	CO2 sink/emission	
Tree scenario	Broadleaf/ Conifer	Park tree/ Street tree	CO2 - 50 years	CO2 - 50 years	Total 50 years	per year
Planted	Broadleaf	Park	-1073	224	-849	-17
		Street	-1073	285	-788	-16
	Conifer	Park	-519	224	-295	-6
		Street	-519	285	-234	-5
Removed - Current	Broadleaf	Park	1631	13	1644	33
		Street	1631	13	1644	33
	Conifer	Park	828	13	841	17
		Street	828	13	841	17
Remained	Broadleaf	Park	-1479	199	-1280	-26
		Street	-1479	197	-1282	-26
	Conifer	Park	-901	199	-702	-14
		street	-901	197	-704	-14

Table 8 Combined results for life cycle GHG emissions and biogenic carbon sink by tree for scenarios (Planted, Removed, Removed current and Remained) and are grouped by broadleaf and conifer type trees and park and street trees. Here, negative values refer to the carbon sink and positive values to the carbon source.

Conversely, soil composition is the primary determinant of GHG emissions produced during a tree's life cycle, and soil composition is included here in the scenarios of planted and remained trees (Table 8). This report has not compared different compositions of soil, but results showed that the highest emissions occur when peat is used. Thus, the peat fraction in soil composition is important when considering GHG emissions.

The scenario comparison shows that the highest carbon sink is achieved when trees are retained in the area. Tree removal results in the highest emissions; however, these emissions can be partly compensated for by planting new trees. It is important to remember that the figures are generalisations based on several assumptions about Finnish conditions and most typical practices; therefore, applicability is important to assess on a case-by-case basis.

The results in this report were calculated using i-Tree data from Sweden and Finland. The results may apply to a geographically similar region but cannot be generalised as such to, e.g. all Northern European countries. Tree growth depends on local conditions and the tree species used, which vary significantly along the north-south axis as one moves from one vegetation zone to another. Differences were visible when comparing carbon sequestration between Swedish cities, although a thorough statistical comparison was not the aim of this study and, therefore, was not carried out. However, the methods used to calculate the results in this report can be used to carry out calculations at the local level in other countries.

Acknowledgements

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Annex 5: Considerations for defining sustainable forestry in LCA for biogenic carbon

Per Erik Karlsson, Eskil Mattsson, Martin Erlandsson

Summary

Renewable wood from sustainable forests is carbon-neutral, and when utilised in long-lived products in buildings, it creates biogenic carbon storage. This inherent characteristic of wood as a construction material can contribute to climate mitigation efforts. These aspects are not valid for wood from non-sustainable forests. Therefore, a definition of ***sustainable forest*** is needed to be defined in the context of life cycle assessment (LCA) and Environmental Product Declarations (EPD), as the forthcoming climate declaration for all new buildings in the EU as outlined in the new Energy Performance of Building Directive (EPBD) directive.

The proposed definition of sustainable forestry to be used in LCA, EPD, etc., is here suggested to be defined following the classification of forestry as applied in international climate reporting:

Wood from sustainable forests is equal to wood from managed forests on the remaining forest land

Non-sustainable forests are equal to forests with deforestation activities

The life-cycle GWP indicator for building declaration in the EPBD may be complemented with "information on carbon removals associated with the temporary storage of carbon in or on buildings". This information might be reported as elementary carbon, as reported in the EPD for construction products (EN 15804). Nevertheless, in the future, the recommendation is that this biogenic carbon stored in the product and the forest carbon stock changes in relation to different forest management are accounted for in the climate indicator for land-use and land-use change: GWP-luluc. The biogenic carbon stored in Harvested Wood Products (HWP) is accounted for in international climate reporting.

In brief, the suggestion is that the same climate impact in LCA, EPD, and the EPBD life-cycle GWP indicator shall, as the first choice, follow the same methodology as defined in international climate reporting. The indicator should be applied at the landscape level for the entire land of productive forests under the control of the forest owner, not for single forest stands. If this is followed for climate neutrality and carbon removal, including these methodology settings for biogenic carbon in LCA will very likely align with the upcoming EU carbon removal certification framework that will set the rules for climate mitigation actions that can be accounted for as carbon removal.

Introduction

Biobased products originating from sustainably managed forests will ideally be carbon neutral over their life cycle, compared to fossil-based carbon that contributes to an increased concentration of carbon dioxide in the atmosphere. Moreover, if biobased products are used in long-lived products, e.g. in the construction sector, it results in a temporary carbon sink. This effect is accounted for in international climate reporting as Harvest Wood Products (HWP[59]) and its positive climate change mitigation carbon sequestering effect, which is considered by accounting for the net added mass and calculating a half-life.

In the EU, future Carbon Removal Certification[60] aims to scale up carbon removal activities and fight greenwashing. This proposal sets out a voluntary EU-wide framework to certify carbon removals generated in Europe. It sets criteria to define high-quality carbon removals and the process to monitor, report, and verify the authenticity of these removals. The pathways for approved removal and storage of carbon, listed by the EU's framework, include:

- Nature-based solutions, e.g. restoring forests, soils, and innovative farming practices
- Technology, e.g. bioenergy with carbon capture and storage, or direct air carbon capture and storage
- Long-lasting products and materials, e.g. wood-based construction

According to the upcoming climate declaration according to the EPBD directive[61], new buildings with a useful area larger than 1000 m^2 shall report a life cycle GWP indicator from 2028, and all new buildings starting in 2030. A limit value will be introduced in 2030. The directive also states that another indicator result that may be reported is "information on carbon removals associated with the temporary storage of carbon in or on buildings".

Besides this sink effect, when long-lived biobased products are used in society, the forest can also, through different silviculture strategies, contribute to increased carbon storage in the forest or, in a worst-case scenario, reduced net growth and, in the long run, a decrease in the carbon stock. Therefore, accounting for biogenic carbon storage fluxes in the forests and the context of an overall assessment based on a common methodology is also essential.

Biobased products in construction offer a potentially long-term storage of carbon. However, the climate benefits of long-term carbon storage in relation to different forest

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59. IPCC (2019). IPCC Guidelines for National Greenhouse Gas Inventories. Tillgänglig: https://www.ipccnggip.iges.or.jp/public/2019rf/pdf/4_Volume4/19R_V4_Ch12_HarvestedWoodProducts .pdf
60. Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL establishing a Union certification framework for carbon removals. Brussels, 30.11.2022 COM(2022) 672 final.
61. Council of the European Union. Brussels, 14 December 2023. Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the energy performance of buildings (recast) - Analysis of the final compromise text with a view to agreement.

use scenarios need to be clarified regarding land use and land-use change (LULUC). The potential to use different forestry management strategies for different competing combinations of goals and their effect on the forest ecosystem carbon balance should also be part of an assessment of the harvested wood if all significant aspects should be accounted for. The same applies to validating the sustainability of forestry and reducing biodiversity loss.

Sustainability impact assessments of forestry are extremely complex and may include widely different aspects, particularly regarding biodiversity issues. Discussions concerning Nordic forestry are characterised by strong polarisation and conflicts. In the forestry sector, the concept of sustainability has transitioned from a narrow emphasis on sustainable wood production to a broader assessment of climate, environmental, social, and economic sustainability across entire value chains[62].

It is evident that forestry's impact on all aspects of sustainability will not be fully optimised. Consequently, there is a tremendous need for standardising methods and target values to assess sustainability for Nordic forestry in broad dialogue with various stakeholders at the national and international levels. Various aspects of sustainability need to be quantified, compared, and linked to the production of forest resources and their products because there are increasing demands from consumers for environmental performance disclosure for a product. In particular, there are potential conflicts between the aim to increase the carbon sequestration in Nordic forests while promoting the conditions for improved biodiversity.

Managed forests are typically assessed on the landscape scale across a mosaic of forest stands in different states of the rotation cycle and assessed as a dynamic system. Hence, forest management is based on a long-term overall strategy for all available productive forests within the property of the forest owner. Consequently, all forestry in all available productive forest lands should be assessed, not only the specific forest stands from which a specific timber originates[63]. As the forest owner holds the legal responsibility for forest management, the sustainability assessments for forest raw material production should focus on the forest owner's behaviour[64].

In the context of systems analysis, a reference scenario typically aims to assess how the studied "system" influences the aspects of interest. One perspective is that sustainability indicators should help accurately assess the system's impact over time based on the long-term goals one aims to achieve.

The overarching system analytic question asked for in a climate declaration of building is to assess the influence of selecting different technical solutions and their material choices. Thus, this kind of assessment is necessary for the building climate assessment, not covering aspects of optimal use of forestry or alternative uses of biomass.

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62. Karvonen, J., Halder, P., Kangas, J. et al. Indicators and tools for assessing sustainability impacts of the forest bioeconomy. *For. Ecosyst.* **4**, 2 (2017). https://doi.org/10.1186/s40663-017-0089-8
63. Eliasson, P.; Svensson, M.; Olsson, M.; Ågren, G.I. Forest carbon balances at the landscape scale investigated with the Q model and the CoupModel—Responses to intensified harvests. For. Ecol. Manag. 2013, 290, 67–78.
64. Cintas, O.; Berndes, G.; Cowie, A.L.; Egnell, G.; Holmstrom, H.; Ågren, G.I. The climate effect of increased forest bioenergy use in Sweden: Evaluation at different spatial and temporal scales. Wiley Interdiscip. Rev. Energy Environ. 2015, 5, 351–369.

Forestry can be associated with a wide range of sustainability aspects. On a basic level, there are important forestry-based principles, such as that the rates of harvests must not exceed the forest gross growth rates. Besides these basic principles, four important sustainability aspects of forestry may be suggested:

1. Impact on biodiversity
2. Impact on climate change, separated into fossil and biogenic origin
3. Impact on social values, e.g. the recreational values of the forest and reindeer husbandry
4. Impact on the economic values, e.g. national economic values, economic revenues for the forest owner, and job opportunities

However, several more aspects may be considered for forestry, e.g. air pollutant emissions from forestry operations, delay or reversal of recovering surface waters affected by acidification, and the discharge of nitrogen and mercury into surface waters. However, it is also important to emphasise that forestry can contribute positively to the environment, such as providing sources for clean drinking water.

Definitions of sustainable forestry

The most common system analytic tool is a life cycle assessment (LCA); the framework is described in an internationally agreed-upon and commonly used framework (ISO 14044). LCA constitutes a tool to assess ecological sustainability and other dimensions of sustainability need to be covered by other measures and assessment methods if the goal is to account for three pillars of sustainability. The result of an LCA depends on the goal, scope, and settings made by its practitioners. When LCA shall be used for quantifying ecological sustainability from a legal perspective, it is needed to set common goals and scope to match the purpose of the decision support the LCA shall be used for.

In this process, it is noticed that the development of the Environmental Product Declarations (EPD) (ISO 14025) can be reused and constitute the basis for stricter implementation of LCA, where the settings shall guarantee the same assessment result independent of the practitioner who calculates the result. This development will be part of the EU's so-called Digital Product Passport (DPP), which, in future European legislation, will mean all products will have a climate declaration.

Introduction to EPD

In the context of reporting the environmental performance of products so-called Environmental Product Declarations (EPD) are widely used. EPDs are internationally standardised in ISO 21930 and EN 15804 and used for business-to-business and business-to-consumer communication. Compared to a traditional LCA, EPDs are divided into different information modules that can be added to a full life cycle.

In many applications, only the cradle-to-gate data (A1-3) is used from EPD in an LCA calculation; the other information modules are just illustrative examples (i.e. not representative) of what a full life cycle can look like. EPD for construction products is suggested to be mandatory for all products that fall within the forthcoming constructing product regulation (CPR) and in an LCA for new buildings, according to the new Energy Performance Declaration Directive (EPBD) to be launched in 2024. This kind of communication product is based on an attributional LCA, which theoretically allows for aggregating environmental impacts from, e.g. all new buildings based on the LCA result A1-5. The sum will be the same as in national statistics for the building sector if a life cycle approach is used in that statistic.

The current impact assessment of climate impact in EPD used for construction products and buildings (EN 15804 and ISO 15978) is not rigorously scientifically endorsed since the impact assessment of Global Warming Potential (GWP), besides characterisation factors based on radiative forcing integrated over 100 years is also complemented with a life cycle inventory flow of biogenic carbon. This GWP-biogenic indicator accounts for greenhouse gases that arise from biogenic carbon and the carbon stored in the assessed product and its packaging material. However, the general rule says such inherent properties cannot be allocated away. Thus, the 'real GWP indicators' are based on radiative forcing added with the biogenic carbon stored in the product and its packaging, which is reported as a negative CO_2e when sequestrated through photosynthesis and then as a numerical positive emission at the end-of-life (inapproachable if combusted or recovering). This implies that the sum of biogenic carbon in the product and its packaging material shall always be zero when summed over the full life cycle. If not, an error is made in the calculation and needs to be corrected. Altogether, this means the modular approach in EN 15804 is lost, and it is no longer possible with this GWP indicator to compare the contribution to the climate impact module by module, but only if a full life cycle is considered since this biogenic carbon is then balanced out.

