Project on LCA and socioeconomics

Task 2 - Analysis of other countries' approach to building LCA

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Content

1. Introduction

This study was conducted by the Danish Technological Institute (DTI) and Ramboll for the Danish Housing and Planning Authority, 2.-21. October 2020. The study was updated April 2021 to reflect the content of the political agreement on the Danish National Strategy for Sustainable Construction from March 2021. The agreement entails, among others, an introduction of limit values for CO_2 for new buildings from 2023. Possible developments in the other Nordic countries are not covered by this update.

The study is part of a larger project on green buildings, life cycle assessments (LCA) and socioeconomics. This part of the study focuses on the different perspectives for life cycle assessments of buildings in the four Nordic countries: Denmark, Sweden, Norway and Finland.

2. Objectives

The objective of this part of the study is to compile knowledge and experience on building LCA from the four Nordic countries: Denmark, Sweden, Norway and Finland. Based on the desk research the variations in LCA methods, databases, benchmarks and regulation across the four countries will be illustrated. The differences will be assessed and clearly described to form a transparent basis for legislators and the building industry.

3. Methods

The parameters to be analysed, as well as the relevant schemes, methods, standards, pieces of legislation and LCA tools, have been chosen based on a preliminary list (Excel-sheet) provided by TBST ("Nordic LCA comparison") and developed by different experts in the Nordic countries. The list has then been updated and extended by experts from DTI and Rambøll based on their experience with the topic. The final list of investigated parameters, which can be seen in its entirety in Appendix A, includes e.g. reference study period, reference service life, life cycle phases, building components and reference unit as well as available calculation tools.

The single parameters and research questions have then been investigated by coupling literature research with interviews with relevant key-persons, as described below.

3.1. Desk Literature Research

Relevant reports, documents, standards, manuals and legislation have been examined, with the purpose of investigating the analysed parameters as much as possible. The preliminary literature screening has allowed to target the questions in the subsequent interviews to few, still unclarified points. The list of consulted literature is reported in Section 6.

3.2. Interviews

Interviews with relevant experts from the four Nordic countries included in this study have been conducted. Table 1 provides an overview over interviewed experts, their affiliation and primary focus, among others.

Table 1 List of interviewed experts.

Expert name	***Affiliation***	***Country***	***Primary focus***	***Interviewed by***	***Interviewed when***
Sarah Cecilie Andersen	EPD Danmark	Denmark	EPD use in Denmark	Stefania Butera, Asger Karl, DTI	10.09.2020
Luzie Rück	Danish Housing and Planning Authority	Denmark	Voluntary sustainability class and upcoming legislation in Denmark.	Stefania Butera, Asger Karl, DTI	11.09.2020
Ingunn Marton	Directorate for building quality (Direktoratet for byggkvalitet - DIBK)	Norway	Use of building LCA in Norway	Stefania Butera, Asger Karl, DTI	14.09.2020
Kristian Bøe	Rambøll	Norway	Use of BREEAM in Norway	Stefania Butera, Asger Karl, DTI	14.09.2020
Lars Petten Bingh	Statsbygg	Norway	Use of building LCA in Norway	Stefania Butera, Asger Karl, DTI	14.09.2020
Harpa Birgisdóttir	Build AAU	Denmark	LCAbyg, Voluntary sustainability class	Stefania Butera, Asger Karl, DTI	15.09.2020
Maria Rydberg	Swedish Life Cycle Center (SLC)	Sweden	Upcoming legislation in Sweden (Klimat-deklaration)	Nana Lin Rasmussen, Lise Hvid Horup Sørensen, Rambøll	11.09.2020
Sanni Heikkinen	Rambøll	Finland	Upcoming legislation in Finland (Climate Declaration) and RTS certification scheme	Nana Lin Rasmussen, Christine Collin, Rambøll	11.09.2020
David Althoff Palm David Linden	Rambøll	Sweden	Practical use of LCA, with focus NollCO2, Miljöbyggnad, BREEAM-SE	Nana Lin Rasmussen, Lise Hvid Horup Sørensen, Rambøll	14.09.2020
Kristina Einarsson Cathrine Engström	Boverket	Sweden	Upcoming legislation in Sweden (Klimat-deklaration)	Nana Lin Rasmussen, Lise Hvid Horup Sørensen, Rambøll	15.09.2020
Matti Kuittinen	Ministry of the Environment	Finland	Upcoming legislation in Finland (Climate Declaration)	Nana Lin Rasmussen, Christine Collin, Rambøll	29.09.2020

