

SYNTHESIS

Reduced carbon footprints of buildings: new Finnish standards and assessments

Matti Kuittinen^{1,2} and Tarja Häkkinen³**Abstract**

The Nordic countries are working towards regional carbon neutrality ahead of the European Union's goals. Finland is aiming at carbon neutrality by 2035, and developing a set of policies, including legislation for low-carbon construction. The new approach includes normative carbon limits for different building types before 2025. Finland's Ministry of the Environment has developed an assessment method and will develop a generic emission database. The database will cover all main types of products and materials, sources of energy, modes of transportation as well as other main processes such as site operations and waste management. Furthermore, the criteria for green public procurement have been developed from the viewpoint of reducing the climate impacts of buildings: incorporating global warming potential and climate benefits. However, there are several open questions regarding both the assessment method and the database. These questions are outlined and discussed. The consideration of the foreseen decarbonisation of energy, the relation of the generic data to specific data and the requirements for generating valid generic data are key issues of discussion. The Finnish assessment method is also compared with the methodological development in other Nordic countries and to the proposed Level(s) framework of the European Commission.

Policy relevance

The carbon limits for buildings will introduce the construction sector to life-cycle approach and assessment. The scope of optimisation will widen from operational emissions to buildings' full life-cycle. This brings changes to building design, as the carbon footprint limit becomes an additional performance requirement for a building permission. For product manufacturers, this may lead to increased market demand of environmental product declarations and their availability in digital format. From the client side, the introduction of limits opens a possibility for setting quantitative targets that go beyond the legal minimum. Furthermore, the proposed concept of carbon handprint (for positive carbon impacts) may become an award criterion in public procurement. The ongoing normative development in the Nordic countries has timely relevance for the development of the Level(s) framework, a common assessment scheme for the European Union. Fora for discussion and co-development are therefore also required at the European level.

Keywords: buildings; carbon footprint; carbon handprint; database; life-cycle assessment; net zero; standards; Finland

1. Introduction: towards carbon neutrality and negativity

The Finnish government of Prime Minister Sanna Marin (Finnish Government 2019) is aiming for carbon neutrality by 2035. A cross-parliament decision was made 2018 by eight government and opposition parties that after reaching carbon neutrality Finland will continue its climate action towards carbon negativity in the 2040s (Government Communications Department 2018). While only Bhutan fulfils this goal, Finland's schedule for reaching carbon neutrality is the third most ambitious in the world: Norway and Uruguay have set their ambition to 2030 (UNEP 2019).

¹ Aalto University, Department of Architecture, Espoo, FI. ORCID: 0000-0003-3101-458X

² Ministry of the Environment, Helsinki, FI.

³ SBE Research, Espoo, FI. ORCID: 0000-0003-0744-5590

Corresponding author: Matti Kuittinen (matti.kuittinen@aalto.fi)

The goals towards carbon neutrality are being further allocated into different sectors. Work is going on for setting sector-specific goals for heavy industries—including energy, chemicals, technology and forest industries—transportation, agriculture and forestry, food, tourism, textiles and fashion, construction and real-estate (Ministry of Economic Affairs and Employment of Finland 2019). Furthermore, one of the specific climate objectives in the government's programme is 'reducing the carbon footprint of construction and housing' (Finnish Government 2019: 41).

Similar national low-carbon roadmaps have been set for Sweden (Fossilfritt Sverige 2020) and the UK (Department for Business, Innovation and Skills & Department of Energy and Climate Change 2015). The entire European Union is aiming to carbon neutrality by 2050 (Directorate-General for Climate Action 2019), and construction sector's role in this quest has recently been brought into focus (von der Leyen 2019; European Commission 2019).

2. Objectives and methods

The aim is to present current attempts to manage the greenhouse gas (GHG) impacts of building with the help of legal requirements in Finland and to introduce and discuss the problematics that are likely to follow. The paper presents the Finnish assessment method and related planned emission database as an example for legal approach and it compares the Finnish situation with that in other Nordic countries. In addition, the purpose is to introduce the current state in national database development and discuss alternative approaches and their benefits and drawbacks. Furthermore, Finland's voluntary criteria for green public procurement (GPP) of low-carbon buildings are presented.

A four-phase methodology is used to accomplish objectives.

First, the situations and targets are clarified for low-carbon building in the four other Nordic countries. The relevant ministers and authorities responsible for building and construction issues were contacted for information.

Second, a study of professional and peer-reviewed literature was done to explain:

- the significance of buildings as source of GHG emissions;
- the opportunities and power to limit the GHG of buildings significantly with the help of regulations and limits;
- the status of life-cycle assessment (LCA) as a method to assess building related emissions; and
- the types of building-related emissions and the significance of embodied and operational emissions.

In order to apply successfully regulatory carbon guidance for the built environment, information about the GHG of products and services is needed. Thus, thirdly, the availability and the eligibility of relevant life-cycle-based GHG emission was studied by reviewing and assessing the availability and suitability of data. The criteria for the eligibility were as follows: relevance (information for products and services currently used in the Finnish building sector, age (data from recent years), and provider (transparent expert data provided by independent research institutes or universities or data provided as environmental product declarations validated by a third party).

Fourth, different actors were interviewed. They represent product manufacturers, designers, construction companies, LCA service providers, design and modelling software providers, providers of cost accounting, and project management software and services. The total number of face-to-face interviews was 20, and the duration of each interview was 30–60 minutes. The interviewees were asked to describe their views regarding:

- Is your organisation likely to use the emission database in its own work?
- What is the probable way of using it?
- Are there specific requirements for instance for the content and structure of the database?

3. Background

3.1 Nordic climate ambition

The Nordic Prime Ministers (2019) of Denmark, Finland, Iceland, Norway and Sweden set themselves a goal in August 2019 that the Nordic region become 'a global leader in combating climate change and achieving a more sustainable society'. This goal has also been set for the built environment, as the Nordic declaration on low-carbon construction was given in October 2019 by Nordic ministers responsible for construction and housing (Nordic Council of Ministers 2019).

According to the declaration, Denmark, Finland, Iceland, Norway and Sweden agree to collaborate towards the harmonisation of a life-cycle approach to buildings. As a part of these efforts, Finnish and Swedish authorities arranged a Nordic Climate Forum for Construction for authorities and stakeholders (Boverket and Ministry of the Environment 2019). A survey was conducted among the around 100 participants of the climate forum regarding the harmonisation efforts in the field of LCA of buildings (Swedish Life Cycle Center 2019). The results show that 97% of respondents would like to have common definitions for LCA of buildings in the normative context. Furthermore, 93% were in favour of methodological harmonisation, including jointly defined system boundaries for normative LCA, and 90% asked for a common Nordic database for environmental information of construction products.

3.2 Carbon neutrality and the built environment

Carbon neutrality is most often used to describe an equilibrium of GHG emissions and sinks. The term is used for both scientific measurements and political goals.

As a country aims at carbon neutrality, its GHG emissions must not exceed its GHG sinks. Currently, several European countries are considering approaches for allocating GHG 'budgets' and environmental benchmarks for the construction sector (Frischknecht *et al.* 2019). Finland (Ministry of the Environment 2017b), France (Ministère de la Transition écologique et solidaire & Ministère de la Cohésion des territoires et des Relations avec les collectivités territoriales 2019) and Sweden (Boverket 2019) have set the aim to issue GHG budgets for buildings. In Germany, a similar approach is discussed, and an allocation method has already been developed (Frischknecht *et al.* 2019). Furthermore, a methodological proposal for setting carbon budgets for the real-estate sector has been developed with the financial support of the European Union (Hirsch *et al.* 2019).

The built environment is often referred to as causing around one-third of society's GHG emissions, when demand-side sectors are considered (ECORYS; Copenhagen Resource Institute 2014). The energy used in buildings constitutes around 40% of all primary energy use. Furthermore, the manufacturing of construction materials has a dramatic impact on GHG emissions. As the production of cement, steel, aluminium and plastics may result in GHG emissions of 920 GtCO₂e by the end of the century (Material Economics 2018)—which is almost twice the amount of existing GHG budget for the Intergovernmental Panel on Climate Change's (IPCC) 1.5°C pathway (IPCC 2018)—stronger mitigation measures are required.