EN 15804

The construction industry is a forerunner, leading in publishing EPD; now, almost 20 000 EPDs are valid on the European market. The DPP for construction products will be based on the core product category rules (PCR) EN 15804, which is valid for all construction products. The PCR EN 15804 establishes rules for the direct evaluation of construction products or is a foundation for developing more intricate PCR tailored to specific product categories. Essentially, EN 15804 outlines the procedures for collecting, reporting, verifying, and presenting data for EPDs. It also incorporates the elements of an LCI: guidelines for a life cycle impact assessment (LCIA) and inventories (LCI).

Complementary PCR rules (i.e. a cPCR) for wood and wood-based products are defined in the standard (EN 16485) that complements the core PCR for all construction products and services established in EN 15804. This cPCR for wood is being revised. One important issue to be covered in this cPCR is the definition of the term 'sustainable' in the context of forestry. The basic idea is that renewable material from a non-sustainable forestry will be considered fossil, and the carbon emitted as carbon dioxide will to climate impact (1 kg non-sustainable CO_2 = 1 kg CO_2e).

The suggested standard sent for inquiry (dated June 2023) gives the following specifications on sustainable forest management under 6.3.5.1.1 and instead refers to forestry certification that must be fulfilled to be defined as sustainable; see below (EN 16485: 2023 June):

"Resulting from the fundamental principle of sustainable forest management to preserve the production function of forest[s], total forest carbon pools shall be considered stable (or increasing) under sustainable forest management. This is due to the fact that temporal decreases of forest carbon pools resulting from harvesting on one site are compensated by increases of carbon pools on the other sites, forming together, at the landscape level, the forest area under sustainable forest management.

Effects on forest carbon pools related to the extraction of slash, litter or roots shall not be attributed to the material use of wood and are, therefore, not considered in this document.

NOTE 1 In accordance with European policies, forests are understood as a natural system with multiple functions, the production function of timber being one of them. The existence of forests as natural systems is protected by European and national legislation.

NOTE 2 Harvesting operations lead to temporal decreases in forest carbon pools in the respective stand. Impacts on forest carbon pools resulting from the sustainable or unsustainable management of forests, however, cannot be defined or assessed on [the] stand level but requires the consideration of carbon pool changes on [the] landscape level, i.e. the level based on which management decisions are made.

NOTE 3 It is acknowledged that excessive extraction of slash, litter or roots for the purpose of bioenergy generation can lead to decreases in forest carbon pools. These activities, however, are not causally linked to the extraction of timber for the material use of wood."

Also, specifications concerning the accounting of LULUC can be found in the latest standard:

"GWP-luluc is 0 for countries that have decided to account for Art. 3.4 of the Kyoto Protocol or for wood originating from forests, which are operating under established certification schemes for sustainable forest management."

The cPCR that is in its final stage after the inquiry suggests that a sustainable forest is defined, as in international climate reporting, where each county will classify forests where the harvested wood can be classified as:

Wood from sustainable forests: managed forests on remaining forest land

Wood from non-sustainable forests: forests with deforestation activities

In this draft after the enquiry is the definition of sustainable wood:

"In order to assess whether the wood being used in the defined product system originates sustainably managed forests and/or managed forests on remaining forest land (i.e. land that is categorized as forest in line with REGULATION (EU) 2018/841 and REGULATION (EU) 2023/839) and/or IPCC (2019 Refinement to the 2006 IPCC Guidelines for National

Greenhouse Gas Inventories, Chapter 4: Forest Land), two alternative verification options can be chosen:

- by checking the share of the land use category of the respective country and/or countries of origin for the raw wood material used in the construction product. The country and/or countries of origin shall be determined during the data collection as set out in 6.4.1.
- by chain of custody certification demonstrating that the used wood feedstock originates from relevant forest certification schemes for sustainable forest management, whereby the proportion of wood certified as sourced from sustainably managed and certified forests must be at least 95%."

It is also noticed that in this version, the soil carbon is unaccounted for: "Effects on the forest carbon pools below-ground biomass (roots), litter (related to the extraction of slash) or dead wood shall not be attributed to the material use of wood and are, therefore, not considered in this document." It should be noted that the final cPCR text is not known when this paper is published, thus describing the state of discussion.

To understand the importance of this system boundary for a tropical forest, we have calculated for the forest land GHG balance for a major pulp and paper factory in Indonesia. The factory used timber from acacia plantations on mineral and peat soils and set aside forests for conservation purposes. The calculated GHG balance describes the consequences before and after the company took responsibility for the forestry land.

The GHG emissions from plantations on peatland are very high – up to 60 t CO_2e/ ha/ yr. This did not include GHG emissions from the transfer to the plantation, which involved ditching of the land, among other things. In comparison, GHG emissions from Swedish forests on drained peatland in southern Sweden can be estimated to 5–16 tonnes CO_2e / ha/ yr.

One might question why LCA for harvested woods fails to consider forests' contribution to climate change mitigation through carbon sequestration from different management intensity strategies.

FSC and PEFC

Two important systems for certifying sustainable forestry in Sweden are the Forest Stewardship Standard of Sweden (FSC) and the Programme for the Endorsement of Forest Certification (PEFC). The FSC was developed by international environmental movements while the PEFC was originally developed within the family-owned forest sector.

The FSC and PEFC focus on the performance of the forest owner and the management of the total area of productive forest.

The FSC was first published in 1998; the most recent revision was published in January 2020. Certified forest owners have their own certificate or are certified through a group entity. The whole area of the management unit, including wetlands and small water bodies, is included in the certified area. The requirements can differ depending on the size of the landholding.

The FSC has numerous overarching principles:

PRINCIPLE 1: COMPLIANCE WITH LAWS

PRINCIPLE 2: WORKERS' RIGHTS AND EMPLOYMENT CONDITIONS

PRINCIPLE 3: INDIGENOUS PEOPLES' RIGHTS

PRINCIPLE 4: COMMUNITY RELATIONS

PRINCIPLE 5: BENEFITS FROM THE FOREST

These principles focus mainly on social and economic values and deal with basic forestry principles, such as keeping harvest products from the management unit at or below a level that can be permanently sustained.

PRINCIPLE 6: ENVIRONMENTAL VALUES AND IMPACTS

This principle states that the forest owner shall maintain, conserve, and/or restore ecosystem services and environmental values of the management unit and shall avoid, repair, or mitigate negative environmental impacts. Examples of the most important criteria under this principle are that Woodland Key Habitats are exempt from all management activities other than the management required to maintain or promote natural biodiversity. It should be mentioned that the registration of Woodland Key Habitats by the Swedish Forest Agency is controversial and has been intensively debated and subject to legal conflicts.

Furthermore, a selection of the productive forest land area, covering a minimum of 5% of the productive forest land area, has to be set aside and exempt from measures other than management to maintain and promote natural biodiversity or biodiversity conditioned by traditional land use practices. Moreover, at least 5% of the productive forest land area has to be managed with long-term protection and enhancement of conservation and/or social values as the primary objective. Hence, the set-aside areas comprise at least 10% of the productive forest land area.

Several more restrictions apply to forest management operations, e.g. harvesting, protecting surface waters, ditching of wetlands, etc. Furthermore, the forest owner may not convert natural forests to plantations. The definition of plantations is similar to that of Norway spruce forests on former agricultural land in southern Sweden.

There are more principles, 7–10, which are not described here.

The PEFC was formed in 1998 because small-scale family forest owners, mainly in Finland, Germany, France, Norway, Austria, and Sweden, together with some industry partners, did not approve some of the criteria in the FSC. Generally, the PEFC is organised similarly to the FSC, but the PEFC has somewhat less strict regulations than the FSC. For instance, the FSC has a criterion that 10% of the forest owner's productive forest area should be set aside for purposes other than wood production based on clear-cut forestry, while the PEFC requires only 5%.

GHG inventories

Forests play a vital role in the climate change abatement strategies. On the global scale, forests represent a sink for approximately a quarter of the total GHG emissions. Forest carbon sequestration also has a critical role in the EU climate change abatement strategies, which is expressed in the EU directive on land use, land-use change, and forestry (LULUCF) directive[65].

GHG inventories generally do not include general forestry sustainability assessments. However, for reporting the LULUCF sector, the EU has stated that each country has to report a Forest Reference Level (FRL) for reporting GHG sources/sinks for the activity Managed Forests. The FRL shall be based on the continuation of sustainable forest management practices. Each member state has to submit a national forestry accounting plan that describes how the different EU countries aim to maintain sustainable forestry to mitigate climate change, represented by the FRL. Hence, the national forestry accounting plans, at least partially, describe each country's forestry sustainability policy.

The Swedish GHG inventory for the land use sector, LULUCF, is described in Figure 1 below.

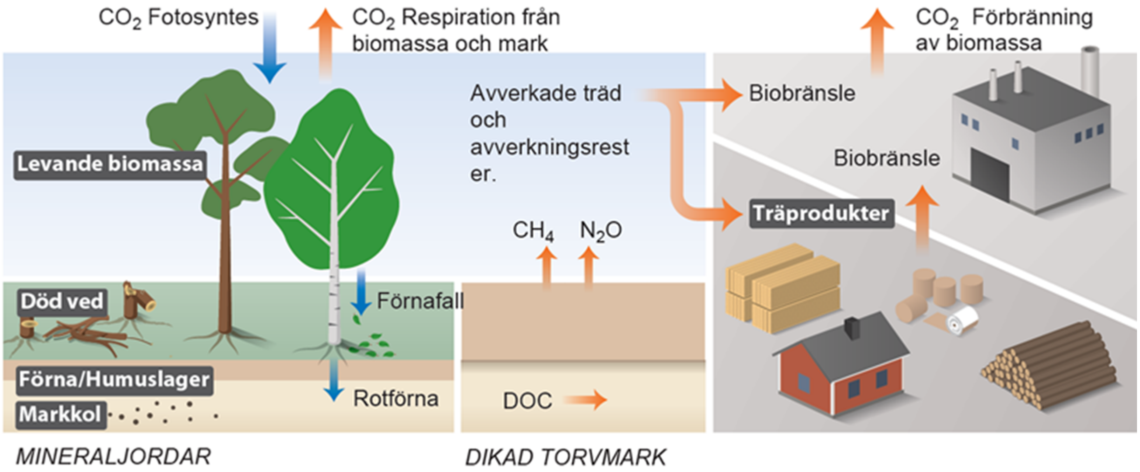

Figure 1 An illustration of the Swedish GHG inventory principles for the land use sector, LULUCF[66]. Biogenic emissions from the combustion of biomass are not included in the Swedish territorial GHG balance. However, the yearly balance of harvested wood products (HWP, "träprodukter") is included, even if these products are exported.

The annual sink of CO_2 in the Swedish land use sector was estimated to be 35 M tonne CO_2e for 2019. The total annual emissions from all other sectors in Sweden in the same

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[65] EU, 2018. REGULATION (EU) 2018/841 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 30 May 2018 on the inclusion of greenhouse gas emissions and removals from land use, land-use change and forestry in the 2030 climate and energy framework, and amending Regulation (EU) No 525/2013 and Decision No 529/2013/EU.

[66] Karlsson, P.E., Lundblad, M., Josefsson Ortiz, C., Wikberg, P.-E., Gustafsson, T. 2023. Kartläggning av inhemska biogena koldioxidutsläpp i Sverige. SMED Rapport Nr 3 2023.

year were 51 M tonnes of CO_2e (Naturvårdsverket, 2021). The dominant sink in the Swedish LULUCF sector was the "forest land remaining forest land", with the main sink in the living biomass carbon stocks. The main reason is that the total gross growth in Swedish forests consistently exceeds the total yearly removals.

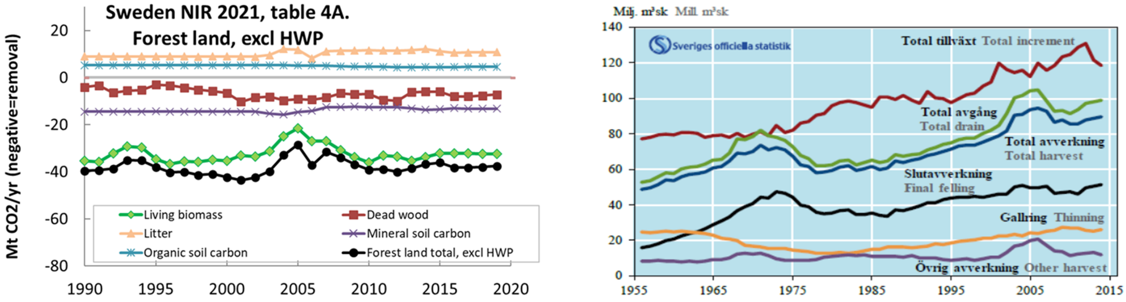

Figure 2 A, Yearly balance of GHG in different parts of the Swedish forest ecosystems in Sweden, "forest land remaining forest land", until 2019. Negative values represent the removal of GHG from the atmosphere to the forest. Source: "National Inventory Report" (NIR), Swedish submission to the climate convention. B, Yearly gross growth (including the growth of harvested trees in the same year), yearly harvests, and yearly natural removals for the total Swedish forests 1956–2014. Formally protected forests are not included. Running 5-year mean values. Source: Skogsdata, 2018. SLU, Institutionen för skoglig resurshushållning.