4. Results

4.1. Denmark – legal requirements and experiences with building LCAs

The Danish national building regulations (Bygningsreglementet 2018 or BR18) does not contain any specific requirement for building LCA. However, the Ministry of Transport, Building and Housing (Transport- og Boligministeriet) has in May 2020 introduced a *voluntary sustainability class* applicable to all building types (Trafik-, Bygge- og Boligstyrelsen, 2020) in case of both new buildings or major renovations. The class is now in a two-year test phase, and it might be introduced as legal requirement in the beginning of 2023 as part of the national building regulations after the test phase is finished. The voluntary sustainability class includes 9 requirements, which must all be met in order for the sustainability class to be awarded a building[1], and one of those requirements involves carrying out an early LCA during the project phase (when applying for building permission) and a final LCA when the construction works are completed.

In March 2021, a political agreement was made with respect to the Danish National Strategy for Sustainable Construction. It was decided to make building LCAs mandatory for new constructions, and it will be a legal requirement in the national building regulations from 2023. For buildings larger than 1000 m^2 a limit value for CO_2 of 12 kg CO_2-eq./m^2/year will be introduced in 2023. From 2025 limit values will also be introduced for buildings smaller than 1000 m^2. Finally, from 2023, a voluntary CO_2 class will be introduced with limit values lower than those included in the national building regulations (Contracting party, 2021).
Trafik-, Bygge- og Boligstyrelsen (2020) contains detailed guidelines regarding methodology and key assumptions, e.g. the LCA is to be performed according to EN15978, EN15804 and relevant product category rules (PCRs). It is recommended to use the free tool LCAbyg (developed by BUILD, AAU (Birgisdottir & Rasmussen, 2019)), however equivalent LCA software can be used, provided the same methodology and requirements are followed.

While the application of the voluntary sustainability class has necessarily been limited so far, due to its very recent introduction, *DGNB certification* has played a relatively large role regarding building LCA in the past 8 years, where 90 buildings have been certified (Green Building Council Denmark, 2020a)[2]. Here the (non-obligatory) requirement for an LCA is one of 40 criteria, however it has a relatively large weight on the final score, of 7,9 % and 5,6 % respectively for environmental impacts and energy consumption (Green Building Council Denmark, 2016). The LCA to be

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[1] During the test phase it is however possible to participate without fulfilling all criteria.
[2] Against e.g. 25 buildings certified according to BREEAM in Denmark (https://www.greenbook-live.com/search/scheme.jsp?id=202).

performed in connection with DGNB needs to include a minimum of 3 "alternatives" for selected building parts. The upcoming version of DGNB (Green Building Council Denmark, 2020b), which is expected to be introduced at the end of 2020, will contain a requirement for both an early and a final LCA, and additional LCA points will be awarded for optimising the whole building or specific building parts through LCA. LCA in connection with DGNB may be performed with e.g. LCAbyg (which had been developed, among other things, for this purpose).

4.2. Norway – legal requirements and experiences with building LCAs

In Norway there is no specific requirement for building LCA in the national legislation. However, many public building owners are setting requirements for it, e.g. Statsbygg (public buildings owner), and large municipalities (e.g. Oslo, Throndheim, Stavanger). On top of this, several projects and initiatives have promoted the use of building LCA, e.g. Future Build, ZEB and ZEN (described in more details, below).