For mitigation of the GHG impacts from the building sector, countries, cities and non-governmental organizations (NGOs) have made several policy proposals. The World Green Building Council published a global call to action in 2019, according which all buildings should be 'net zero carbon' by 2050 (World Green Building Council 2019). The World Resource Institute (WRI) launched the 'Zero Carbon Buildings for All' initiative in 2019, aiming for 'decarbonisation of all new buildings by 2030 and all existing buildings by 2050' (WRI 2019). To achieve this, the Ross Center of the WRI presented eight alternative policy paths for making net-zero-carbon buildings attainable (Becqué *et al.* 2019).

Bionova (2018) studied over 150 different regulations and rating schemes for reducing the embodied carbon. They conclude that setting carbon limits or strong reductions coupled with compensating the remaining emissions (*e.g.* by exporting surplus renewable energy or purchasing offsets) are the most effective means for the decarbonisation of buildings. Assessments have also been performed by modelling the current building stock, annual number of new buildings, building demolitions and refurbishments, and embodied and operational GHG emissions. The conclusions have been that significant reduction in GHGs of buildings can be achieved by regulating and setting limits for GHGs. However, this would require that limits would cover a large part of the building stock (Häkkinen *et al.* 2012; Häkkinen & Ruuska 2013; Häkkinen & Vares 2018).

3.3 Existing assessment methods for the GHG emissions

The overall GHG emissions through building life-cycle are assessed with the help of LCA methodology. The basic principles are internationally agreed upon and standardised in ISO 14040, EN ISO 14044 and ISO 14067 (2006a, 2006b, 2018). Specific guidelines and rules for construction products are presented in EN 15804 (CEN European Committee for Standardization 2019) and by IEA EBC Annex 57 (Lützkendorf & Baloutski 2016). For buildings, the guidance is provided in standard EN 15978 (CEN European Committee for Standardization 2011).

The main source for GHG emissions is the use of fossil fuels. The building-related emissions can be divided to so-called embodied emissions and operational emissions. Embodied emissions are related to manufacturing, transportation, assembly, maintenance, repair and replacement, disassembly and final disposal or recycling of products, while operational emissions of buildings are related to the emissions caused by the use of fossil fuels to provide the heat and electricity needed to maintain the required performance of the building. Embodied GHG emissions are also mainly caused because of the use of fossil fuels in manufacturing, transportation and other processes of products. However, a remarkable part of embodied emissions is based on the nature of certain manufacturing processes. In construction sector process-based CO₂ emissions are induced to a considerable extent in the decomposition of limestone in cement manufacture (Andrew 2018). The management of GHG emission information is supported by the availability of extensive information about the GHG emissions from fossil fuels regarding combustion and extraction and manufacturing of fuels (Sokka, Correia, & Koljonen 2018). In addition, the consumption of fossil fuels in different unit processes of products is normally available, as it is followed because of its cost impacts.

The assessment of embodied GHG impacts takes place by combining the information about material types and quantities with the data of the environmental impacts of these materials (Alwan & Jones 2014). Correspondingly, the assessment of operational GHG impacts is carried out by combining the information about the assessed energy use with the information about the GHG emissions related to the energy sources. Both embodied and operational emissions need to be considered. The amount and share of embodied GHGs compared with operational GHGs depends on the design solution, climate, comfort requirements and local regulations (Cabeza *et al.* 2014). However, research emphasises the significance of embodied GHGs in comparison with operational GHGs (Alwan & Jones 2014; Moncaster & Symons 2013; Ruuska & Häkkinen 2014). The relative significance of embodied emissions increases as the operational GHG emissions are reduced because of the better energy efficiency of buildings, the increasing use of distributed renewable energy, and the increased use of renewable sources in the generation of heat and power. GHG emissions from materials' production may increase in absolute terms if some materials are used in larger quantities or others have higher GHG emissions (Vares *et al.* 2019). The results of the recent global survey of more than 600 buildings around the world (Röck

et al. 2019) show that embodied emissions have risen in both residential and office buildings. The findings also suggest that although the energy efficiency of buildings has improved, the development of embodied emissions is almost the opposite. The importance of the construction phase-related GHG emissions may also be emphasised because of timing and the significant carbon spike during this phase of construction (Säynäjoki, Heinonen, & Junnila 2012).

Applying LCA in the building sector has become a distinct working area within LCA practice already since the 1990s. However, several factors complicate the application of LCA to buildings (Khasreen, Banfill, & Menzies 2009). These include the long service life and its strongly stochastic nature, many potential changes that buildings may undergo during the life span, and lack of knowledge of final disposal and/or recycling circumstances and possibilities after a building's lifetime. The scenarios and choices that are done regarding these issues may decisively affect the assessment result (Kangas *et al.* 2019). This weakens the possibilities to set legally binding requirements for GHG emissions of buildings.

4. Finnish approach to LCA

4.1 Methodological background

The Finnish method for whole-life carbon assessment of buildings (Kuittinen 2019) is based on European standard EN 15978 (CEN European Committee for Standardization 2011). Thus, the assessment uses process-based, attributional LCA, which is commonly used in the building sector.

The aim was also to ensure compatibility with the European Union's (EU) Level(s) framework for metering and reporting the sustainability of buildings (Dodd *et al.* 2017). Level(s) has been developed by the European Commission in order to set a common language for sustainability performance assessment. The framework includes six macro-objectives:

- GHG emissions;
- resource efficient and circular material life-cycles;
- water efficiency;
- healthy and comfortable spaces;
- adaptation to climate change; and
- life-cycle cost and value.

Methodologically Level(s) is based primarily on EN standards. The beta test of Level(s) took place in 2018–19; the updated version will be published in 2020.

However, as both standards and the Level(s) method allow for a certain amount of interpretation and adaptation to local conditions, the Finnish method has been more tightly defined within these methodological frameworks. This is necessary because of the normative nature of the assessment and because the calculation of carbon budgets for a building should give the same values regardless of the assessor. The most important adaptations to the current version of the Finnish assessment method include the selection of physical and temporal system boundaries, the possibility of using predefined table values for certain parts of the assessment, the use of scenarios and the communication of environmental benefits in addition to loads.

4.2 System boundaries

The physical system boundaries include the loadbearing frame, ground work and external structures, supplementary structures and the main components of building service systems, as described in **Table 1**. The covered building parts are specified with the help of existing national classification schemes: The Construction 2000 classification system for building parts and components (Haahtela-kehitys Oy, Rakennustietosäätiö RTS & Rakennustieto Oy 2010), the S2010 classification for electric parts (Sähkötieto ry 2016) and the LVI2010 classification for heating, ventilation and air-conditioning (HVAC) components (Rakennustietosäätiö RTS 2011). These classification schemes are commonly used for construction projects and their quantity estimations in Finland.

The temporal system boundary of the Finnish assessment method is described in **Table 2**. Of the life-cycle modules described in standard EN 15978, they include the production (A1–A3) and construction (A4–A5) phases, the main parts of the use phase (B3–B4, B6) and the entire end-of-life phase (C1–C4). In addition, the net benefits that extend beyond the system boundary (D) are included.

4.3 Predefined calculation values

In early design phases, the level of detail of especially building service components is often inadequate to support accurate assessment. To enable the inclusion of these components, the assessment system makes use of predefined table values for certain building service systems, such as ventilation, electric cables, lifts and photovoltaic panels. As the design proceeds, these proxy values can be replaced with accurate values. The proxy values have been developed based on earlier studies. The intention is to develop the proxy values further with wider statistical reference data.

The same approach is applied for those life-cycle phases that may be time-consuming to investigate, but which have a marginal impact. These phases include transports to and from the site (modules A4 and C2 of standard EN 15978), construction work (A5), energy used for repair and replacement processes (B3–B4), demolition work (C1) and waste

Table 1: Summary of the Finnish method for the whole-life carbon assessment of buildings: scope of the assessment and physical system boundaries.