Workshop

General information

In the context of WP1 in the project 'Nordic Harmonization of Life Cycle Assessment', an online expert consultation workshop on considerations for defining sustainable forestry was held on Thursday, January 18th, 2024. The workshop aimed to gather essential viewpoints that need to be considered in defining sustainable forestry, particularly regarding the LCA rules for biogenic carbon.

Agenda of the workshop

1. Welcome, practicalities, and tour de table
2. Introduction to the project
3. Why and how information on sustainable forestry is needed in LCA rules for biogenic carbon
4. Definition of sustainable forestry in EN15804
5. Definition of sustainable forestry in FSC and PEFC certification
6. Definition of sustainable forestry in GHG inventories
7. Discussion with the following lead questions:

- What are the essential viewpoints in defining sustainable forestry in LCA in construction works?
- Which existing definitions of sustainable forestry are applicable/relevant for biogenic carbon LCA, and which are not?
- Should biodiversity be included in the sustainable forestry definition for biogenic carbon LCA? If yes, how?
- Should the leaching of nutrients and solid matter into water bodies be included in the sustainable forestry definition for biogenic carbon LCA? If yes, how?
- How should the biogenic carbon flows in forestry be accounted? Is (mineral and organic) soil carbon included, and how?
- What are reasonable data requirement demands for biogenic carbon LCA? What do the suggested requirements mean for the forest owners?

8. Closing of the workshop.

Presentations

Janne Pesu, Finnish Environment Institute, SYKE introduced the project's overall objective and workstreams. Pesu explained that the work supports Nordic common understanding and harmonisation of LCA data, including generic databases.

Martin Erlandsson, IVL Swedish Environmental Research Institute, continued to explain different approaches to measuring climate benefits of wood construction and why and how information on sustainable forestry is needed in LCA rules for biogenic carbon.

Questions emerged after his presentation, as there is no common understanding of how GHG inventory should be carried out in LCA regarding biogenic carbon. Also, different LCA standards provide different guidance. A key issue is how the reference land use is defined and how this relates to the question we would like to respond to, which is related to the temporal scope of the system.

Martin Erlandsson, IVL Swedish Environmental Research Institute, further elaborated on various approaches to accounting for sustainable forestry in relation to EN15804. In short, a native forest can be considered equal to fossil emissions.

In the ensuing discussion, the issue of a reference system was raised. For example, if a reference system is not applied, then the coherent application of an LCA is limited. For example, comparing wooden and non-wooden systems does not provide useful information without applying a reference system, which makes sense. A key question is for which purposes do we use an LCA based on in "absolute GHG emissions and removals"? The current praxis is too simplified, and the potential to improve it could be to include a more sophisticated approach in the new product category rules for wood-based products prEN16485.

Per Erik Karlsson, IVL Swedish Environmental Research Institute gave a presentation on the definition of sustainable forestry in FSC and PEFC certification.

In the following Q&A session, it was raised that certification is voluntary and market-based. Also, the fact that the forest sink in Finland and Sweden has decreased over the last years with regional differences due to declining growth in the forest and the high levels of logging in recent years was discussed, which have implications for baselines (there can be many). A European standard for the sustainability of construction works is proposed on how to handle mass balances and change of custody, such as mixed products (CEN/TC 350). This might also affect how forest certifications can be used in LCA assessment.

Sampo Pihlainen, Finnish Environment Institute, SYKE, presented how sustainable forestry is defined in EU Taxonomy, which is referred to in his presentation on the EU Taxonomy guide – a simple and practical guide for users; see https://ec.europa.eu/sustainable-finance-taxonomy/home. From forest management in a climate change mitigation aspect, Sampo focused his presentation on the substantial contribution criteria.

After the presentation, similarities between EU Taxonomy and the EU Carbon Removal Certification Framework (CRCF) were mentioned. It was argued that these initiatives must be coordinated in some way, as there are two criteria for the same carbon sink. EU Taxonomy has a wider scope, as the CRCF strongly focuses on carbon removal and has no effect on other environmental factors. It is debated whether one could use regional baselines, as CRCF is based on agriculture. Hence, one must model the carbon because most of the carbon is in the soil. Many are concerned about using regional baselines because there will be winners and losers. In forestry, most carbon is accumulated in the living biomass and is more straightforward to measure. In this case, sustainability must be compared to something – to the surrounding areas or the activity itself. Someone also emphasised that the taxonomy criteria are defined in political processes, not on scientific evidence.

Workshop discussion

After the presentations, the lead questions above were discussed. These discussions were categorised into the topics (sub-headings) below.

Purposes and scales

The purposes for which we use LCA results are important to consider. We should always clarify who should use these results and for what. The goal and scope are key but are overlooked in many cases. We influence carbon stocks if we use a lot of material; if we want to use biomass, we could use that to study those consequences and, in that case, monitor the consequences closely whether they are from sustainable forests (editor's comment, see purpose with LCA here given in heading "Introduction").

Furthermore, when using building products, there are agreed-upon limitations on what we consider sustainable forestry. We need to look holistically at raw material sustainability, and the criteria we should set are important for all segments.

Emphasis was placed on the notion that this is a challenging topic. For example, the time aspect will greatly impact the result. Forestry is planned with a time horizon of several decades, which means the assessment periods must also cover several decades. Also, the increasing/decreasing carbon stock depends on the area. Our results could differ In the landscape from those of northern and southern Sweden. Should we look at a country as a whole? Substitution affects what we think, as long-lived products today might change someday and how long they exist in the system.

Definition of sustainable forestry in relation to an LCA

The question of whether the definition of sustainable forest management (SFM) is necessary in an LCA was also posed. An LCA should support climate mitigation; in that sense, the reference situation is important. Also, one could argue that we need a definition of SFM to determine whether a building is carbon neutral if the materials were taken from sustainably managed forests. Simply, if we are considering temporary storage in a building, we should also measure its impact in the forest; however, measuring carbon in the forest (averages could be formulated) is difficult. Many uncertainties exist at the building level. Can we improve the system? For example, we must now justify renewables as they are counted as zero. Discounting ideas were suggested to be easy to grasp in relation to an LCA. Also, in principle, SFM entails harvesting less than the growth, but this cannot be sustained indefinitely and is a factor to consider. Many countries in Europe have already become saturated with living biomass.

Fairness could also be considered. How is sustainability defined? The terminology of sustainability is sometimes confusing. What implications would arise from the absence of this dichotomy between sustainable and non-sustainable? Someone argued that we should stick with carbon to avoid complexity. Other instruments and certification systems could be used to account for other environmental pressures.

Accounting for other sustainability impacts and materials

If we want to use more wood for construction, that will be a conflict with biodiversity, which we will have to deal with. Otherwise, a large part of the sustainability criteria will be lost. Sustainability implies a broader implication than just carbon. You can deal with sustainability in different ways, e.g. measuring or considering do no significant harm (DNSH) principles for example. New indicators for biodiversity are being developed but will not be included for now as input data are mainly based on land use management for agriculture. New biodiversity indicators should be tested and accounted for as they are being developed.

It was also observed that materials other than wood have an environmental impact in relation to an LCA for construction works. Forest owners and authorities should be included this discussion. The position of wood construction will change when other energy sources of hydrogen increase. Emissions from forestry biomass will be less of an issue then. The industry is looking at practical solutions. Here, more research is needed on climate's impact on biobased products and other materials.

Another participant emphasised the importance of determining why we intend to use the methodologies. If they are for policymaking, simplification is necessary when implementing them.

Views regarding carbon measurements across scales

It was proposed that a development stock change in the forest and the building should be included in the inventory. Some say it is too complicated to measure, but have we tried calculating it this way?

One participant clarified that many desire to attribute the carbon in the forest to their credit, e.g. the landowner. One can only account for the carbon sinks once, and once one has attributed the carbon to the landowner, one cannot take these benefits into the building. In many cases, carbon removal is also attributed to an organisation, but how could it be attributed to a product? That is an open question. Once again, understanding the intended use of an LCA is crucial. Clarity regarding the context is essential to achieve the desired impact. We should also consider the risk of double accounting. When the forest owner sells his or her timber, he or she should sell a certificate of the carbon with a similar methodology for other environmental factors.

Who owns the carbon? Distributing the carbon stock change, starting with the forestry, is needed to sort out the degree of the carbon balance of a proper system there, continuing with the storage downstream of the value chain. If one has a net growth, some of the carbon can stay within the forest domain and have a certain value. If it continues to be a product, it has a certain market value that needs to be calculated in an LCA. If an LCA reveals a carbon sink element in the building's construction, safer storage could be outside the forest. Results can be used to develop a product's value chain without a carbon footprint. This should also connect to the EU carbon removal certification framework (CRCF) process. These processes could help each other.

Suggestion for a new method

Forestry assessment in an EPD as an additional indicator

Assessing the degree of sustainable forest is needed when only a climate declaration is requested. Traditionally, an LCA accounts for ecological sustainability but not a social or economic assessment. Moreover, a current LCA does not cover all impact categories or include biodiversity. EPD can include other information not based on an LCA to handle the other dimensions of sustainability as a complement to the LCA result. No system analytics-based indicator quantitatively established accounts for all dimensions of sustainability. In the climate declaration of buildings, the primary focus naturally revolves around the GWP indicator. The fact is that decision support for climate mitigation is the most important aspect to account for and address in a climate declaration for forestry and wood-based products.

Climate neutrality is not the same as carbon neutrality since forestry can affect the climate in several ways besides impacting the carbon balance. Such impacts involve, in particular, the forest balance of other important greenhouse gases, e.g. methane and N_2O. In addition, the emission of organic compounds from the forest may induce the formation of particles in the atmosphere, which has important climate impacts.

There is a data gap in the current LCA methodology described above. An alternative approach is described here and its first development step. This approach is basically the same as described in Karlsson et al. (2023)[67], with the result being recalculated per m^3 harvested wood. An extended approach (based on the current methodology setting in this report) can be added later once there is greater clarity on how the EU carbon removal certification framework system will be operationalised and how biogenic carbon sinks will be handled. It should be noted that the scope of that system will likely be business-oriented, and how this certificate shall be handled on a product level will likely need to be defined outside the system as such.

A basic starting point to assess an individual forestry owner position(s) and its management is to consider the yearly net balance of harvested wood, gross forest growth, and soil carbon change. If this ratio is calculated, a figure equal to 1 means forestry management where there is a carbon balance, if larger than 1, an increase in bio stock, and the reverse if less than 1; see Figure 3 to get an illustrative example of what it could look like on a landscape level.

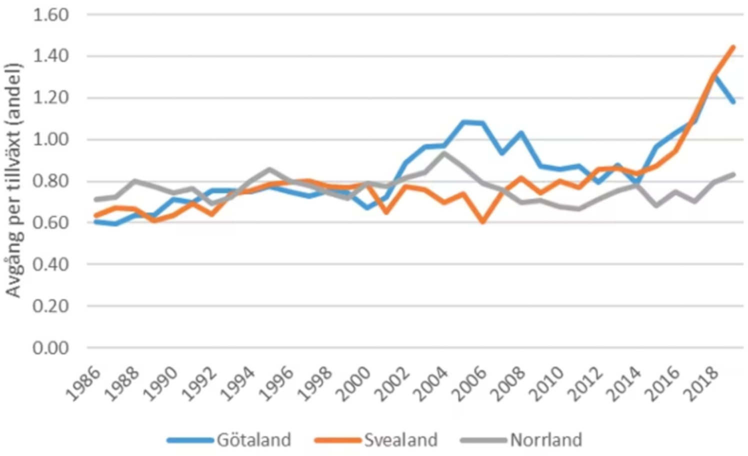

Figure 3 Harvested volume and mortality divided by data from the National Forest Assessment. Götaland and Svealand account for two-thirds of the entire annual felling in Sweden.
(Ref: /www.aftonbladet.se/debatt/a/gEMxO5/forskare-avverkning-och-skogsdod-ar-storre-an-tillvaxten)

This approach can be directly adopted in LCA and EPD, where the biogenic carbon stock loss of 10% results in a GWP-luluc of 0.1 kg CO_2e per kg biogenic carbon stored in the harvested wood. An extreme is a native forest that is the final cut, where the GWP-luluc will then be 1 kg CO_2e per kg biogenic carbon stored in the harvested wood. In a well-managed forest, the reverse will be the case with a net increase in the forest ecosystem carbon stocks, and the GWP-luluc will result in a numerical negative number, which, in this context, shall be evaluated as a positive climate aspect and increased net carbon storage.

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[67] Karlsson P E, Erlandsson M, Mattsson E, Nilsson Å :Klimatpåverkan från skogsbruk inom Sveaskogs produktiva skogsmark. Biogen och fossil påverkan (komplement). IVL Svenska Miljöinsitutet på uppdrag av Mistra Digital Forest, IVL rapport C 741, Jan 2023.