Future Build is a cooperation between 10 partners, among which several municipalities, the Ministry of Local Government and Modernisation, the Norwegian State Housing Bank, Enova (Norwegian energy national fund), the National Office of Building Technology and Administration, the Green Building Alliance and the National Association of Norwegian Architects. It has been running from 2010 to 2020, and its goal is to complete a number of pilot projects (both new buildings and renovations) set to reduce GHG emissions from transport, energy and material consumption by at least 50 %, involving high quality architecture (Future Build, 2016). The pilot projects are meant to inspire and change practices in both the private and the public sector.

The *Zero Emission Buildings Program*, or ZEB, ran from 2011 to 2016 and aimed at developing competitive products and solutions for existing and new buildings that would lead to market penetration of buildings that have zero GHG emissions related to their production, operation and demolition (Research Centre on Zero Emission Buildings, 2011). The *Zero Emission Neighbourhood Program*, or ZEN, is the successor of ZEB, was established in 2017 and is still running (Research Centre on Zero Emission Neighbourhoods (ZEN) in Smart Cities, 2017). It aims at creating solutions for the zero emission buildings and neighbourhoods of the future by developing 9 test areas («pilot projects») spread all over Norway.

Statsbygg, the Norwegian Directorate of Public Construction and Property, is the government agency that manages the public real estate portfolio. Statsbygg sets specific requirements for the sustainability of its buildings, in particular a minimum number of EPDs to be achieved for all building projects in Statsbygg. This requirement has contributed substantially to the promotion and diffusion of EPDs in the country in the past 15 years, to the point that EPDs are now very widespread in Norway. Statsbygg is therefore currently shifting their attention to a) EPDs for products that have received little focus so far (e.g. technical installations and

Heating, ventilation, and air conditioning, HVAC), and b) specific carbon footprint requirements in project contracts. This would typically mean that an early and a final LCA are required, often including several updates. Statsbygg requires the use of LCA tool One Click LCA, which is developed by the Finnish company Bionova Ltd.

Finally, the certification scheme *BREEAM-NO* is quite widespread in Norway, having so far lead to more than 300 certified buildings since its introduction in 2012 (Norwegian Green Building Council, 2020), and it contains a requirement for building LCA. This typically consists in an early and a final LCA. BREEAM requires the development of a reference building design, which serves as a baseline to assess the final environmental performance. Often the early LCA is done on the reference building only, to get a reference for CO_2, and then the real LCA is done at the end. The Norwegian version of BREEAM (BREEAM-NO) recommends the use of One Click LCA (Bionova Ltd, 2020b), however other tools are allowed (Bøe, 2020). Extra points are though given to the use of One Click LCA, making it de facto the most widespread software used for the purpose.

4.3. Sweden - legal requirements and experiences with building LCAs

In Sweden the National Board of Housing, Building and Planning (Boverket) is the national authority that publish regulations and guidelines regarding buildings and construction (Boverket, 2019b). Boverket is currently working on an upcoming regulation, *Klimat-deklarationen*, where it will become mandatory for developers to conduct an LCA for new buildings from the 1st of January 2022, which is the first phase of the legislation. A second phase of the legislation is planned to be developed by 2027, where more strict requirements for the LCA will be introduced, and limit values for CO_2 possible introduced. Introduction of limit values depends on a political decision, though (Boverket, 2020; Finansdepartementet, 2020; Palm & Linden, 2020; Rydberg, 2020). In collaboration with the Ministry of Environment in Finland, Boverket is also developing an open generic LCA database, which is set to be done by January 2021. This generic database is to be used in building LCAs (Boverket, 2020; Swedish Life Cycle Center, 2020).