Projects assessed	New buildings, extensive repairs	
Types of building assessed	Residential buildings Office and health centres Business premises, theatres, libraries, museums Accommodation establishments, hotels, hostels, sheltered accommodation buildings, nursing homes, care facilities Educational establishments and daycare centres	
Parts of a building assessed	Assessed	Not assessed
Site	Earth works, soil stabilisation and reinforcement elements, paved areas, site structures	Site equipment, vegetation, soil and bodies of water
Load-bearing structures	Foundations, ground floors, structural frame, facades, doors and windows, external decks, roofs	Separate fasteners
Supplementary structures	Interior walls, doors, stairs, surfaces, fittings, ducts and fireplaces, box units	Mouldings, surface materials and surface treatments, separate fasteners
Building systems	Energy systems, water and drainage systems, air-conditioning systems, power distribution and operating systems, solar panels and collectors, lifts	Information systems, emergency power, escalators, separate machinery and equipment
Construction site	Energy consumed	Scaffolding and protective covers, temporary structures, moulds, life-cycle of worksite facilities, site personnel traffic
Reference study period	Fifty years (or design service life, ^a if used as a basis for the design)	
Reference unit	1 m ² of the building's heated net space/year	
Database	Environmental Product Declarations, national generic database (forthcoming)	
Tool	Not specified. Must be compatible with the assessment method	
Competency and verification	Not specified. Requirements still under way	

Note: ^aThe period used as a design requirement for the minimum technical service life of the building.

management processes (C3–C4). It is also possible to calculate these phases with specific information, and instructions are given for scenarios that are to be applied when doing so.

4.4 Use of scenarios

As the assessment will be used for defining whether a building meets regulatory limits, life-cycle scenarios need to be defined. The most important scenario is the decarbonisation of energy used during the use phase of the building (B6). Generally, the environmental impacts of a kWh of electricity or district heating can be assumed to stay stable during the entire reference study period. Alternatively, these impacts can be assumed to follow certain scenario, *e.g.* for the decarbonisation of energy.

Standard EN 15643-1 (CEN European Committee for Standardization 2010: 20) gives three requirements for the use of scenarios: they 'shall be taken from the clients brief, the regulatory requirements and from the project specification'. The wording of the standard leaves room to select the reference for scenarios. When basing the scenarios on 'regulatory requirements', a degree of decarbonisation for the operational energy is to be expected.

The Finnish Climate Change Act (Finlex 2015) states that national GHG emissions in 2050 need to be at least 80% lower than in the reference year 1990. This inevitably requires that the emissions of the energy sector will be lowered. In addition, using coal for energy after 2029 is prohibited by law (Ministry of the Environment 2019). This will have a significant impact on the GHG emissions of both district heating and electricity. Furthermore, the National Energy and Climate Strategy (Government of Finland 2016) specifies the key objectives and policy outlines until 2030 concerning both the emissions trading and the non-emissions trading (effort sharing) sectors.

Based on these regulatory requirements, a decarbonisation scenario for district heating and electricity has been developed. It follows the measures that have already been laid out in the National Energy and Climate Strategy (Government of Finland 2016). The GHG values per kWh have been calculated using the existing policy measures until 2030 (Ministry of the Economic Affairs and Employment 2016) and plans until 2050 (Koljonen *et al.* 2019). The exponential decarbonisation curve from this period has been used to extrapolate the GHG coefficients for the period

2051–2120. The GHG values do not include emissions from fuel production or from the life-cycle of the required energy infrastructure.

However, the national goals of carbon neutrality by 2035 and carbon negativity in 2040s may require additional policy measures. These are not included in the scenarios of the assessment method. **Table 3** shows the GHG scenarios for various forms of energy.

4.5 Footprints and handprints

The Finnish assessment method includes reporting of both carbon ‘footprint’ and ‘handprint’. As the former describes the global warming potential (GWP) associated with a building’s life-cycle, the latter is used in the Finnish assessment method to describe those climate benefits that would not be achieved without the building project. The handprint is a proposal in the Finnish assessment method and not traditionally used in building LCA context.

Dyllick & Hockerts (2002) introduced the idea of reporting positive sustainability impacts already in 2002. The first documented use of the term ‘handprint’ was in UNESCO’s 4th International Conference on Environmental Education in 2007 (Centre for Environment Education n.d.). Thereafter, Sala, Farioli, & Zamagni (2013) state that ‘life cycle-based

Table 2: Summary of the Finnish method for the whole-life carbon assessment of buildings: temporal system boundaries according to the life-cycle modules of standard series EN 15643.

	Evaluation	Data used
Before use		
A0 Pre-construction stage	Not assessed	
A1–3 Production stage	Assessed	Only project-specific inventory
A4 Transport	Assessed	Project-specific inventory or proxy values
A5 Construction	Assessed	Project-specific inventory or proxy values
During use		
B1 Use of products	Not assessed	
B2 Maintenance	Not assessed	
B3–4 Repairs and replacements	Assessed	Project-specific inventory or proxy values
B5 Refurbishment	Independent, separate analysis	
B6 Operational energy use	Assessed	Only project-specific data on energy demand
B7 Water consumption	Not assessed	
B8 User’s utilisation ^a	Not assessed	
After use		
C1 Demolition work	Assessed	Project-specific estimation or proxy values
C2 Transport	Assessed	Project-specific estimation or proxy values
C3 Waste processing	Assessed	Project-specific estimation or proxy values
C4 Disposal	Assessed	Project-specific estimation or proxy values

Note: ^a Proposed new life-cycle stage in standard prEN 15643-5.

Table 3: Scenarios for the decarbonisation of energy in Finland (gCO₂/kWh)^a.

Form of energy	2020	2030	2040	2050	2060	2070	2080	2090	2100	2110	2120
Electricity	121	57	30	18	14	7	4	2	1	1	0
District heating	130	93	63	37	33	22	15	10	7	4	3
District cooling	130	93	63	37	33	22	15	10	7	4	3
Fossil fuels	260	260	260	260	260	260	260	260	260	260	260
Renewable fuels	0	0	0	0	0	0	0	0	0	0	0

Note: ^a The figures do not include emissions from the production of fuels or energy infrastructure. The allocation of fuel consumption and the related CO₂ emissions between electricity and heat in combined heat and power production is based on a benefit-sharing method.

Source: Kuittinen (2019).

methodologies should be broadened [...] to also proactively enhancing positive impacts'. Norris (2015) suggests that both footprints and handprints should be compared with each other, and 'net positivity' be aimed at. Recently, methodological proposals for the use of handprint have been developed to assess how businesses contribute to United Nations' Sustainable Development Goals (SDGs) (Kühnen *et al.* 2019). Handprint comparisons have been carried out for products, such as diesel fuels (Grönman *et al.* 2019) and applications, such as the cooling of telecommunication base stations (Kasurinen *et al.* 2019). Green building certification schemes can be seen as an example of already existing socially accepted and collectively developed form of handprint schemes in the construction sector (Biemer, Dixon, & Blackburn 2013).

While the handprint concept is still far from standardised LCA, its elements are present in the existing standards. According to the suggested Finnish method, handprints can only be calculated based on either method described in EN standards or national norms for energy performance calculations for buildings (Ministry of the Environment 2017a). These suggested quantifications of the carbon handprint include the long-term storage of biogenic carbon in wood-based products, based on EN 16485 (CEN European Committee for Standardization 2014). The uptake of carbon through the carbonisation of concrete can also be quantified as a part of the handprint, based on the calculation rules of EN 16757 (CEN European Committee for Standardization 2017). Furthermore, the net benefits achieved by reusing or recycling of construction products after their use, *i.e.* module D in standard EN 15804 (CEN European Committee for Standardization 2019), are proposed to be included under the term. In addition, the surplus renewable energy uploaded into the grid can also be calculated into the proposed concept of handprint. In all these cases, the claimed climate benefits are calculated as CO₂-equivalents. In the Finnish proposal, the handprints do not lower footprints, nor are these two indicators merged.