Since the evaluation is made yearly, the running balance is always correct from a bookkeeping perspective. A purchaser of wood can compensate for wood from non-balanced forestry with forestry with a surplus. In the long run, a relationship between the yearly carbon stock attributed to the harvested wood and the CE certification scheme is needed. Since this system is not in force, we can start using such indicator as it is and then make the needed additions and adoptions when the EC certification system is launched. Note that the system is operational for a large forestry owner or when different smaller forestry owners cooperate and can be assessed as a group. The approach described here must be further elaborated on if it is valid for small forestry owners or alternatively, the regional figures that are ready to use for small forestry owners.

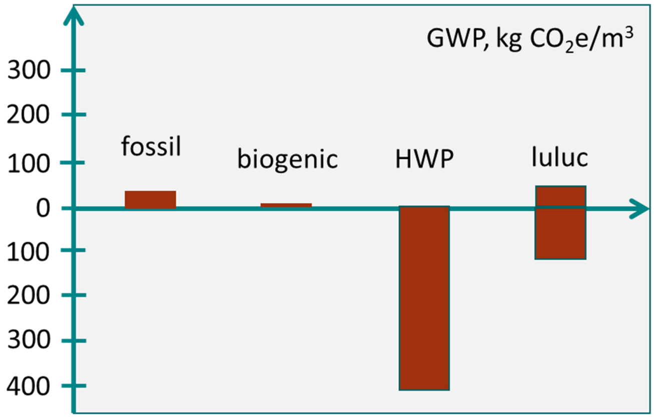

Figure 4 Conceptual illustration of all parts of the expanded GWP indicators suggested here exemplified for planed boards, divided in fossil, biogenic excluding stored in the product, HWP and luluc for sawn boards

The GWP-fossil in Figure 4 represents 1 m^3 planed boards that are about 35 kg CO_2e/m^3. The GWP indicators suggested here are based on EN 15804, with the difference being that if biogenic carbon stored in the product is from a sustainable forest, GWP-biogenic is directly balanced out (set to zero), and the emissions of methane, etc., from the manufacturing of the planed wood is the only GHG accounted for. HWP follows the approach of calculating HWP as used in LFM30 (Erlandsson, 2020), where 1 kg of biogenic CO2 stored equals 0.5 kg CO_2e. The indicator results for GWP luluc is not set to zero as in EN 15805 but is divided into two components:

1. net biogenic carbon balance valid for the year the wood was harvested
2. other luluc emission, e.g. from soil carbon

If the biogenic carbon in the wood does not originate from sustainable forests, pEN 16485 suggests that this carbon, when emitted, will be accounted for in GWP-biogenic calculation (and 1 kg CO2 emitted is then equal to 1 kg CO_2e).

Annex 6: Data for old buildings

Sirje Vares, Jarmo Linjama, Janne Pesu

Introduction

The current focus of building LCA regulation is very much on new buildings, and no country has proposed limit values for renovating existing buildings.

If renovation would require a climate declaration for a building permit, the deconstruction phase would need to be assessed to evaluate the deconstruction, transport, waste management, and disposal of the to-be-removed material. Current construction processes and tools enable good knowledge of the material composition of new buildings, but little data exists on the material content of old buildings.

Our building stock volume, which grows annually through new construction, is very limited. According to Eurostat, 85% of buildings in the EU were built before 2000. It is estimated that 85%–95% of the buildings today will still exist in 2050, and as 75% of buildings are energy inefficient, Member States should set continuous targets and plans for building renovations. Otherwise, fully decarbonising EU building stock by 2050 would be impossible (EC 2021/0426 [COD]).

Renovations and refurbishments will improve the functionality of existing buildings and align them with current requirements. However, this does not apply to all types of buildings. Depending on the building's condition, demolition may be the best economic and environmental option. In Western countries, buildings are largely assumed to be in good condition, but Estonia, for example, has many Soviet-era buildings whose condition is questionable for refurbishment.

Deciding on demolition or refurbishment requires assessing the building's condition in advance. In the case of new construction and renovation projects, conducting preliminary CO2 calculation is often necessary to choose the best solution according to the climate impacts or compare proposed solutions. Calculations could be performed, although future construction or a renovation project is not properly designed yet, and there is very little information about the specific case.

In renovations, much can be predicted about the case beforehand; however, the assessment should be based on data or knowledge of historical structures and common practices in the past. An LCA calculation could be performed by using structure types typical for each era (archetypes). A material declaration helps make assessments for renovation (and refurbishment), decide what material will be removed, and choose the best solution for their treatment and utilisation.

The management, renovation, and refurbishment of the building stock will improve our residents' quality of life, reduce the energy consumption of buildings, and, in the long run, lower the buildings' environmental impact, but all these activities are having an impact now. Because renovation processes generate much demolition waste, treating demolition materials consumes energy in the dismantling, transporting, treating, landfilling, and even the treatment of utilising demolition materials; all these processes detrimentally impact our environment.

Construction and renovation activities need new materials to replace demolished building parts, and demolished materials turn into waste. It is estimated that of the total waste generated in the EU, up to 32% of that is construction and demolition waste, consisting mainly of inert materials, e.g. bricks, tiles, asphalt, and concrete (> 50%), wood, plastics, and metals (EEA 2012, Figure 3.2). Every demolished structure would require at least as much as was used but usually needs more materials to maintain and improve the quality of buildings, but very often, renovation projects consider expanding the initial construction volume into additional spaces.

Buildings that are relatively new have been built according to the BIM-based design[68], but as the building stock is much older than the BIM-based design, much information about existing buildings is in physical documents or drawings or have been lost.

All information about our old historical buildings, their structure, and their material types promotes organising better waste management and use of materials through material circulation. The information also helps renovation projects compile their work in an environmentally friendly way by enabling environmental calculations for climate- and material declarations. However, knowing the types of structures and the distribution of materials in an existing historical building does not yet tell us about their condition nor directly help us make decisions regarding renovation or demolition. The condition of materials should be assessed using a scenario-based ageing method, and the cost and environmental profitability of the operation should be assessed by comparing life cycle costs and environmental impacts.

Discussion and definition of data needs and use cases

Data sources for old/existing buildings

A building is a separate structure, permanently constructed or erected in its location, with its own entrance, containing covered space intended for different functions and usually bounded by external walls or walls separating it from other structures (buildings) (according to Building classification in Finland)[69].

Buildings are classified according to their general purpose, e.g. residential and non-residential buildings. Classification is organised according to main building categories, which contain subclasses. When part of the building has a different purpose, a building is

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[68] BIM - Building Information Modelling, creating, and managing information for a built asset using an intelligent model.

[69] Luokitukset | Rakennusluokitus 2018 | Tilastokeskus (stat.fi)

classified into the class where most of the building is used. However, building categories might be classified differently in different countries.

Some data on old/existing buildings can be collected from centralised databases (e.g. National Statistics or from the building cadastre). Statistics Finland provides building stock-related data in two separate databases:

- A building and dwelling production database contains monthly or quarterly data about building permits by volume, floor area, and dwelling number.
- A building and free-time residences database has building stock data according to the building classifications based on the main use purpose. Data that can be retrieved freely is gross m^2, m^3, and the number of buildings in stock by year of construction. Regarding the building materials, statistics are compiled on the material types and quantities of façade- and load-bearing materials, but this information is not freely available.

Another source for collecting information about existing buildings is 'Building and Dwelling Register'[70]:

- building register related to the single building location, construction year, building size (gross- m^2., number of storeys), construction and facade material, method for heating, number of apartments, residents, etc.
- dwelling register related to the floor area, tenure status, number and purpose of rooms and spaces (living room, sauna, balcony, etc.), type of kitchen, number of inhabitants, etc.

As these building and dwelling statistics are intended for the statistics of population and housing[71], these data sources are insufficient for the building stock and material content assessment for the LCA. Thus, other sources of information would be needed.

In Denmark, the publicly available building stock register (BBR) compiles extensive information on buildings, including their location, size (footprint, floor area, number of floors, etc.), type of use, roof and facade material, construction, latest renovation years, etc.

Sweden does not have a centralised public database; instead, building information is collected and managed primarily at the municipal level.

In assessing existing buildings, the source of the building data could be generic or actual:

- generic data is based on the typical building type and its typical components and materials (This case is based on very wide generalisations, making it vulnerable to wrong mapping).
- data about actual products and components based on the measurements from the

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[70] Statistics Finland: Statistical databases | Statistics Finland (tilastokeskus.fi); Statistics Denmark: www.dst.dk; Statistics Norway: StatBank Norway – SSB; Statistics Sweden: www.scb.se; Statistics Estonia Home | Statistikaamet; Eurostat: Home - Eurostat (europa.eu)

[71] Building Stock Register (In Danish): www.bbr.dk; Building Stock Register, Finland: Real estate, building, and spatial information | Digital and population data services agency (dvv.fi)

design documents, drawings, specifications, CAD/BIMs, and materials used in construction (as built Wmodel) (This is the most desirable and correct case; however, this is only possible for a few newer building cases).

Existing buildings with BIM based-design

In existing buildings where construction has been carried out based on BIM design, building size, structural solutions, and material types can be found in digital documents – in the 'as-built model'. This is the best information for calculating the types of materials and their actual weights at the building level.

Existing buildings without BIMs (older, historical buildings)

The only data source for existing buildings without a BIM-based design is the "Building and Dwelling Register". This source also gives information only on the building level but estimates about structural solutions, material types, and the quantities required. Such information must be sought from various sources, e.g. building history books, statistics, publications presenting building solutions, etc.

Historical buildings are built in different eras and consist of different building types; they have typical architectural solutions and historical structures. Typical buildings in the Nordic countries have some similarities but still many differences. There is rarely a detailed material description of those old buildings on a building stock level, so a library of typical structural solutions (archetypes) of old buildings would be very useful.

In Denmark, danskbyggeskik.dk has a multi-storey building library with historical architectural structures. This 3D library applies to the building construction period from 1850 to 2000. Similar solutions would also be needed for existing/old buildings in other Nordic countries.

Use case: Material declaration

A material declaration provides information on the building's components, the materials used, and the origin of the materials. Such material declaration was drafted for Finnish regulation, but it has later been replaced by a construction product listing. None of the Nordic countries has current regulations on material declaration.

It is assumed that, for the most part, the material description would be created the same way the data would be collected to prepare a climate declaration on the building. Even so, as this material declaration is meant for new construction, it could be produced retroactively, e.g. for renovation and refurbishment projects.

Calculating material weights could be performed using typical building types and their typical structure types (archetypes) according to the construction era.

As an example of structure types, Finnish Construction 2000 classification system (Talo 2000) includes three major building element classes: site, building, and internal space (infilling) (Table 1). The base of this classification is to support BIM-based design, cost estimation, production planning, and control[72].

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72. Finnish construction 2000 classification system (Talo, 2000) The_Finnish_Construction_2000_classification_system.pdf (rakennustieto.fi).

Class	Building element	Justification
Site elements	1.1.1 Ground elements	A significant mass fraction where many recycled materials can be used.
	1.1.2 Soil stabilisation and reinforced elements	A significant site element concerning the impact of climate change.
	1.1.3 Paved and green area	Area coatings, which are known at the design stage (with the necessary accuracy).
	1.1.3.4 Vegetation	Trees to be planted are included because of their impact on carbon sinks and biodiversity.
	1.1.5 Site construction	The technical service life of yard storage or canopies may be shorter than that of the main building. Cataloguing helps later use of materials.
Building elements	1.2.1 Foundation	A mass-significant group that usually causes the highest product-specific environmental and climate impacts. Construction planning covers these elements. Building elements and materials, which are removed from the deconstruction phase, form a base for further utilisation.
	1.2.2 Ground floor	
	1.2.3 Structural frame	
	1.2.4 Facades	
	1.2.5 External decks	
	1.2.6 Roof	
Internal space elements (infill)	1.3.1 Internal dividers	An important component for the building's operation. The materials are usually specified when applying for a permit.
	1.3.2 Space surfaces	A wear-prone part whose materials may be changed several times during a building's lifetime. Cataloguing enables planning for utilisation.
	1.3.3 Internal fixtures	Frequently replaced parts. Cataloguing enables utilisation planning.
	1.3.4.2 Flues and fireplaces	The element necessary for the building's technical operation. Flues can be significant in weight or contain many usable materials.
	1.3.5 Space unit	May contain a wide variety of materials – an essential part of the recovery design.

Table 1 Building structures according to Finnish Construction 2000 classification (Talo, 2000).

Classification of materials and their origin

The EU's LCA calculation method level(s) proposes material type classes for materials used in construction. Building material types in level(s):

- Concrete, brick, tile, natural stone, ceramic
- Wood
- Glass
- Plastic
- Bituminous mixtures
- Metals
- Insulation materials

- Gypsum
- Mixed
- Electrical and Electronic Equipment

The ‘Material declaration’ can ensure a reliable and harmonised compilation of statistics on building materials, thus creating a uniform basis for assessing the low-carbon performance of buildings.

Since half the raw materials used annually are used in construction, monitoring the total amount of materials and their origin may impact the resource efficiency of construction through an information effect. From the perspective of the sustainable use of natural resources, the resource efficiency of buildings can help curb the consumption of building materials.

EXAMPLE: Utilisation of archetypes in material declaration

In this example, material consumption has been calculated for an external wall structure used in multi-storey residential buildings about 20 years ago (2000). This wall solution has a concrete inner shell as the load-bearing layer and façade, either a concrete layer or brick structure. In both options, glass wool 50+150 mm was used as thermal insulation (MSR 2000 US concrete and MSR 2000 US concrete + brick) (*Table 2*).