Besides the upcoming *Klimat-deklarationen*, the voluntary certification schemes for buildings, *Miljöbyggnad 3.1* and *BREEAM-SE* are already in use in Sweden. *Miljöbyggnad 3.1* is very common in Sweden and it operates with three levels of certifications; bronze, silver and gold, where different requirements regarding life cycle modules and EPDs in the LCA occur. This certification can be applied for new builds, renovations and buildings in use (Sweden Green Building Council, 2020b). *BREEAM-SE* is an international certification scheme adapted to Swedish rules and standards, for new builds, where there is no actual requirement for conducting an LCA, as the certification can be reached by obtaining more points in the other criteria (Palm & Linden, 2020). If an LCA is conducted, more points are awarded if a cradle to grave perspective is assessed compared to the mandatory cradle to gate perspective (bre, 2016b). The newest certification scheme is *Noll*CO_2 *version 1.0* (expected launch September 2020), which can be used as an add-on to the existing schemes such as Miljöbyggnad, BREEAM-SE, LEED and Svanen (Eco label). *NollCO*$_2$ is only valid for new build (Sweden Green Building Council, 2020a, 2020c). The *NollCO*$_2$ has been developed as part of The European Green Deal, where EU should be climate neutral in 2050. It is a certification system where a zero climate impact for a building is reached through the entire life cycle of the building (Sweden Green Building Council, 2020d). Even though all three certification schemes have been developed by the Swedish Green Building Council (SGBC) different requirements for conducting the LCA occur. As for the LCA-tools used in Sweden, One Click LCA is the most widely used (Palm & Linden, 2020), but *Byggsektorns miljöberäkningsverktyg* (BM-verktyget) is an upcoming tool developed by the Swedish Environmental Institute (IVL). BM-verktyget is freely available at the moment, but may potentially be licensed later on (Palm & Linden, 2020).

In Sweden more than 425 buildings have achieved a LEED certification (U.S. Green Building Council, 2020), while around 155 buildings have undergone BREEAM-SE certification for New construction and around 650 buildings have been certified under the In Use scheme (bre, 2020). More than 1500 buildings have achieved a Miljjöbyggnad certification (Sweden Green Building Council, 2020e).

4.4. Finland - legal requirements and experiences with building LCAs

In Finland the Ministry of Environment introduced a roadmap to low-carbon construction in 2017 and has since been preparing a new legislation which is expected to be launched before 2025 and probably in 2024, perhaps already in 2023, herein referred to as the *Climate Declaration* (Kuittinen, 2020). Even though it is still in a planning and testing phase it can already be used, as it is the best available guideline for climate friendly buildings in Finland (Heikkinen, 2020). In the first phase, the legislation will only apply to new builds and not renovation. After a planned second piloting round, benchmarks and results will be available and will allow to set limit values for CO_2 in the LCA legislation. In the beginning the limit values for LCAs will most likely be relatively unchallenging, as the Ministry of Environment will be collecting more data from actual projects over time (Heikkinen, 2020).

Regarding certification schemes, Finland uses the voluntary certification systems *RTS*, developed by the Building Information Foundation, which has been in use since 2017, as well as *BREEAM* and *LEED*, which are international standards. For the *Climate Declaration* and *RTS* it is mandatory to conduct an LCA, whereas for BREEAM and LEED you can obtain a certification without, depending on the ambition level of the project. For conducting LCAs One Click LCA is the most used LCA-tool in Finland and is required for the *Climate Declaration* and *RTS*. In Finland more than 350 buildings has achieved a LEED certification (U.S. Green Building Council, 2020) and almost 100 buildings have undergone BREEAM certification for New construction and around 250 buildings have been certified under the In Use scheme (bre, 2020). The RTS certification is still very new and has not awarded any certifications yet, but more than 100 projects are registered as ongoing in the certification tool (Heikkinen, 2020).

Figure 1 illustrates a timeline for the introduction of legislation in the analysed countries.