The carbon handprint of buildings is in the current assessment method calculated as the absolute climate benefits that would not be achieved without the project. It is not a relative figure that indicates improvement in relation to market average or other benchmark. In this respect, the Finnish handprint method for buildings differs from proposals suggesting that a handprint would stand for the reduction of the footprint in comparison with a baseline solution (Pajula *et al.* 2018). Such relative improvement may report the relative climate friendliness at a given time against a given benchmark and be valid only at the moment of the assessment. Buildings have very long service lives compared with products such as fuels, for which some of the handprint assessment case studies have been developed. Therefore, if relative benchmarking would be used for defining the handprint of a building, the handprint value would rapidly be outdated and would not reflect the calculated life-cycle performance of the building. In a normative context, it is important to maintain the comparability between the performances of objects of assessment. **Figure 1** illustrates the differences between relative and absolute handprints.

4.6 Field of application

The Finnish assessment method is applicable to all kinds of buildings. It can be used for new buildings and refurbishment projects. The method is not directly applicable to the assessment of infrastructure works or for the assessment of products.

As the assessment method is aimed at normative use, the scope of application is to be defined. The preliminary plan is to require the assessment of new buildings and make it possible for refurbishment projects. Included building categories consist of residential buildings, offices and healthcare, commercial buildings, accommodation establishment

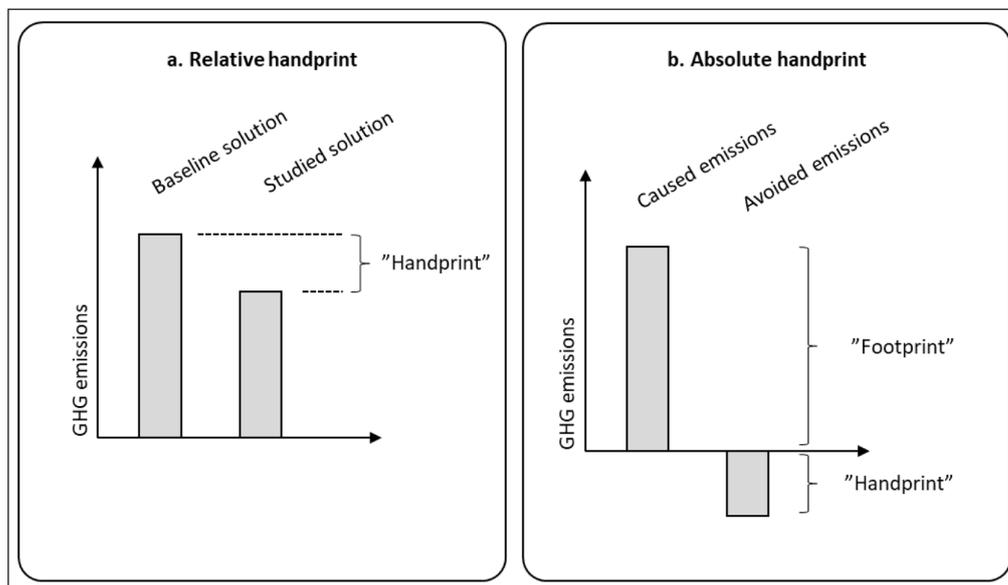


Figure 1: (a) Relative and (b) absolute handprints.

buildings, and education and daycare buildings. Small residential buildings, holiday cabins, factories or specific sports facilities may fall outside the scope of the assessment requirement.

4.7 Testing and further development

The assessment method is currently in its test phase. Over 40 construction projects are used to test the robustness and applicability of the method. The results from the test phase are used as the assessment method will be further developed for normative use.

A significant area of development will be the setting of limits for different building types. This requires that several buildings from each building category will be calculated with the assessment method using the same life-cycle inventory (LCI) data for generic building products and processes.

5. Availability and need of GHG emission data

5.1 Development of a generic database

The regulation of the embodied and operational GHG emissions of buildings requires the availability of a common assessment method. In addition to a coherent methodology, information on GHG emissions from products and energy, transport and construction services is needed. However, the availability of emission data is partly inadequate and inappropriate. These shortcomings relate, among other things, to the data eligibility for Finnish construction, the varying quality of data, the payment of databases, access to databases and the ease of use of data in various software. The need is for an open and free, transparent and easy-to-use emission database suitable for construction processes in Finland.

The Ministry of the Environment in Finland plans to support the establishment of a GHG emission database suitable for use in the connection of the assessment method. During 2019, the Finnish Environment Institute studied various approaches and alternatives to create an appropriate database (Häkkinen & Pesu 2019). The analysis and definition of the low-carbon construction emission database was carried out through interviews, stakeholder workshops, and an in-depth study of research and professional literature.

5.2 Availability of eligible data

The emission data are needed at different stages of the design process. Background information on GHG emissions is already needed in the initial stages of projects in strategic planning and goal-setting. Future regulatory control will determine the stages in which the assessment is to be made, and the calculation results should be presented for inspection. According to the current view, the legislative guidance would take place with the help of a limit value presented as a maximum for GHG emissions per area unit of building.

GHG emission data can be either generic or specific. The generic product information can represent a standard level in Finnish construction, which was formulated by considering an integral part of the supply, or the most typical level in Finnish construction.

On the basis of this review, the situation regarding the access to and availability of good-quality GHG information is very good for energy services and transport services. There is also a large amount of information about building products' GHG emissions, but much work is needed to gather, refine and update it. There are shortcomings in the availability of GHG data for construction services, including construction and assembly, refurbishment, disassembly, and waste management. However, the number of relevant various services to be covered by the generic database is limited, which would ease the data-collection work.

Specific emission data can be defined as information of a product or product group manufactured in a specific production plant. Although many of the building products used in Finland already have environmental declarations, GHG information is not sufficiently comprehensive in terms of Finnish conditions, but GHG data would still be needed for very many specific products. Regarding data usability, the problem is also that the data are scattered in different Environmental Product Declaration (EPD) databases and elsewhere and are largely not digitally transferable. In addition to adequacy, fragmented availability and transferability, the quality of the data is also a challenge. Although the EPDs or reports are drafted according to the same standard (EN 15804), there are differences in the transparency and detailed accounting principles or applied scenarios. In addition, the outline of data varies from one system to another, and there is no unified division in different categories. Furthermore, there is no obligation to the manufacturers to make an environmental declaration based on an LCA, and thus the availability of specific information can remain a permanent problem.

However, product-specific information would also be needed to encourage the market to compete with the value of a carbon footprint. It is important that competition does not occur only between products based on different materials, but also between alternative manufacturers' products based on the same materials. It would therefore be very desirable that the GHG information could be required from product manufacturers. However, the current interpretation of the Construction Products Regulation (CPR) (European Parliament & Council of the European Union 2011) does not allow member states to impose additional requirements on the construction products covered by the harmonised product standard. The current CPR dates from 2013. Its revision has not yet officially begun, but the European Commission is tentatively preparing the agenda for a future change by clarifying the reform needs of the regulation. As part of the autumn 2019 EU Presidency, Finland established under the lead of the Ministry of the Environment a Council Working

Party Technical Harmonization (Construction Products), where the member states discussed the circular economy in the construction sector and reform needs of the regulation. It is very important that the notification of harmful emissions could be required, notwithstanding the harmonised product standards and interpretation of the construction products regulation. One of the main messages of the Council's conclusions is that the important characteristics of the construction product must be declared in one way or another, even if the harmonised product standard has a lack of those characteristics.

5.3 Need of use of GHG emission data

Owing to the shape of the GHG limit used in the envisaged legislative guidance, the greatest need for GHG emission data is likely to be in developed design (Häkkinen *et al.* 2015) and the building permissions' stages of the design process. For the building permit, the calculation of the product-linked life-cycle GHG emissions, the energy consumption of the building and the related operational emissions would be necessary. Since this stage often does not yet make specific product choices, there is a need for generic GHG information on products and services. The eventual review, which checks that the authorised estimate is not exceeded, should be done with the acquired quantities and preferably product-specific values. The emissions for services could probably continue to be generic values, although the energy consumption should be based on actual consumption estimates.

It is noteworthy that emissions data are needed not only in building design processes but also in the preparation of legislative guidance, in order to be able to set the correct limits. In the preparatory phase of the GHG regulation, different kinds and types of buildings are likely to be calculated in order to provide an understanding of the potential low-carbon levels of buildings. It is recommended that while this information is compiled, it is also published in a form that serves the needs of building owners and investors who may target low-carbon building and the needs of designers when they compare tentative design options for low-carbon building during concept design (Häkkinen *et al.* 2015).