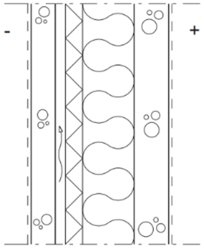
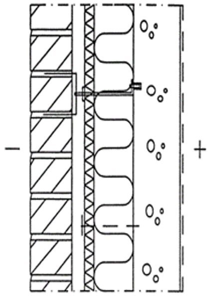
	Structure layer (from outside to inside)	Layer thickness, mm	Material density, kg/m^3	Material weight, kg/ m^2
MSB, concrete 2000				
	External concrete wall	80	2400	192
	Air gap	30		0
	Glass wool wind protection	50	80	4,0
	Glass wool insulation	150	20	3,0
	Load-bearing concrete	100	2400	240
	Steel content in concrete reinforcement			7,6
SUM		**410**		**447**
MSB, concrete + brick, 2000				
	Clay brick	130		147
	Mortar			71
	Air gap	30		
	Mineral wool wind protection (glass wool)	50	80	4,0
	Mineral wool insulation (glass wool)	150	20	3,0
	Load-bearing internal concrete	100	2400	240
	Estimated steel content			4,5
SUM		**460**		**470**

Table 2 An example of weight calculation for a concrete wall archetype (a structure from a building built approximately 20 years ago).

Based on this result, the material intensity is 447 kg/wall-m^2 and 470 kg/wall-m^2 for the external wall structures under consideration.

For example, in an apartment building with a floor area of 1850 m^2 and an external wall area of 900 m^2, the material intensity of the wall structure per floor area of the building is respectively (900 x 447)/1850 = 218 kg/m^2 and (900x470)/1850=229 kg/m^2.

All parts used in construction can be assembled by continuing the calculation in the same way for other structural elements. When a library of historical structural solutions already exists, it can be used to calculate different types of houses, where, for example, several façade solutions were used, while house-specific comparisons of houses built in different eras can be made based on material content.

Historical building archetypes could also be used to report material sources (Table 3).

	Concrete, bricks, ceramic, natural stone	Steel	Insulation materials	Non-renewable source	Recycled source
Concrete wall archetype					
External concrete wall	192 (44 %)			192 (43 %)	
Mineral wool, wind protection			4,0 (57 %)	2 (0,5 %)	2 (18 %)
Mineral wool, insulation			3,0 (43 %)	1,5 (0,3 %)	1,5 (14 %)
Load-bearing concrete, internal	240 (56 %)			240 (54 %)	
Seel content estimation		7,6 (100 %)		7,6 (2 %)	7,6 (68%)
Data for material declarations	**432**	**7,6**	**7**	**443**	**11,1**
Concrete wall archetype, wall with brick facade					
Clay brick	147 (32 %)			147 (32 %)	
Mortar	71 (16 %)			71 (15 %)	
Mineral wool wind protection (glass wool)			4 (57 %)		2 (25 %)
Mineral wool insulation (glass wool)			3,0 (43 %)		1,5 (19 %)
Load-bearing internal concrete	240 (52 %)			240 (52 %)	
Estimated steel content		4,5 (100 %)		4,5 (1 %)	4,5 (56 %)
Data for material declarations	**458**	**4,5**	**7**	**463**	**8**

Table 3 An example of a wall structure archetype and use of material weights in material declaration (a structure from the building built approximately 20 years ago).

An assessment of the material types and their quantities may help determine the impact of different spatial planning strategies on the consumption of building materials, demolition waste generation, and related environmental impacts at different territorial levels.

These inventories can also help estimate materials stored in cities, sub-regions, or individual buildings, which can serve as secondary sources of building materials in the circular economy of the future. Such information can be important for public decision-makers as well as circular economy companies, e.g. demolition companies and manufacturers of construction products.

Use case: Building renovation/refurbishment

Renovation is the action that changes previously built construction in the desired direction. Some of the objectives set for renovating structures are quite concrete. For example, the desired U-value can be defined for a new façade, new windows, or roof. Conversely, specifying only desired appearance requirements for maintenance, which is included in the predicted renovation works, is possible.

Renovations can be classified according to the quality level of the building achieved post-renovation:

- the quality level of the building does significantly improve (despite the project being a separately financed and implemented complete renovation project)
- process that improves the quality level of the building
- annual renovation, based on the building's annual renovation plan, in which the building's renovation is carried out preventively (maintenance, pipeline renovation, and correction works, according to a 5-year plan)
- refurbishment, i.e. renovation carried out as a large-scale modification and functionality improvement project (where changes may concern, e.g. the appearance of the façade, structures, change in the building's purpose/use, etc.)

A building requires regular maintenance during its service life (use phase) to retain it or an assembled system (part of works) in a state in which it can perform its required functions. Relevant information concerning the building renovation/refurbishment shall be obtained and collected according to the LCA evaluation requirement. Available underlying information shall be reviewed and assessed according to relevant sustainability assessment standards (EN 15978, EN 16309, and EN 16627).

If an existing building is insufficiently documented, deviations in the structures, use, and condition of materials may exist. In such cases, concluding that the documentation is generally insufficient and does not meet current requirements may be appropriate. The results of the analysis can be used to make fundamental decisions on how to deal with existing buildings and, in general, life cycle assessments for refurbishment projects (EN 17680:2023). However, the standard does not say how these decisions should be made.

In the case of renovation projects, the performance of buildings should be assessed against expected requirements and needs, now and going forward, including a comparison of environmental impacts between different options. Each performance level (current and proposed) should be recorded (EN 17680:2023).

The existence of structural types corresponding to the era and construction at hand helps calculate the environmental impact of refurbishment projects. Structural types help calculate the materials used in the building, but conclusions/decisions on what materials are transferred to waste and which parts can be utilised cannot be made before the condition survey. However, calculations can be made on a scenario basis.

Climate impact calculation for the refurbishment project

The life cycle assessment method applies not only to new construction but to existing buildings and their refurbishment projects (EN 15978:11). The standard is being revised, and harmonising it with other sources that have already been updated is its primary purpose.

According to EN 15978, rebuilding is assessed like a new building (reported in module A1-5). The partial demolition of the existing building is attributed to the rebuilt building, and all reuse of the existing construction is considered sink costs. This approach supports circularity and recovering as much of the existing building as possible when rebuilt.

According to the Finnish Building Act (1.3.2023) a building's carbon footprint and handprint must be assessed for a new building and for a building undergoing large renovation (refurbishment). This act is being revised, and assessment of renovation will no longer be required.

In Finland, the environmental impacts of renovation projects have been assessed to a limited extent thus far. In most cases, these assessments were made for research purposes, related to improving the level of energy efficiency, and making declaratory assessments based on that research.

In Denmark, Kanafani et al. (2022) developed a model to facilitate an LCA for renovation projects, focusing on typical apartment buildings constructed from 1850 to 1920. Rather than relying on material amounts per m^2, the model generates a full life cycle inventory based on a few dimension parameters, assuming a typical layout for an apartment building from this period. The model is implemented in the Danish LCA tool LCAbyg. A user working on a renovation project can thus input a few parameters related to the building's dimensions. LCAbyg generates an approximate LCA model for the existing building, which the user can then edit based on the renovation measures considered. The possible inclusion of mandatory requirements and/or standardised methods for an LCA of renovation projects is under negotiation. Notably, the Danish Strategic Network for Sustainable Construction has recently published recommendations regarding such methods and requirements.

LCA boundaries for the refurbishment

Estimating the renovation project's carbon footprint is limited to the new materials needed for the repair or building elements and products to be repaired in connection with it. It does not retroactively calculate the effects that occurred before the major correction. The impacts of the construction products manufactured, the construction work phase, and the energy used are part of the previous life cycle of the building are not included in the low-carbon assessment of the renovation (Low carbon building assessment method 2021. Ministry of Environment, Finland 6/21).

Major renovations may affect the building's layout, structures, components, and technical systems, a change in the building's intended use, or construction activities by renewing, adapting, or improving the building's performance. The next table (*Table 4*) gives the assessment stages for the refurbishment project.

Prior to refurbishment				During refurbishment	
C1	Demolition	A1	Raw material acquisition	A4	Transportation of any new materials, products, parts, components, etc., needed for the refurbishment
C2	Waste transportation	A2	Raw material transportation	A5	Construction and installation activities
C3	End-of-life treatment	A3	Material production (any new material, products, parts, etc., needed for the refurbishment)	C2	Transportation of installation wastes and packages to the waste handling plant
C4	Final disposal			C3	End-of-life treatment
				C4	Final disposal

Table 4 Life cycle phases, which should be included for assessment of the refurbishment project

Data on the end-of-life phases of building materials are required to calculate an LCA for renovation projects. Such information can be found in the Danish Building Materials Database and partly in the Finnish CO2data.fi database. The Norwegian database EPD Norge contains manufacturer-specific EPD data; when the EPD has been prepared for the entire product life cycle, an estimate of its end-of-life information can also be found. However, in the Swedish Boverket database, this information is completely missing.

The latest account on a national method Denmark for renovation was made by the Strategy Network this year (2024). The network gathers industry representatives and various interest group organisations and is facilitated by Aalborg University. The independent network aims to make recommendations regarding the further development of building carbon regulation in Denmark. It should be highlighted that this proposal does not have an official status.

Proposed method for renovation, Denmark:

- Requirements include larger (>1,000 m^2) and, later, smaller buildings too.
- Larger renovations are divided into simple or deep renovations (refurbishments).
- Included: New materials (A1-3, B4, C3-4) and materials removed during renovation (C3-4).
- In the case of implementing stages A4 and A5 in the 2025 regulation, construction waste from removed materials will be allocated to A5.
- Use stage and end-of-life of existing materials are omitted; no remaining service life is assumed.
- Reference unit: Assessment focused on components for which reference values will be developed and against which the assessment will be measured.

EXAMPLE. Utilising archetypes in assessing climate impact from refurbishment

Table 5 gives an example of the climate impact from refurbishment project for a concrete building exterior wall. In this example, it is assumed the concrete element outer layer will be removed with the thermal insulation, and during the refurbishment, a new insulation and outer shell will be installed.

Other assumptions for this case are:

- Table 7 shows the life cycle impacts on building materials. The Finnish database on treating (C3) and disposing of construction waste (C4) contains only some results.
- The Finnish database (CO2data.fi) provides transport impacts for different load sizes and vehicle loads, assuming the transport distance to the waste treatment plant is 50 km and that the truckload of mixed construction waste is 20%. According to this step, the C2 effect is 0.285 kg CO_2e/tkm. This value is missing in the Danish database.
- The Finnish database gives a general impact value for demolition work of different building types (phase C1); this is 7 kg/floor-m^2 for residential buildings (this total value is allocated to demolishing the wall structure according to the wall/floor ratio). The Danish database does not include any impacts for stage C1.
- The assessment was made for a hypothetical 5-storey residential building with a floor area of 1850 m^2 and a wall area of 900 m^2.

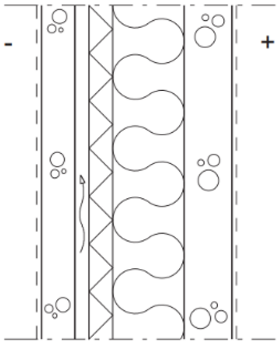
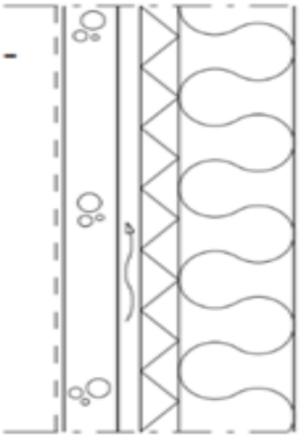
CONCRETE BUILDING (1850 floor-m^2), concrete exterior wall element (900 m^2/building)		
Material specification: exterior wall archetype	Replaced outer shell	Saved inner shell
		
Material specification (kg/wall-m^2)		
Actual structure: Concrete 432 kg/m^2 glass wool 7 kg/m^2 steel 14 kg/m^2 (used for reinforcement)	**Refurbishment waste**: Concrete 192 kg/m^2, mineral wool 7 kg/m^2, steel 3,8 kg/m^2 (used for outer shell reinforcement) **New materials:** Concrete 192 kg/m^2, mineral wool 7 kg/m^2, steel 3,8 kg/m^2 (used for outer shell reinforcement	**Life cycle continues:** Concrete 240 kg/m^2

Table 5 Refurbishment of the exterior wall from the residential multi-storey concrete building (removal of concrete exterior wall shell and insulation and replacement of a new wall shell) (MRB 2000 US concrete)

Building material	**Finland, CO2data.fi**			**Denmark, GENDK + okobau.dat**		
	A1-A3	C3	C4	A1-A3 kg CO2e/kg	C3	C4
Concrete in wall	0,17 kg CO_2e /kg	0,006 kg CO_2e /kg		282 kg CO_2e /m^3	6,72 kg CO_2e / m^3	4,97 kg CO_2e / m^3
Glass wool	1,2 kg CO_2e /kg		0,57 kg CO_2e /kg for mixed waste	40 kg CO_2e / m^3	0,72 kg CO_2e / m^3	0,39 kg CO_2e / m^3
Reinforcement steel	0,56 kg CO_2e /kg	0,002 kg CO_2e /kg		0,68 kg CO_2e /kg		0,00067 kg CO_2e /kg

Table 6 CO_2e unit values for the building materials used for calculating this renovation project example

	Material type and kg/structure-m^2	Finland	Denmark	Building, Finland	Building, Denmark
A1-A5	192 kg concrete	33	23		
	7 kg mineral wool	8,4	8		
	3,8 kg steel	2,1	2,6		
C1	202,8 kg of demolition materials	4,6	not considered		
C2	202,8 kg of waste	2,9	not considered		
C3	192 kg of concrete	1,2	0,54		
	7 kg of insulation		0,14		
	3,8 kg steel	0,01	0		
C4	concrete		0,40		
	mineral wool	0,40	0,08		
	steel		0,00066		
TOTAL		**53 kg/structure-m^2**	**34 kg/structure-m^2**	**50 400 kg/building**	**30 600 kg/building**

Table 7 Climate impact from the refurbishment project of the residential building (removal of concrete exterior wall shell with an insulation layer and replacement of a new wall shell) (MRB 2000 US concrete, Finland)

The previous example was a hypothetical refurbishment case where it was assumed the concrete outer cell had deteriorated so much that repair was impossible. In any case, assessing the actual object requires knowledge of the technical conditions of the structures and an assessment of the service life of the products and materials used.