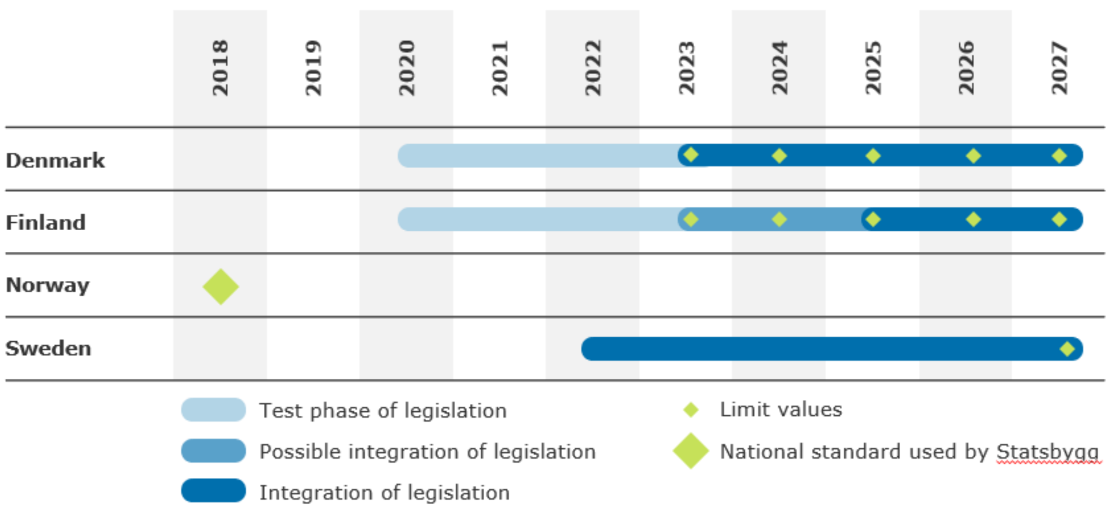

Figure 1 – Timeline for the introduction of legislation regarding building LCA in the Nordic countries and for the development of databases/case-banks and methods. In Denmark, benchmark values will in 2023 and 2024 apply only to buildings larger than 1000 m^2. From 2025 benchmark values will apply to all buildings.

4.5. Critical parameters

4.5.1. Reference study period (RSP)

The reference study period (RSP) is an expression of the number of years the building is analysed for in the LCA. Thus, the actual service life of the building may be longer than the used RSP (e.g. the average service life of Danish buildings was found to be 70 years (Østergaard et al., 2018)). The longer the RSP, the less emphasis is placed on the impacts occurring during construction phase, and greater emphasis is put on impacts occurring during the building's use phase, including replacement of materials and energy consumption during operation.

In **Denmark** both the voluntary sustainability class and the DGNB certification scheme are based on an RSP of 50 years, with no possibility of user-defined RSPs. Regarding DGNB specifically, at the time of its introduction in Denmark it was decided to use the same RSP used for DGNB Germany and internationally, i.e. 50 years. In a subsequent update of DGNB, it was chosen to use two RSPs in parallel: 50 years for all building types, and 80 years for offices, 100 years for schools, childcare institutions and hospitals, and 120 years for housing (in line with SBi 2013:30 (Aagaard et al., 2013)). The results from the two parallel calculations are then weighted. In the upcoming update of the Danish DGNB manuals, expected at the end of 2020, the RSP is expected to be limited to 50 years only. The background for the choice of an RSP of 50 years in Denmark for both the voluntary sustainability class and DGNB is manifold: on the one hand it stems from the economic depreciation periods of construction investments (Zimmermann et al., 2020), and on the other hand it was chosen to reflect common international practice, which has been found to use predominantly 50 years (Frischknecht et al., 2019; Röck et al., 2020), including the German DGNB and the European framework Level(s). A third crucial reason was however also the wish to place more focus on "current impacts" (i.e. materials and construction phase) and less on impacts happening several decades ahead (i.e. replacement of materials) in a historical moment where crucial GHG reduction goals need to be achieved in relatively short timeframes (Birgisdóttir, 2020). On the other hand, longer RSP are normally chosen to reflect expectations on the real service life of buildings (Aagaard et al., 2013; Zimmermann et al., 2020).