The current plan is to start the establishment of the generic database in 2020 and, at the same time, to consider the possibilities to gather specific data later into the same system. Based on the interviews, an open, good-quality and transparent emission database is necessary from the perspective of many operators. Different actors (including manufacturers, designers, consultants, contractors and project managers) want to use the database in different phases of the process through design software, cost accounting and other software.

In the future preparation of the emission database, the main resource needs are related to the determination of the generic GHG emissions of the products and to assess the construction, repair, disassembly and waste management services. In terms of energy and transport services, good-quality information is already available. It is noteworthy that while much work is needed to compile and update generic product information, it should be able to take advantage of the vast amount of information that has already been gathered through different projects.

6. GPP and low-carbon construction

In Finland, the financial value of public tenders is around €24 billion per year (average from 2010 to 2016) (Ministry of Economic Affairs and Employment of Finland n.d.), of which the construction-related contracts account for around 30%. From the total sum of annual construction spending, around 47% is spent on infrastructure projects, 32% on renovations and 21% on new buildings. The largest constructors for new buildings are cities and municipalities, which use around 68% of the €1.5 billion budget used for new building construction. Hospitals, schools and housing are the three largest categories of the value and area of public building every year (Statistics Finland n.d.).

As public construction projects consume a significant share of the annual tax income, there has been strong interest among several consecutive governments to use these funds in an environmentally accountable manner (Finnish Government 2019). Therefore, the Ministry of the Environment has published a set of voluntary GPP criteria for low-carbon public buildings (Kuittinen & le Roux 2017). These criteria are used before the mandatory legal requirements that set the GHG limits for all buildings. After the mandatory criteria for all buildings are in place, the intention is to revise the GPP criteria so that public construction projects would have lower GHG emissions than required by the forthcoming legislation.

The development of the Finnish criteria for the GPP of buildings started during the update of the act on public procurement and concession contracts (Ministry of Economic Affairs and Employment 2016). The GPP criteria for construction are adopted from the corresponding criteria of the European Commission (Dodd, Garbarino, & Gama-Caldas 2016).

The GPP criteria for low-carbon public buildings consist of five classes: competence; energy; materials; innovation; and costs. These criteria classes are applied to five possible procurement cases: design services; construction work; purchase of materials or appliances; design and build contracts; and design, build and operate contracts.

Because the nature of construction projects follows a cascade of decision-making, the criteria are different for each procurement phase. For example, energy criteria for design project include designing a building's energy-efficiency minimum 10% better than required by law. In the construction stage, the minimum energy criteria include metering energy consumption on the building site, mandatory energy-efficiency training at the building site, and finally mandatory air-permeability testing and thermal scanning of the finished building. The criteria for low-carbon public building are described in **Table 4**.

Table 4: Finnish procurement criteria for low-carbon public buildings.

Energy	Materials	Innovations
A. Design projects		
<p><i>Minimum requirement:</i> Calculation of the greenhouse gas (GHG) emissions from the use of energy New construction: minimum 10% better energy efficiency than required by law Refurbishment: minimum 20% better energy-efficiency than required by law Refurbishment: review of the energy performance of the existing building before design</p>	<p><i>Minimum requirement:</i> Calculation of the GHG emissions from the life-cycle of construction materials. Recommendations to the client for choosing the most cost-optimal low-carbon solutions Minimum 10% of the weight of construction materials either renewable or recycled Refurbishment: pre-demolition audit before design stage <i>Award criteria:</i> Updating the life-cycle GHG calculations to the as-built stage</p>	<p><i>Award criteria:</i> Innovative design processes that help to lower the carbon footprint of the building</p>
B. Procurement of materials or equipment		
<p><i>Minimum requirement:</i> Energy-consuming devices selected from the two best energy-efficiency classes</p>	<p><i>Minimum requirement:</i> Minimum 10% of the weight of construction materials either renewable or recycled <i>Award criteria:</i> More than 10% of materials renewable or recycled</p>	<p><i>Award criteria:</i> Innovative products or equipment that help to lower the carbon footprint of the building. Verification of the carbon savings through comparative calculation according to EN 15804 or EN 15978</p>
C. Construction projects		
<p><i>Minimum requirement:</i> Metering the energy consumption on the building site Energy training of site personnel (using, e.g., BUILD-UP Skills) Air-permeability testing and thermal scanning of the finished building</p>	<p><i>Minimum requirement:</i> Documentation of the amount of renewable or recycled construction materials Construction and demolition waste reported according to the European Union’s waste list classification</p>	<p><i>Award criteria:</i> Innovative construction processes that help to lower the carbon footprint of the building. Verification of the carbon savings through comparative calculation according to EN 15978</p>
D. Design and build contracts		
Implementation of the above criteria (A–C)		
E. Design, build and operate contracts		
Implementation of the above criteria (A–C) Environmental management scheme required from real-estate maintenance companies		

Note: ^a Renewable materials must be sustainably sourced. Recycled materials need to fulfil the requirements of respective national regulations.

7. Discussion

7.1 Comparison with other Nordic countries

During the Nordic Climate Forum for Construction 2019 in Malmö, a comparison of the LCA methodologies for buildings was presented. It was based on interviews of each Nordic country’s authority which is in charge of the development of the LCA methods for buildings. The results reflect the ongoing development of the Danish voluntary building certification scheme and studies commissioned by the (Danish Transport, Construction and Housing Authority n.d.), the Norwegian approach based on standard NS 3720 (Standard Norge 2018) and the Swedish approach based on the decree proposal for ‘Climate declaration’ of buildings (Boverket 2018). For Iceland, the survey was based solely on interviews.

To ensure a European comparison, the results were summarised in the format applied by Frischknecht *et al.* (2019). In addition to the Nordic methodologies, the beta version of the European Commission’s Level(s) framework was also included in the comparison (Dodd *et al.* 2017). The comparison was made for temporal and physical system boundaries. **Tables 5–7** present the comparisons.

By comparing the Nordic approaches with each other, it can be seen that the included building types are very similar (**Table 7**). However, the physical and temporal system boundaries show greater variance (**Tables 5** and **6**). This indicates a need for further development if the Nordic goal (Nordic Council of Ministers 2019) of working towards the harmonisation of the LCA approach to buildings is aimed for.

Table 5: Temporal system boundaries in Nordic assessment schemes and their drafts.

	Production			Construction		Use							End of life				Additional
	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
Denmark (LCAbyg)	x	x	x						x		x				x	x	
Finland	x	x	x	x	x			x	x		x		x	x	x	x	x
Iceland	x	x	x	x	x		?	?	?	?	?				x	x	
Norway	x	x	x	?	?		?	?	x	x							
Sweden ^a	x	x	x	x	x												
Level(s) beta	L1	L1	L1	L2	L2	L2	L2	L2	L1	L1	L1	L2	L2	L2	L1	L1	L1

Notes: x = Included; ? = under consideration; L1 = included in Level 1 assessment; L2 = included in Level 2 assessment; L3 = included in Level 3 assessment.

^aThe new governmental assignment in Sweden requires that the full life-cycle will be integrated into the sustainability assessment in the near future. Thus, the revised temporal system boundary may include parts of modules B–D as well.

Table 6: Physical system boundaries in Nordic assessment schemes and their drafts.

		Denmark (LCAbyg)	Finland	Iceland ^a	Norway	Sweden	Level(s) beta
Sub-structure	Foundations	x	x		?	x	x
	Basement walls	x	x		?	x	x
	Ground floor structure	x	x		x	x	x
Structure	External walls	x	x		x	x	x
	Loadbearing frame	x	x		x	x	x
	External doors	x	x		x	x	x
	Windows	x	x		x	x	x
	Internal walls	x	x		x	x	x
	Floors	x	x		x	x	x
	Ceilings	x	x		x	x	x
	Roof	x	x		x	x	x
	Stairs and ramps	x	x			x	x
	Building Services	Water system	x	x			
Sewage system			x				x
Electrical system		x	x				x
Heating system		x	x				x
Cooling system		x	x				x
Ventilation system		x	x				x
Conveying system							x
Data system							x
Finishes	Fire protection system						x
	External finishes	x			?		x
	Internal finishes	x			?		x
	Fixed furniture		x				x
External	Furniture						
	Balconies	x	x				x
	Vegetation						
	Pavements		x				x

Notes: x = Included; ? = under consideration.