The existence of historical archetypes does not yet justify conclusions on the condition of the products in any specific case and their remaining service life.

The demolition material and construction waste report shall be updated at the end of the construction or demolition project to include information on the quantities, delivery locations, and treatment of construction and demolition waste leaving the construction site. However, this cannot be based on an estimate but on actual amounts.

Use case: Building stock as a material bank

“Buildings as Material Banks” is a concept that aims to reduce waste and use of virgin resources in the construction industry by increasing the value of building materials. The idea is to design buildings that can be disassembled and the materials reused in other buildings, creating a circular economy where materials sustain their value. The project “BAMB” (Buildings As Material Banks)[73] developed Materials Passports and introduced Reversible Building Design[74].

Over the last few years, initiatives aiming at modelling material amounts in existing buildings with a high level of precision and accuracy to facilitate reuse have been launched in multiple European countries.

Several research projects have investigated material amounts in the existing building stock in Denmark. Lanau and Liu (2020) and later Li et al. (2022) developed an “urban resource cadastre” to identify opportunities for urban mining. At its core, the cadastre uses material intensity coefficients for various archetypes derived from case study buildings. The cases focused on the city of Odense but were later generalised to the entire country.

Information about building archetypes and material amounts are relevant for material stock analyses or for estimating the end-of-life impact of an existing building, but some types of analyses require more detailed data. For instance, estimating the number of reusable materials in a building requires more detailed product-level information. Francart et al. (2023) developed an open-source model to estimate material amounts at the product level in existing buildings[75]. The model delivers more granular estimates, but the

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[73] BAMB. Grant agreement ID: 642384. European Union’s Horizon 2020 research and innovation program.
[74] About bamb - BAMB (bamb2020.eu)
[75] https://github.com/NFrancart/iBuildGreen

total material amounts for the building are less accurate than the ones from Lanau and Liu (2020).

Overall, such building stock models may provide relevant information for strategic planning related to urban mining, but they do not yet reach a high enough level of precision and accuracy to support operational decisions related to reuse. Case by case, detailed assessments of the amounts and properties of materials in existing buildings remain necessary to enable reuse in most cases. Private sector initiatives aimed at facilitating these assessments have also emerged across Europe, e.g. the Dutch company Madaster or the Danish Milva.

Robust classification of building types

Statistics Finland classifies Finland's building stock into 13 main categories[76] according to the purpose of use. There is also one main building class category: a free-time residential building. Free-time residences are treated separately, except for permanent residential second homes, which have been classified as separate small houses in the category of residential buildings.

Meanwhile, the Danish building stock database, BBR, uses a more fine-grained description of building use types, with 104 different building types. However, for comparison purposes, they are reported below in the same categories as in the Finnish statistics (although it should be noted that this mapping is uncertain: the categories might not contain the types of buildings in both countries).

In Estonia, buildings are also classified according to the building's purpose:

- small residential buildings (single-family homes, two-apartment buildings, or terraced houses)
- multi-apartment buildings (residential buildings with three or more apartments, including buildings of social welfare institutions and residence halls, except terraced houses)
- office buildings, libraries, and research buildings
- business buildings (accommodation buildings, food service buildings, service buildings), except office buildings and commercial buildings
- public buildings (entertainment buildings, except zoological parks or botanical gardens; sports buildings, except indoor ice rinks and riding halls; museums and library buildings, except libraries and terminal buildings)
- commercial buildings and terminal buildings
- educational buildings (except preschools)
- preschools
- healthcare buildings (hospitals and other medical treatment buildings)

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76. Classification of Buildings 2018, Finland: Classifications | Classification of Buildings 2018 | Tilastokeskus (stat.fi)

Building types	FINLAND m²	DENMARK m²	ESTONIA m²	ICELAND m²
Detached houses	168 649 672	188 901 000		7 154 537
Linked and terraced houses	36 704 988	38 223 000		2 840 715
Residential apartment buildings (multi-storey)	111 616 101	92 953 000		9 626 354
Commercial buildings	31 417 128	25 872 000		8 759 199
Office buildings	20 169 210	26 903 000		1 343 617
Transport buildings	13 816 119	7 364 000		219 710+
Buildings for institutional care	11 699 263	9 709 000		415 081
Assembly buildings	11 606 836	reported with 'industrial building'		1 152 128
Educational buildings	22 747 150	25 980 000		106 371
Industrial buildings	51 952 994	40 701 000		638 948
Warehouses	25 718 735	37 279 000		3 286 194
Agricultural buildings*	22 063 885	97 206 000		3 676 568
Other buildings**	6 668 582	45 096 000		9 626 354
TOTAL	**537 816 971**	**636 187 000**	**134 244 005**	**39 219 424**

* Class 'Agricultural buildings' (Finland) has uncomplete statistics (data from 1995)
** Class 'Other buildings' (Finland) include saunas and outbuildings, huts, lodges, 'Energy supply buildings' 'Public utility buildings', 'Rescue service buildings'
+ In Iceland, only airport buildings
++ In Iceland, cost category no. 9 applies

Table 8 Building classification and building stock. Statistics Finland based on 'Building and summer cottage' database (NOTE: Statistical data until the end of 2020; class detached houses Finland also includes building class: summer cottages, but only habitable) (Statistics Finland data obtained 29.1.2024[77] and Statistic Denmark).

In Finland, construction was most active from 1970 till 1989 (Figure 1). At the end of 2020, the total floor area of existing buildings in Finland was approximately 516 million square metres. Residential buildings accounted for approximately 60% of the estimated decades (totalling 317 million square metres). Regarding the statistics, most blocks of flats were built in Finland from 1960 to 1979, and most detached, linked, and terraced houses from 1980 to 1999 (Figure 3).

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77. Statistics Finland: Rakennukset ja kerrosala muuttujina Vuosi, Alue, Rakennuksen käyttötarkoitus (Rakennusluokitus 2018), Rakennusvuosi ja Tiedot. PxWeb (stat.fi)

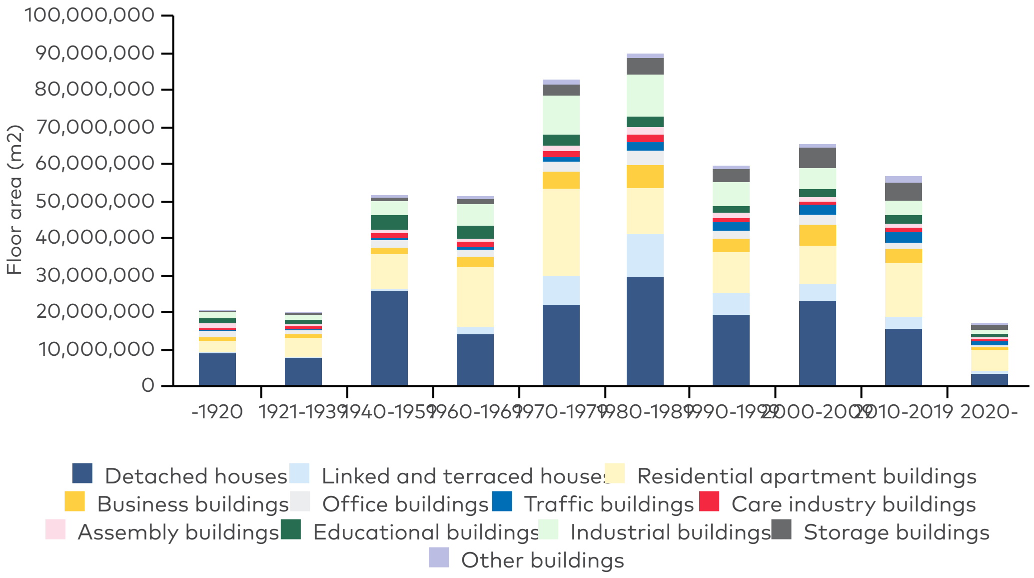

Figure 1 Building Stock, Finland (Statistics Finland, 2020)

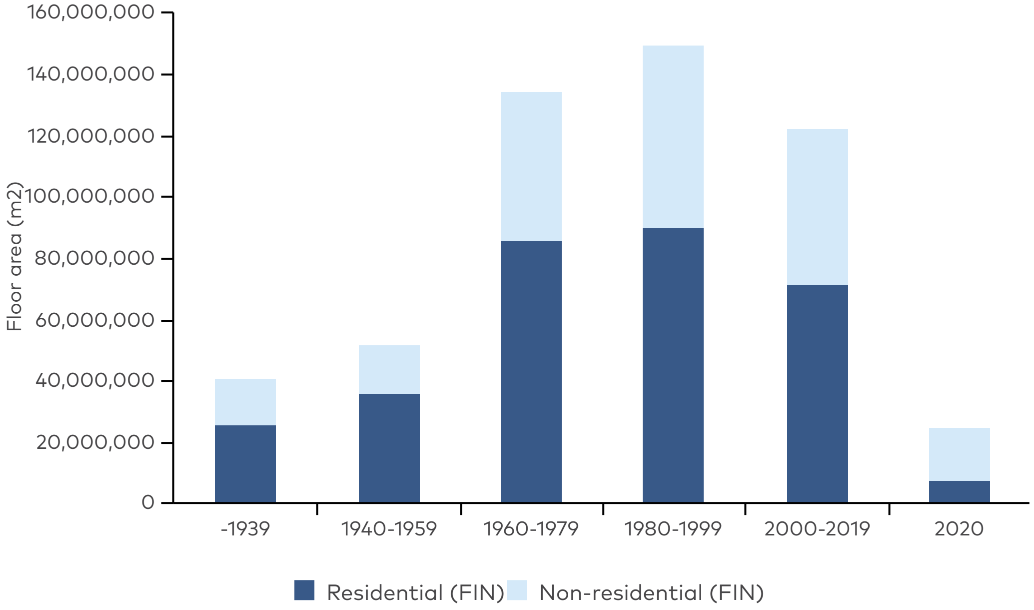

Figure 2 Residential and non-residential buildings, Finland (by construction era) (Statistics Finland, 2020)

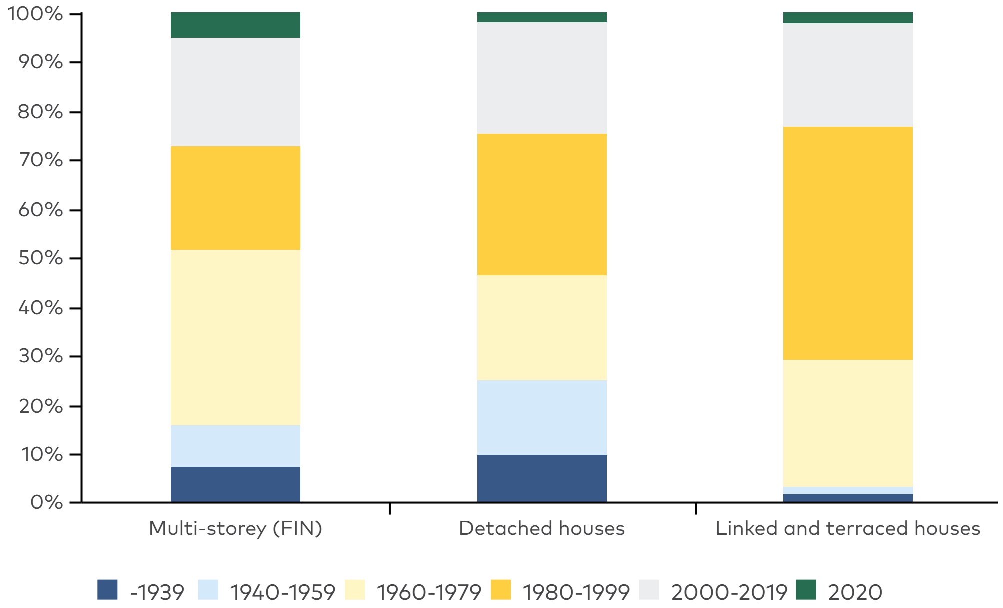

Figure 3 Example of residential building shares by construction year (Statistics Finland, 2020)

According to Statistics Denmark, residential buildings is the largest building category, accounting for approximately 50% of the total building m^2 in Denmark. Single-family houses were the largest group of residential building types according to the total built m^2; until 1979, they represented the largest era-based constructed -m^2.