The Danish sustainability class requires that the following life cycle modules are covered by the LCA: A1-A5, B4, B6, C3-4, D; the DGNB certification requires on the other hand modules A1-A3, B4, B6, C3-4, while the upcoming DGNB 2020 version adds modules A4-A5 as optional (giving extra credits).

The **Norwegian** standard for building LCA (NS 3720) sets a RSP of 60 years (where all life cycle modules are covered apart from B7), and the main practice in Norway is thus adjusted accordingly, with both BREEAM-NO and Statsbygg recommending the same RSP of 60 years and the same set of life cycle modules. While users are allowed to define a different RSP if relevant (in presence of a convincing argument), this is not commonly the case, and often a calculation for the standard RSP of 60 years would be run in parallel (Bingh, 2020; Bøe, 2020). Interestingly, NS 3720 standard has introduced an extra module, B8 (Operational transport), which is also prescribed by BREEAM-NO (and by Statsbygg when deemed relevant): building placement has emerged as a critical parameter in Norway (Bøe, 2020).

In **Sweden**, the upcoming legislation, the *Klimat-deklaration*, only has a requirement to include the life cycle stages A1-A5, which is the reason why no reference study period is included in the LCA (Finansdepartementet, 2020). The same is valid for *Miljöbyggnad*, where only the life cycle modules A1-A3 or A1-A4 (depending on the certification level) are obligatory in the first phase of the legislation in 2022 (Sweden Green Building Council, 2020b). For the second phase in 2027 the plan is to have a requirement to conduct a complete LCA also including the life cycle modules B2, B4, B6 and C1-4 (Palm & Linden, 2020). For *BREEAM-SE* and *NollCO$_2$* an RSP of 60 years and 50 years respectively is applied in the LCA. For BREEAM-SE the life cycle modules A1-A4 are the minimum requirement for conducting an LCA, but if the modules B1-B7, C1-C4 D also are included extra points can be obtained from the LCA calculation (bre, 2016b)

A similar situation is found in **Finland**, where RSP of both 50 and 60 years are found depending on the scheme: while the upcoming legislation (Climate Declaration) prescribes an RSP of 50 years (covering phases A1-5, B3-4, B6, C1-4, D), both BREEAM and LEED set an RSP of 60 years. Additionally, the Climate declaration allows to have a user-defined RSP for longer than 50 years (Heikkinen, 2020).

RTS requires that modules A1-5, B1-4, B6, C1-4 are included, while BREEAM has only A1-3 as mandatory requirement (A4, B1-7, C1-4 are optional which provide extra points, if included). Mandatory life cycle modules in LEED are A1-4, B1-5, C1-4.

Figure 2 provides a summary of the reference study periods (RSP) and included life cycle modules in the four Nordic countries included in this study.