^aNot yet defined.

Table 7: Included building types Nordic assessment schemes and their preliminary drafts.

	Single-family	Residential	Office	Retail and restaurant	Schools and daycare	Hospitals and health	Hotels and dorms	Industrial	Sports facilities	Summer cottages	Renovation projects
Denmark (LCAByg)	×	×	×	×	×	×	×	×	×	×	×
Finland	?	×	×	×	×	×	×	×	×		?
Iceland	?	×	×	×	×	×	×	×	×		?
Norway	?	×	×	×	×	×	×	×	×		?
Sweden	×	×	×	×	×	×	×	×	×		
Level(s) beta		×	×								

Note: × = Included; ? = under consideration.

7.2 Implications: the steering impact of the assessment method

The steering impact of the assessment methods is of high importance. It is directly related to system boundaries and scenarios. If the system boundary omits important life-cycle stages or substantial parts of the building, this will ease the assessment and make its implementation into design and construction practices more acceptable. However, such a choice would not help to build an understanding of the impacts of the full life-cycle. In the Finnish method, this problem has been solved by including the full life-cycle into the assessment, but allowing the use of statistical table values for those parts of the life-cycle or those parts of the building that may be time-consuming to assess.

Setting the scenarios will also affect the results and thus have an impact on the steering mechanism of the assessment. For instance, if the GHG intensity of energy is assumed to remain stable during the entire reference study period (module B6), this choice will lead into an overestimation of energy efficiency and an underestimation of material efficiency (assuming that in reality the emissions from the energy sector would decarbonise according to existing regulations or policy roadmaps). Such a methodological choice would include an assumption that national legislation, where it includes policy measures for decarbonisation of energy, would be either altered or violated during the reference study period. On the other hand, if scenarios were overly optimistic regarding the decarbonisation of energy, the impact would be the opposite.

However, the chosen scenarios include a potential risk of the proposed assessment scheme. If the regulation on a coal ban were cancelled or postponed, then the buildings designed with optimistic scenarios for the decarbonisation of energy could unintentionally lead into higher life-cycle emissions. The same risk also applies to other life-cycle stages than B6. For example, the replacement of materials in module B4 can be considered vulnerable to scenarios that affect the impacts of the production of new products as well as energy used for repair works. This also applies to all end-of-life scenarios that include fixed reuse or recycling shares for different waste streams.

Here, the cross-comparison of different regulations becomes important. As EU member states have already adopted the Energy Performance of Buildings Directive (European Parliament & Council of the European Union 2010), they have also set maximum levels for energy consumption for buildings (Ministry of the Environment 2017a). Thus, the choice of an LCA scenario will in fact not affect the consumption of energy or the associated GHG emissions. In the Finnish assessment method, the solution has been that the bottom-up approach of building LCAs should be comparable with the national top-down GHG inventory and the consequent allocation of emissions to different end-use sectors.

8. Summary

The Finnish method for whole-life carbon assessment of buildings was presented. Alongside, the requirements for GHG emission data, the development possibilities for a generic database for LCA calculations were described. In addition, the GPP criteria for low-carbon public buildings were presented. The presented assessment method was compared with methods in other Nordic countries.

In the near future, the Nordic collaboration in the normative development of building LCAs is likely to proceed. In addition, the development and future position of the European Commission's Level(s) framework is of key importance. The resolution of the European Council for the need to revise the CPR may also bring important aspects for consideration. In addition, the national goals for reaching carbon neutrality and negativity may affect the emission quotas available for the supply and demand-side sectors. These variables will influence the evolution of the Finnish assessment method and database.

Acknowledgements

Materials and presentations from the Nordic Climate Forum for Construction 2019 were used as background for section 3.1. The authors thank the Danish Transport, Building and Housing Authority (TBST), the Swedish National Board of

Housing, Building and Planning (Boverket), the Norwegian Direktoratet for Byggkvalitet, the Icelandic Construction Authority (Mannvirkjastofnun), and the Swedish Life Cycle Center of the Chalmers University.

Competing interests

The authors have no competing interests to declare.

References

- Alwan, Z., & Jones, P.** (2014). The importance of embodied energy in carbon footprint assessment. *Structural Survey*, 32(1), 49–60. DOI: <https://doi.org/10.1108/SS-01-2013-0012>
- Andrew, R.** (2018). Global CO₂ emissions from cement production. *Earth System Science Data*, 10, 195–217. DOI: <https://doi.org/10.5194/essd-10-195-2018>
- Becqué, R., Weyl, D., Stewart, E., Mackers, E., Shen, X., & Jin, L.** (2019). *Accelerating building decarbonization: Eight attainable policy pathways to net zero carbon buildings for all*. Washington, DC: World Resources Institute.
- Biemer, J., Dixon, W., & Blackburn, N.** (2013). Our environmental handprint: The good we do. Paper presented at the *1st IEEE Conference on Technologies for Sustainability (SusTech), Portland, OR, 2013* (pp. 146–153). Portland: IEEE. DOI: <https://doi.org/10.1109/SusTech.2013.6617312>
- Bionova.** (2018). *The embodied carbon review: Embodied carbon reduction in 100+ regulations & rating systems globally*. Helsinki: Bionova. Retrieved from www.embodiedcarbonreview.com
- Boverket.** (2018). *Klimatdeklaration av byggnader: Förslag på metod och regler* [Climate declaration of buildings: A proposal for a method and rules]. Karlskrona: Boverket. Retrieved from <https://www.boverket.se/sv/om-boverket/publicerat-av-boverket/publikationer/2018/klimatdeklaration-av-byggnader/>
- Boverket.** (2019). *Klimatdeklaration vid uppförande av byggnad* [Climate declaration for buildings]. Retrieved January 3, 2020, from <https://www.boverket.se/sv/byggande/uppdrag/klimatdeklaration/>
- Boverket and Ministry of the Environment.** (2019). *Nordic Climate Forum for Construction*. (Reachem) Retrieved January 2, 2020, from <https://www.delegia.com/app/netattm/attendee/page/89247>
- Cabeza, L., Rincon, L., Vilarino, V., Perez, G., & Castell, A.** (2014). Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and building sector: A review. *Renewable & Sustainable Energy Reviews*, 29, 394–416. DOI: <https://doi.org/10.1016/j.rser.2013.08.037>
- CEN European Committee for Standardization.** (2010). *EN 15643-1:2010 Sustainability of construction works—Sustainability assessment of buildings—Part 1: General framework*. Brussels: CEN.
- CEN European Committee for Standardization.** (2011). *EN 15978. Sustainability of construction works—Assessment of environmental performance of buildings—Calculation method*. Brussels: CEN.
- CEN European Committee for Standardization.** (2014). *EN 16485. Round and sawn timber. Environmental product declarations. Product category rules for wood and wood-based products for use in construction*. Brussels: CEN.
- CEN European Committee for Standardization.** (2017). *EN 16757:2017 Sustainability of construction works. Environmental product declarations. Product Category Rules for concrete and concrete elements*. Brussels: CEN.
- Centre for Environment Education.** (n.d.). *Evolution of handprint*. Retrieved January 2, 2020, from https://www.handprint.in/handprint_legacy
- Danish Transport, Construction and Housing Authority.** (n.d.). *Publikationer*. Retrieved January 2, 2020, from <https://www.lcabyg.dk/publications>
- Department for Business, Innovation and Skills & Department of Energy and Climate Change.** (2015). *Industrial decarbonisation and energy efficiency roadmaps to 2050*. Retrieved December 19, 2019, from <https://www.gov.uk/government/publications/industrial-decarbonisation-and-energy-efficiency-roadmaps-to-2050>
- Directorate-General for Climate Action.** (2019). *Going climate-neutral by 2050: A strategic long-term vision for a prosperous, modern, competitive and climate-neutral EU economy*. Luxembourg: European Union.
- Dodd, N., Cordella, M., Traveso, M., & Donatello, S.** (2017). *Level(s)—A common EU framework of core sustainability indicators for office and residential buildings—Part 3: How to make performance assessments using Level(s)*. Seville: European Commission, Joint Research Centre (JRC).
- Dodd, N., Garbarino, E., & Gama-Caldas, M.** (2016). *Green public procurement criteria for office building design, construction and management*. Seville: European Commission, Joint Research Centre (JRC).
- Dyllick, T., & Hockerts, K.** (2002). Beyond the business case for corporate sustainability. *Business Strategy and the Environment*, 11, 130–141. DOI: <https://doi.org/10.1002/bse.323>
- ECORYS; Copenhagen Resource Institute.** (2014). *Resource efficiency in the building sector*. Rotterdam: European Commission.
- European Commission.** (2019). *The European Green Deal—Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions*. Brussels: European Commission.
- European Parliament & Council of the European Union.** (2010). *Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)*. Strasbourg: Official Journal of the European Union. Retrieved from <http://data.europa.eu/eli/dir/2010/31/oj>