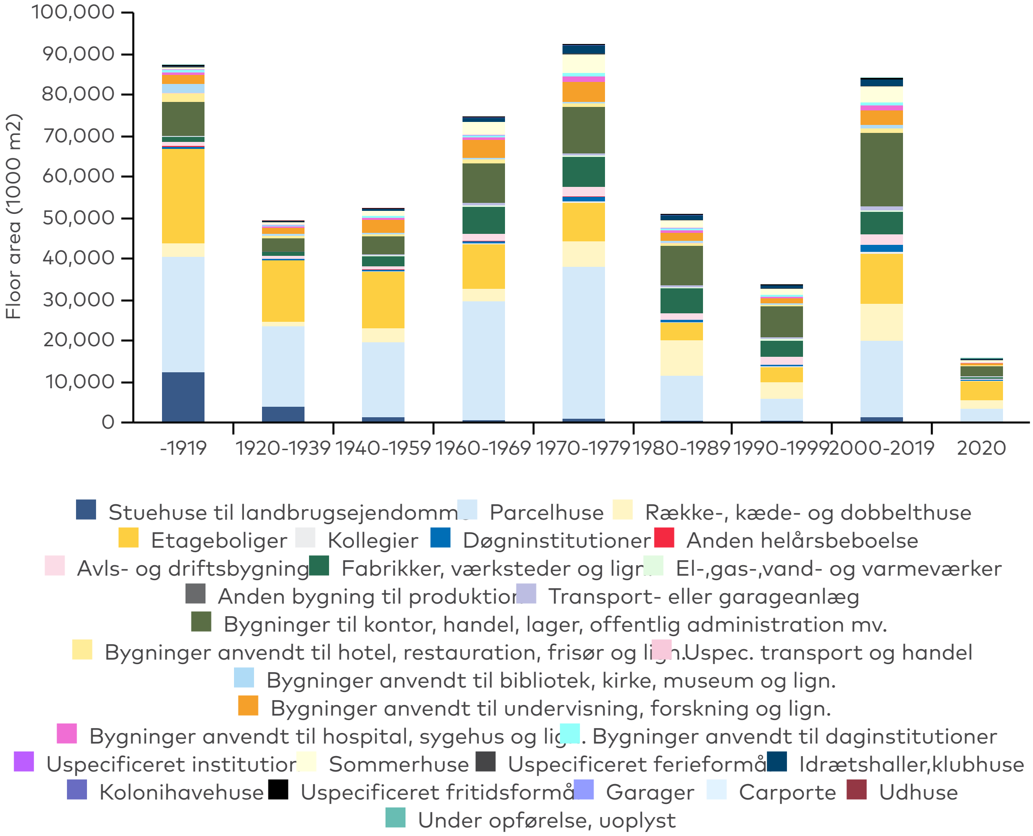

Figure 4 Building stock, Denmark (Building Statistics, 2020)

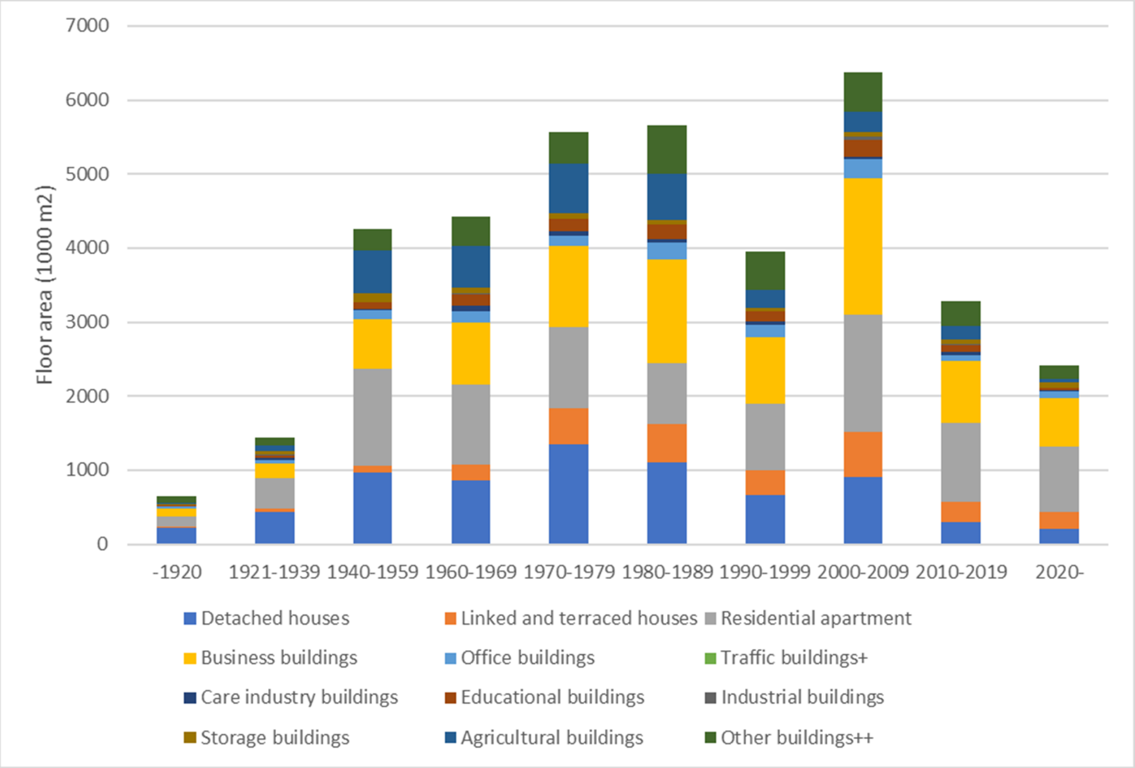

Figure 5 Building stock, Iceland (Housing and Construction Authority, 2024)

Estonia

In Estonia, apartment buildings comprise 70% of the whole dwelling stock. Most of these apartment buildings (blocks of flats) were constructed during the 1960s, 1970s, and 1980s (over three-fourths of the dwellings) (Statistics Estonia, 2016).

Approximately two-thirds of Estonia's population lives in apartment buildings (Statistics Estonia, 2016). Apartment buildings are mostly in urban or suburban areas, while detached houses, primarily farmhouses, are the main dwelling type on the outskirts and in rural areas.

Figure 6 shows the Estonian building stock floor area according to the commissioning data (results presented as of the end of 2020).

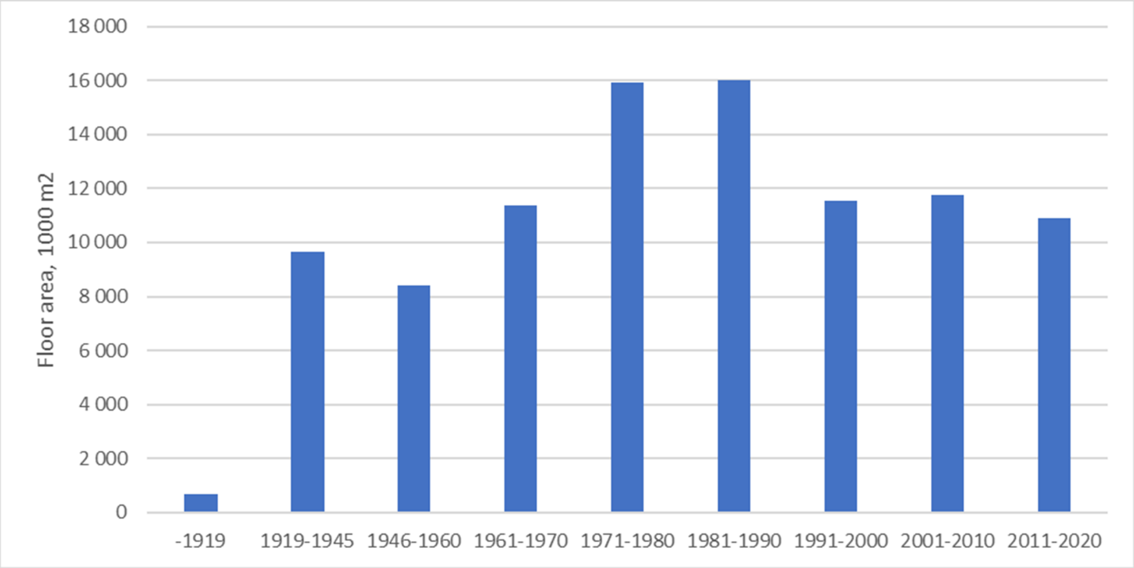

Figure 6 Building stock (according to commissioning date), Estonia (Building Statistics, 2020) (does not include buildings with an unknown construction date)

Identification of representative structure types and typical material contents

Analysing the existing building stocks aims to create a general/typical base of structural types of buildings, thus avoiding building-specific material analyses when similar information is not publicly available. This information aims to provide a sufficiently reliable model description of the materials used in old buildings.

Finnish Construction Information provider (Rakennustieto Oy) has published a comprehensive series of books that describe apartment buildings from 1880 to 2000, their architecture, structure type, etc. This book series was chosen as the source for material type and amount description (Residential blocks of flats: 1880–1940, 1940–1960, 1960–1975, and 1975–2000, Finnish Architects' Association). Residential apartment buildings were selected for review in the first place because the apartment building type and structure archetypes are more homogeneous and better documented (Figure 7).

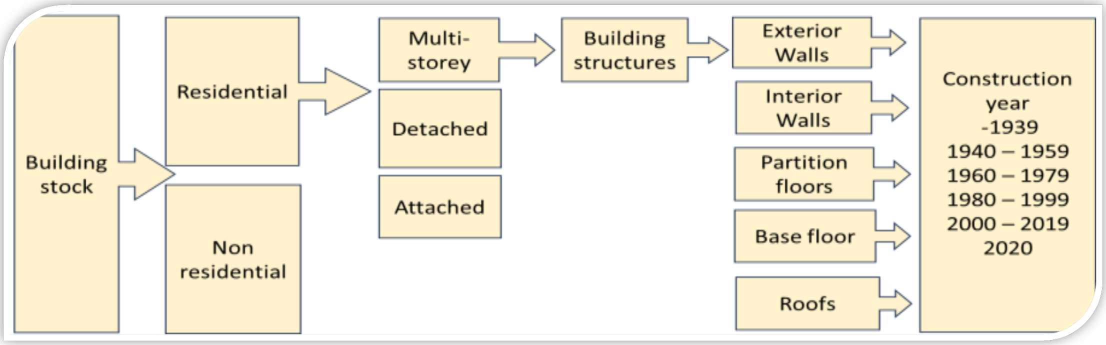

Figure 7 Information about used building structure types collected for the multi-storey residential buildings, Finland

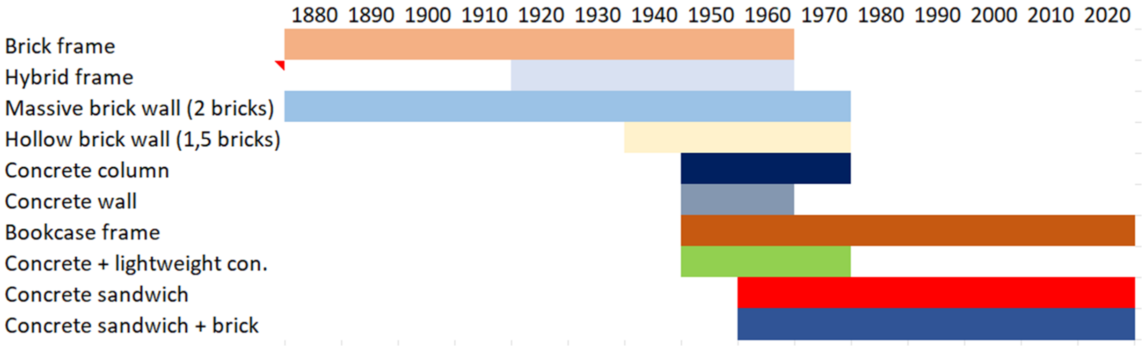

Figure 8 Typical load-bearing structure types in multi-storey buildings, Finland (Neuvonen, P., 2006)

Building character	
Load-bearing structure type	Wood frame used in a small proportion. Main types were brickwork frame, mixed frame, concrete column/wall frame (bookcase frame type was used from 1960 to 1975).
Material type for wooden houses, example from 1940 to 1960	Log frame recedes; only a few log apartment buildings are being built. A typical wooden multi-storey house was a 2-storey timber frame building (puurangalla).
Material types for 'stone' houses	Brick, concrete, and lightweight concrete buildings.
Material share	Buildings from brick frame 40%, concrete 50%, wood 3%.