- European Parliament & Council of the European Union.** (2011). *Regulation (EU) No. 305/2011 of the European Parliament and of the Council of 9 March 2011 laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC*. Strasbourg: European Parliament & Council of the European Union. Retrieved January 4, 2020, from <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32011R0305>
- Finlex.** (2015). *Climate Change Act 609/2015*. Helsinki: Ministry of the Environment. Retrieved from <https://www.finlex.fi/en/laki/kaannokset/2015/en20150609?search%5Btype%5D=pika&search%5Bkieli%5D%5B0%5D=en&search%5Bpika%5D=climate>
- Finnish Government.** (2019). *Inclusive and competent Finland—A socially, economically and ecologically sustainable society. Programme of Prime Minister Sanna Marin's Government 2019*. Helsinki: Finnish Government. Retrieved from <http://urn.fi/URN:ISBN:978-952-287-811-3>
- Finnish Government.** (2019). *Julkiset hankinnat ratkaisemaan ilmastokriisiä* [Solving the climate crisis with the help of public procurement]. Retrieved January 3, 2020, from https://valtioneuvosto.fi/artikkeli/-/asset_publisher/10623/julkiset-hankinnat-ratkaisemaan-ilmastokriisia
- Fossilfritt Sverige.** (2020). *Roadmaps for fossil free competitiveness* (Statens offentliga utredningar). Retrieved December 19, 2019, from <http://fossilfritt-sverige.se/in-english/roadmaps-for-fossil-free-competitiveness/>
- Frischknecht, R., Balouktsi, M., Lützkendorf, T., Aumann, A., Birgisdottir, H., Grosse Ruse, E., Alexander Hollberg, Kuittinen, M., Lavagna, M., Lupišek, A., Passer, A., Peupartier, B., Ramseier, L., Röck, M., Trigaux, D., & Vancso, D.** (2019). Environmental benchmarks for buildings: needs, challenges and solutions—71st LCA forum, Swiss Federal Institute of Technology, Zürich, 18 June 2019. *International Journal of Life Cycle Assessment*, September. DOI: <https://doi.org/10.1007/s11367-019-01690-y>
- Government Communications Department.** (2018). *Eight parties in Parliament decide on common climate policy goals*. Retrieved December 19, 2019, from https://valtioneuvosto.fi/en/article/-/asset_publisher/10616/kahdeksan-eduskuntapuoluetta-paatti-yhteisista-ilmastopolitiikan-tavoitteista
- Government of Finland.** (2016). *Government report on the National Energy and Climate Strategy for 2030*. Helsinki: Government of Finland. Retrieved from <https://tem.fi/energia-ja-ilmastostrategia>
- Grönman, K., Pajula, T., Sillman, J., Leino, M., Vatanen, S., Kasurinen, H., Soininen, A., & Soukka, R.** (2019). Carbon handprint—An approach to assess the positive climate impacts of products demonstrated via renewable diesel case. *Journal of Cleaner Production*, 206, 1059–1072. DOI: <https://doi.org/10.1016/j.jclepro.2018.09.233>
- Haahtela-kehitys Oy, Rakennustietosäätiö RTS & Rakennustieto Oy.** (2010). *Construction 2000 classification*. Helsinki: Haahtela-kehitys Oy & Building Information Foundation RTS.
- Hirsch, J., Lafuente, J. J., Recourt, R., Spanner, M., Geiger, P., Haran, M., McGreal, S., Davis, P., Taltavull, P., Perez, R., Juárez, F., Martinez, A. M., & Brounen, D.** (2019). *Stranding risk & carbon. Science-based decarbonising of the EU commercial real estate sector*. Wörl: Carbon Risk Real Estate Monitor (CRREM).
- Häkkinen, T., Kuittinen, M., Ruuska, A., & Jung, N.** (2015). Reducing embodied carbon during the design process of buildings. *Journal of Building Engineering*, 4, 1–13. DOI: <https://doi.org/10.1016/j.job.2015.06.005>
- Häkkinen, T., & Pesu, J.** (Forthcoming 2019). *Vähähiilisen rakentamisen päästötietokannan laatiminen ja käyttötarpeet* [Establishment and needs for an emission database for low-carbon construction]. Helsinki: Ministry of the Environment.
- Häkkinen, T., & Ruuska, A.** (2013). Environmental and economical assessment of refurbishment concepts. *Proceedings of SB13 Graz, Austria: Sustainable Buildings, Construction Products and Technologies, 25–28 September 2013* (p. 8). Graz: TU Graz.
- Häkkinen, T., Ruuska, A., Vares, S., Pulakka, S., Kouhia, I., & Holopainen, R.** (2012). *Methods and concepts for sustainable renovation of buildings*. VTT Technology. Retrieved from <http://www.vtt.fi/publications/index.jsp>
- Häkkinen, T., & Vares, S.** (2018). *Impact assesment of different measures for controlling GHG emissions of buildings*. Espoo: VTT Technical Research Centre of Finland. Retrieved from <https://www.vtt.fi/inf/pdf/technology/2018/T324.pdf>
- ISO.** (2006a). *ISO 14040 Environmental management—Life cycle assessment—Principles and framework*. Geneva: International Organization for Standardization (ISO).
- ISO.** (2006b). *EN ISO 14044. Environmental management—Life cycle assessment—Requirements and guidelines*. Geneva: International Organization for Standardization (ISO).
- ISO.** (2018). *ISO 14067. Greenhouse gases. Carbon footprint of products. Requirements and guidelines for quantification and communication*. Geneva: International Organization for Standardization (ISO).
- IPCC.** (2018). Special report: Global warming of 1.5°C. World Meteorological Organization (WMO) and United Nations Environment Programme (UNEP). Retrieved from <https://www.ipcc.ch/sr15/>
- Kangas, H.-L., Sankelo, P., Kautto, P., Ruokamo, E., Lazarevic, D., Mattinen-Yuryev, M., Turunen, Y., & Nissinen, A.** (2019). *Use of financial incentives to guide low-carbon construction* (Publications of the Ministry of Environment No. 2019:32). Helsinki: Ministry of Environment. Retrieved from https://julkaisut.valtioneuvosto.fi/bitstream/handle/10024/161923/YM_2019_32.pdf?sequence=1&isAllowed=y
- Kasurinen, H., Vatanen, S., Grönman, K., Pajula, T., Lakanen, L., Salmela, O., & Soukka, R.** (2019). Carbon handprint: Potential climate benefits of a novel liquid-cooled base station with waste heat reuse. *Energies*, 12(23). DOI: <https://doi.org/10.3390/en12234452>

- Khasreen, M., Banfill, P., & Menzies, G.** (2009). Life-cycle assessment and the environmental impact of buildings: A review. *Sustainability*, 1(3), 674–701. DOI: <https://doi.org/10.3390/su1030674>
- Koljonen, T., Soimakallio, S., Lehtilä, A., Similä, L., Honkatukia, J., Hildén, M., Rehunen, A., Saikku, L., Salo, M., Savolahti, M., Tuominen, P., & Vainio, T.** (2019). *Pitkän aikavälin kokonaispäästökehitys* [Long-term development of total emissions]. Helsinki: Prime Minister's Office. Retrieved from <http://urn.fi/URN:ISBN:978-952-287-656-0>
- Kuittinen, M.** (2019). *Method for the whole life carbon assessment of buildings*. Helsinki: Ministry of the Environment. Retrieved from <http://urn.fi/URN:ISBN:978-952-361-030-9>
- Kuittinen, M., & le Roux, S.** (2017). *Procurement criteria for low-carbon building*. Helsinki: Ministry of the Environment.
- Kühnen, M., Silva, S., Beckmann, J., Eberle, U., Hahn, R., Hermann, C., Schaltegger, S., & Schmid, M.** (2019). Contributions to the sustainable development goals in life cycle sustainability assessment: Insights from the Handprint research project. *Sustainability Management Forum*, 27(1), 65-82. DOI: <https://doi.org/10.1007/s00550-019-00484-y>
- Lützkendorf, T., & Baloutski, M.** (2016). *Guideline for designers and consultants. Evaluation of embodied energy and GHG emissions for building construction* (IEA EBC Annex 57). IEA.
- Material Economics.** (2018). *Circular economy—A powerful force for climate mitigation. Transformative innovation for prosperous and low-carbon industry*. Helsinki: Sitra.
- Ministère de la Transition écologique et solidaire & Ministère de la Cohésion des territoires et des Relations avec les collectivités territoriales.** (2019). *Bâtiment à énergie positive & réduction carbone: Background*. Retrieved January 3, 2020, from <http://www.batiment-energiecarbone.fr/en/background-a1.html>
- Ministry of Economic Affairs and Employment.** (2016). *Act on public procurement and concession contracts 1397/2016*. Helsinki: Ministry of Economic Affairs and Employment.
- Ministry of Economic Affairs and Employment of Finland.** (2019). *Vähähiiliset tiekartat 2035* [Low carbon roadmaps 2035]. Retrieved December 19, 2019, from <https://tem.fi/tiekartat>
- Ministry of Economic Affairs and Employment of Finland.** (n.d.). *Hankintailmoitukset* [Statistics of public tenders]. Retrieved January 3, 2020, from www.hankintailmoitukset.fi
- Ministry of the Economic Affairs and Employment.** (2016). *Pitkän aikavälin kokonaispäästökehitys* [Long-term development of total emissions]. Helsinki: Ministry of the Economic Affairs and Employment.
- Ministry of the Environment.** (2017a). *Decree of the Ministry of the Environment on the Energy Performance of New Buildings*. Helsinki: Ministry of the Environment.
- Ministry of the Environment.** (2017b). *Vähähiilisen rakentamisen tiekartta* [Roadmap for low carbon construction]. Retrieved January 3, 2020, from https://www.ym.fi/fi-FI/Maankaytto_ja_rakentaminen/Rakentamisen_ohjaus/Vahahiilinen_rakentaminen/Vahahiilisen_rakentamisen_tiekartta
- Ministry of the Environment.** (2019). *Laki hiilen energiakäytön kieltämisestä* [Act on the prohibition of the use of coal for energy]. Helsinki: Ministry of the Environment.
- Moncaster, A., & Symons, K.** (2013). A method and tool for 'cradle to grave' embodied carbon and energy impacts of UK buildings in compliance with the new TC350 standard. *Energy and Buildings*, 66, 514–523. DOI: <https://doi.org/10.1016/j.enbuild.2013.07.046>
- Nordic Council of Ministers.** (2019). *Nordic declaration on low carbon construction and circular principles in the construction sector*. Copenhagen: Nordic Council of Ministers for Sustainable Growth. Retrieved from <https://www.norden.org/en/declaration/nordic-declaration-low-carbon-construction-and-circular-principles-construction-sector>
- Norris, G.** (2015). *Handprint-based net positive assessment*. Boston: Center for Health and the Global Environment, Harvard T. H. Chan School of Public Health.
- Pajula, T., Vatanen, S., Pihkola, H., Grönman, K., Kasurinen, H., & Soukka, R.** (2018). *Carbon handprint guide*. Espoo: VTT Technical Research Centre of Finland.
- Rakennustietosäätiö RTS.** (2011). *LVI2010-nimikkeistö* [HVAC 2010 classification]. Helsinki: Rakennustietosäätiö.
- Ruuska, A., & Häkkinen, T.** (2014). The significance of various factors for GHG emissions of buildings. *International Journal of Sustainable Engineering*, 8(4–5), 317–330. DOI: <https://doi.org/10.1080/19397038.2014.934931>
- Röck, M., Mendes Saade, M., Balouktsi, M., Nygaard Rasmussen, F., Birgisdottir, H., Frischknecht, R., Habert, G., Lützkendorf, T., & Passer, A.** (2019). Embodied GHG emissions of buildings—The hidden challenge for effective climate change mitigation. *Applied Energy*, 258, 114107. DOI: <https://doi.org/10.1016/j.apenergy.2019.114107>
- Sala, S., Farioli, F., & Zamagni, A.** (2013). Progress in sustainability science: lessons learnt from current methodologies for sustainability assessment: Part 1. *International Journal of Life Cycle Assessment*, 18(9), 1653–1672. DOI: <https://doi.org/10.1007/s11367-012-0508-6>
- Sähkötieto ry.** (2016). *S2010-sähkönimikkeistö* [S2010 classification for electric parts]. Espoo: Sähkötieto ry.
- Säynäjoki, A., Heinonen, J., & Junnila, S.** (2012). A scenario analysis of the life cycle greenhouse gas emissions of a new residential area. *Environmental Research Letters*, 7(3), 10. DOI: <https://doi.org/10.1088/1748-9326/7/3/034037>
- Sokka, L., Correia, S., & Koljonen, T.** (2018). *Lämmityspolttoaineiden tuotannon elinkaariset kasvihuonekaasupäästöt*. Espoo: VTT Technology.
- Standard Norge.** (2018). *NS 3729:2018 Metode for klimagassberegninger for bygninger* [Method for greenhouse gas calculations for buildings]. Lysaker: Standard Norge.

- Statistics Finland.** (n.d.). *Rakentamisen tilastot* [Construction statistics]. Retrieved January 3, 2020, from <https://www.stat.fi/til/rak.html>
- Swedish Life Cycle Center.** (2019). *Summary of round table discussions during Nordic Climate Forum for Construction 3 Oct 2019*. Malmö: Swedish Life Cycle Center. Retrieved from <https://www.lifecyclecenter.se/projects/nordic-working-group-for-harmonization-lca-climate-and-buildings/>
- The Nordic Prime Ministers.** (2019). *Joint statement of the Nordic Prime Ministers and the Nordic CEOs for a sustainable future*. Reykjavik: Nordic Council of Ministers. Retrieved from <https://www.norden.org/en/declaration/joint-statement-nordic-prime-ministers-and-nordic-ceos-sustainable-future>
- UNEP.** (2019). *Emissions gap report, Annex B*. Nairobi: United Nations Environment Programme (UNEP).
- Vares, S., Häkkinen, T., Ketomäki, J., Shemeikka, J., & Jung, N.** (2019). Impact of renewable energy technologies on the embodied and operational GHG emissions of a nearly zero energy building. *Journal of Building Engineering*, 22, 439–450. DOI: <https://doi.org/10.1016/j.jobe.2018.12.017>
- Von der Leyen, U.** (2019). *A union that strives for more. Political guidelines for the next European Commission 2019-2024*. Candidate for President of the European Commission. Publication Office of the EU. <https://op.europa.eu/en/publication-detail/-/publication/43a17056-ebf1-11e9-9c4e-01aa75ed71a1>
- World Green Building Council.** (2019). *Bringing embodied carbon upfront*. New York: World Green Building Council.
- World Resource Institute.** (2019). *Zero carbon buildings for all: Climate Action Summit 2019*. New York: World Resource Institute.

How to cite this article: Kuittinen, M., & Häkkinen, T. (2020). Reduced carbon footprints of buildings: new Finnish standards and assessments. *Buildings and Cities*, 1(1), pp. 182–197. DOI: <https://doi.org/10.5334/bc.30>

Submitted: 06 January 2020

Accepted: 20 April 2020

Published: 03 June 2020

Copyright: © 2020 The Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC-BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited. See <http://creativecommons.org/licenses/by/4.0/>.