Table 9 Example of historical multi-storey buildings Finland (according to the source: Multi-storey buildings 1940–1960, Rakennustieto Oy).

Estonia

In Estonia, apartment buildings comprise about 70% of the dwelling stock, and the dominant building materials are brick or prefabricated reinforced concrete (large panels), accounting for 37% and 36% of all apartment building floor areas, respectively (Allikmaa, 2013).

Estonian housing stock includes apartment buildings made from aerated autoclaved blocks (12%) and old wooden apartment buildings from the beginning of the 20th century (8%).

Iceland

According to Statistics Iceland, the most used building material in existing buildings is concrete.

BUILDING STRUCTURE TYPES EXAMPLE, FINLAND:

Following example illustrates material contents of main structures. These are a group of materials with a significant mass (that usually causes the highest product-specific environmental and climate impacts), the building parts included in the central plans of the building, materials that can be used further as other materials are estimated to be of lower significance (materials with small weights like paints, nails connections, etc.). On this basis, the structural elements were divided into six categories:

- foundation (P)
- ground floor (AP)
- intermediate floor
- exterior wall (US)
- roof (YP)
- partition wall (VS)

The next table presents the structures of residential buildings (typical in Finland between 1960 and 1975) according to material types, quantities, and sources (Table 17).

1960–1975	Type of structure	Concrete, bricks, tiles, ceramics	Wood and natural fibres	Glass	Plastics and rubber	Bituminous materials	Metals	Insulation materials	Gypsum	Other	Soil and stones	Total [kg/m^2]	Renewable	Non-renewable	Hazardous
Base floor	Slab on grade, concrete, expanded clay	207	0	0	0	0	2	54	0	0	380	**643**	0	641	0
Base floor	Slab on grade, concrete, cellular polystyrene	207	0	0	0,2	0	2	3	0	0	380	**591**	0	589	0
Intermediate floor	Cavity slab, mineral wool	253	0	0	0,0	0	2	2	0	18	0	**274**	0	271	0
Intermediate floor	Solid concrete slab, EPS	486	0	0	0,0	0	6,2	0	0	18	0	**511**	0	504	0
Exterior wall	Sandwich concrete element (70 + 80) + brick tiles + insulation 160 mm	396	0	0	0	0	8	3	0	0	0	**408**	0	398	0

Exterior wall	Sandwich concrete element (70 + 150) + brick tiles + insulation 140 mm	564	0	0	0	0	8	2,8	0	0	0	**575**	0	566	0
Exterior wall	Brick-built, burnt brick (270x130x75 mm) in facade + insulation 120 mm	347	0	0	0	0	0	4	0	0	0	**351**	0	349	0
Exterior wall	Brick-built, burnt white brick (285x85x75 mm) in facade + insulation 120 mm	285	0	0	0	0	0	4	0	0	0	**289**	0	287	0

Table 10 Residential buildings: their structure types, material types, weight (kg/structure-m^2) used, and material origin (Finland)

BUILDING STRUCTURE TYPES EXAMPLE, DENMARK

Engelmark (2013) has extensively studied the types of structural solutions used over time in Danish multi-family housing buildings. For some elements, he provides an overview of the time periods over which each solution was typically used. The information below is based primarily on Engelmark (2013), but other design manuals have been consulted to provide a rough overview of the Danish construction landscape.

Figure 9 and Table 12 indicate the time periods over which various structural solutions were typically used in Danish housing construction and the typical material amounts for each solution (expressed per m^2 of wall, floor slab, etc). The actual thickness of insulation depends on the last year of renovation, as it must comply with progressively more ambitious energy regulations.

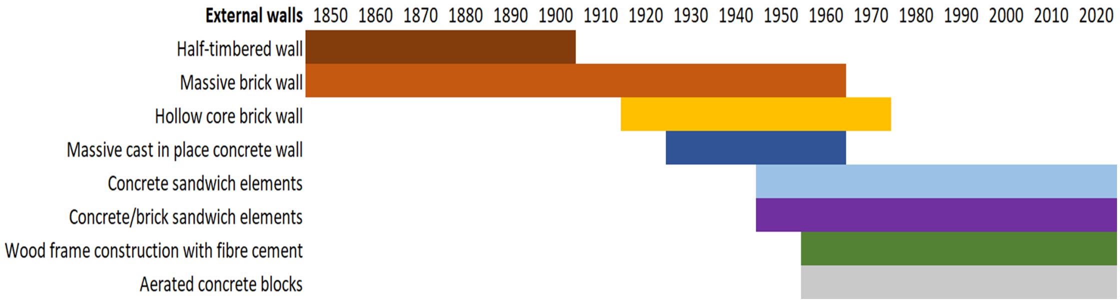

Figure 9 Typical structural solutions (external walls) in Danish housing construction

External wall type	Material	Amount
Half-timbered wall	Brick	0,138 m^3
	Wooden beam	0,052 m^3
	Lime gypsum plaster	0,01 m^3
	Lime mortar	0,038 m^3
Massive brick wall*	Brick	0,263 m^3
	Lime gypsum plaster	0,01 m^3
	Lime mortar	0,079 m^3
Hollow core brick wall	Brick	0,176 m^3
	Lime gypsum plaster	0,01 m^3
	Lime mortar	0,04 m^3
	Mineral wool	0,074 m^3
	Steel bars	1,38 kg
Etc.		

* Typically, the thickness of brick walls would increase by a half-brick for every second floor above the floor considered. A full brick's thickness is 228 mm; a half-brick thickness is 108 mm. So, in a five-storey building, the first floor would be one brick thick; the second and third floors one and a half bricks thick; and the fourth and fifth floors one brick thick.

Table 11 Typical material amounts for each solution (external walls), Denmark

name	min_year	max_year	min_pitch	amount	unit	prodname
Thatched roof	0	1900	10	37	KG	FASBA e.V. Baustroh 100 kg/mÃ,Â³
Thatched roof	0	1900	10	0,18	KG	Glass fibre fleece
Thatched roof	0	1900	10	0,02	M3	Timber pine (12% moisture / 10.7% H2O content)
Thatched roof	0	1900	10	0,1	KG	Galvanised steel screws
Clay tiles	1800	2100	25	38	KG	Roof tile
Clay tiles	1800	2100	25	0,006533	M3	Construction wood, pine and spruce (skeleton)
Slate shingles	1800	1930	20	0,006533	M3	Construction wood, pine and spruce (skeleton)
Slate shingles	1800	1930	20	36	KG	Roof slate (thickness 0.011 m)
Zinc	1800	1930	5	0,006533	M3	Construction wood, pine and spruce (skeleton)
Zinc	1800	1930	5	5,7	KG	Zink, patinated
Concrete tiles	1910	2100	20	0,006533	M3	Construction wood, pine and spruce (skeleton)
Concrete tiles	1910	2100	20	36	KG	Roof tiles, concrete
Glass	1920	2100	12	61,8	KG	Glass roof, aluminium
Roofing felt	1930	2100	1	5	KG	Bitumen sheets G 200 S4 (thickness 0.004 m)
Roofing felt	1930	2100	1	5,21	KG	Bitumen sheets PYE PV 200 S5 (non-slated) (thickness 0.004 m)
Eternit tile without asbestos	1930	2100	25	0,006533	M3	Construction wood, pine and spruce (skeleton)
Eternit tile with asbestos	1930	2100	25	0,006533	M3	Construction wood, pine and spruce (skeleton)
Eternit tile without asbestos	1930	2100	25	18	KG	Fibre cement roof tile
Eternit tile with asbestos	1930	2100	25	18	KG	Fibre cement roof tile
Plastic roof	1970	2100	1	2	KG	EPDM roof sheets (thickness 0.0015 m)

Green roof	1970	2100	1	4	KG	Bitumen sheets G 200 S4 (thickness 0.004 m)
Green roof	1970	2100	1	1,13	KG	Foil for green roof (thickness 0.001 m)
Green roof	1970	2100	1	1,66	KG	PE foil (thickness 0.00125 m)
Green roof	1970	2100	1	0,5	KG	PE/PP fleece
Green roof	1970	2100	1	0,04	M3	Mineral wool (partition walls insulation)

Table 12 Example of roof types in existing buildings, Denmark

EXAMPLE ICELAND

Table 13 presents an example of building material amounts (m^3 and m^2) used in Iceland buildings and their proportional distributions of material types (Iceland buildings from 1950 and 1975 and external wall example.

Building material	Total cubic meters**	Total square meters m^2	
Concrete	4 789 255	4 510 468	86,6%
Hollow concrete brick	200 965	277 100	5,3%
Brick	6 165	11 693	0,2%
Precast concrete	17 850	26 861	0,5%
Timber/wood	198 460	229 293	4,4%
Steel	1 977	864	0,0%
Concrete + wood	110 587	82 225	1,6%
Concrete/loaded	50 338	64 089	1,2%
Concrete + metal	2 325	4 795	0,1%
		5 207 389	

Table 13 Proportional distribution of building materials for housing from 1950 to 1975

Terminology

Building (3.1; EN 15978:2011) construction works that provide shelter for their occupants or contents as one of their primary purposes; are usually enclosed and designed to stand permanently in one place (ISO 6707-1:2020).

Building fabric (3.2; EN 15978:2011) all construction products fixed to the building permanently so that dismantling them changes the building's performance, and dismantling or replacing them constitutes construction operations.

Deconstruction (3.1.17; prEN 15978:2023) process of selectively and systematically dismantling a building (3.3) to reduce the amount of waste (3.68) created and generate a supply of high-value secondary materials (3.58) suitable for reuse (3.56) and recycling (3.48).

Disassembly (3.1.9; prEN 15978:2023) non-destructive dismantling of construction works (3.14) or constructed assets into constituent materials or components (3.9, 3.10) (ISO 20887:2020).

Design for disassembly (3.20, prEN 15987:2023) approach to designing a product or constructed asset that facilitates disassembly (3.19) at the end of its useful life in such a way that enables its components (3.9, 3.10) and parts to be reused (3.56), recycled (3.47), recovered (3.46) for energy or, in some other way, diverted from the waste stream (ISO 20887:2020).

LCA Life cycle assessment

Recovery (3.23; prEN 15978:2023) operation to turn waste into a useful resource; recovery operations can include material recovery and energy recovery (EN 15643-2:2021).

Recycling (3.47; prEN 15978:2023) recovery (3.46) operation by which waste (3.68) materials are reprocessed into products, materials, or substances for their original purpose or other purposes (EN 15643-2:2021).

Refurbishment, deep renovation, deep retrofit (EN 3.50 prEN 15978:2023) large-scale (substantial) modifications and improvements to existing construction work (3.14) (ISO 6707-1:2020).

Repair (3.28; prEN 15978:2023) action outside planned maintenance (3.42) to return a construction product (3.11), component (3.9), or assembled system (3.10) into an acceptable condition by renewing, replacing, or mending worn, damaged, or degraded parts but not changing its original parameters (ISO 6707-1:2020).

Replacement (3.53; prEN 15978:2023) installation of a new construction product (3.11), component (3.9), or assembled system (3.10), which performs the function of the old product, component, or system (EN 15643-2:2021).

Reuse (3.56; prEN 15978:2023) operation by which products (3.11) or components (3.9), having reached their end-of-life stage, are used again without reprocessing but include preparation for further use (Preparation for reuse means, where required, checking, cleaning, removing connections, trimming, stripping coatings, and/or other recovery operations or repair, by which products or components of products that reached their end of life are prepared so they can be reused without any other reprocessing) (EN 15643-2:2021).

Secondary material (3.32; prEN 15978:2023) material recovered from previous use or waste (3.68), substituting other materials for further use. NOTE 1: Secondary material is measured at the point where it enters the system from another system. NOTE 2: Materials recovered from previous use or waste from one product system and used as input into another are secondary materials. NOTE 3: Examples of secondary materials (to be measured at the system boundary) are recycled metal, crushed concrete, glass cullet, recycled wood chips, and recycled plastic (EN 15804:2012 + A2:2019).

Waste (3.40; EN 15978) substance or object that the holder discards, intends to discard, or is required to discard (EN 15643-2:2021).

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Nordic view on data needs and scenario settings for full life cycle building environmental assessment

Authors:

Martin Erlandsson, Frida Görman, Åsa Thrysin, Tarja Häkkinen, Klas Eckerberg, Janne Pesu, Malin Dalborg, Johan Asplund

And annexes with the additional authors:

Tarja Häkkinen

Klas Eckerberg, Tommi Kaartinen, Allan Schiøtz, Trine Dyrstad Pettersen

Ashraful Alam, Martin Erlandsson, Per Erik Karlsson, Eskil Mattsson, Heli Miettinen, Miia Mänttäri, Frans Silvenius and Eeva-Maria Tuhkanen

Per Erik Karlsson, Eskil Mattsson, Martin Erlandsson

Sirje Vares, Jarmo Linjama, Janne Pesu

Other contributors:

Maria Balouktsi, Nicola Francart, Kai Kanafani, Anni Oviir, Anne Rønning, Ólafur Ögmundarson

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Nordic Council of Ministers
Nordens Hus
Ved Stranden 18
DK-1061 Copenhagen
pub@norden.org

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