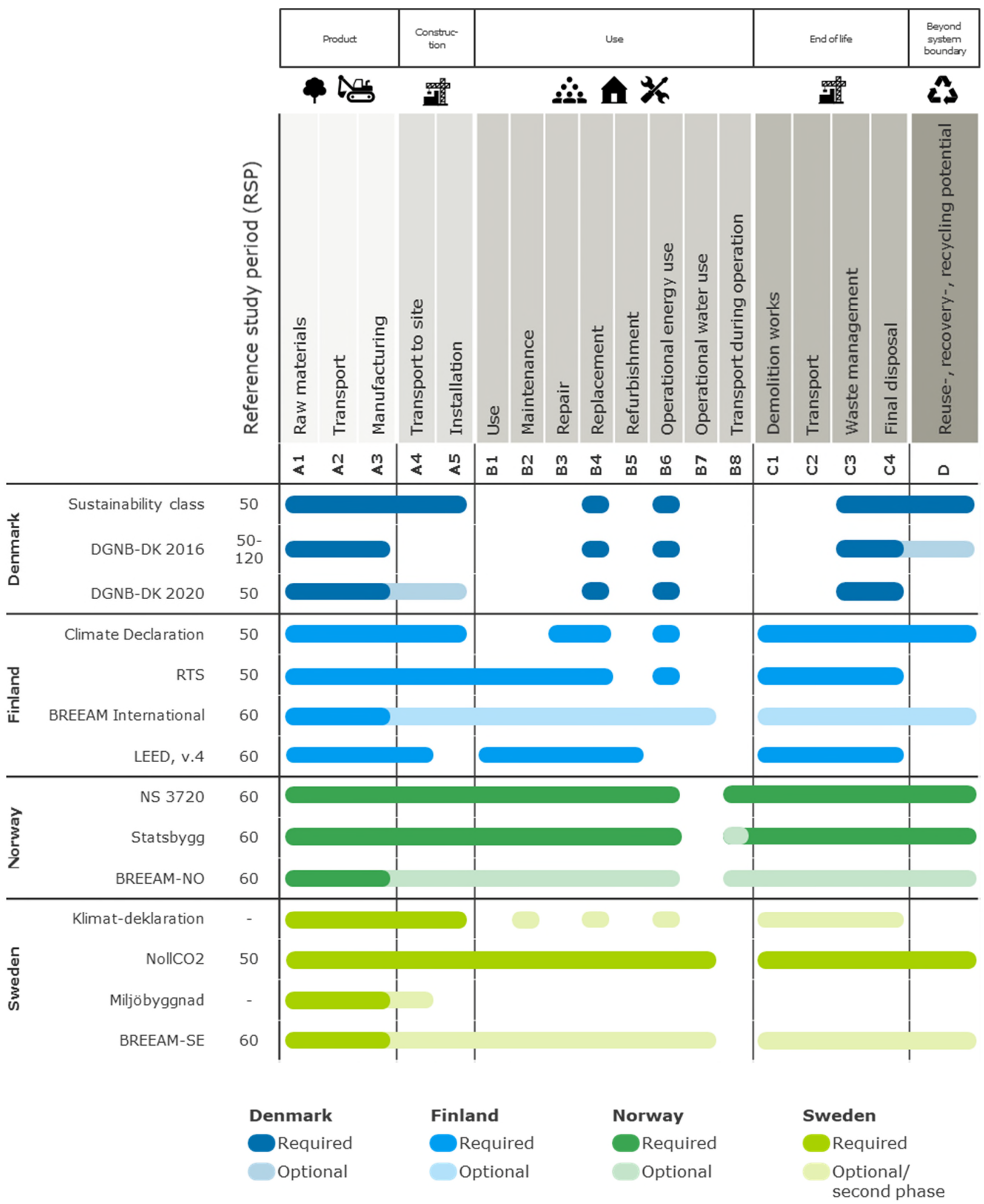

Figure 2 - Reference study periods (RSP) and included life cycle modules for the different coming legislations and certification schemes across the Nordic countries: Denmark, Finland, Norway and Sweden.

4.5.2. Reference service life (RSL)

The reference service life established for building materials and components is highly critical for the overarching building LCA results, as it dictates the number of replacements that are required for the given material/component over the course of the reference study period.

In **Denmark** the RSL for building materials and/or components is based on a report by BUILD (previously SBi) from 2013 (Aagaard et al., 2013; Zimmermann et al., 2020). This report forms the basis for applied RSL in building LCAs, both in the voluntary sustainability class and in DGNB certification schemes – 2016 & 2020 (Green Building Council Denmark, 2016, 2020b). In Denmark RSL values found in EPDs are typically not used, since the SBi values for RSL are generally longer and widely accepted (Collin, 2020).

In the voluntary sustainability class RSL values are fixed, meaning that user-modified RSL of building components are not allowed. On the contrary, this will be possible in DGNB calculations, if the modification is properly motivated and there is documentation/declaration available from the manufacturer.

In **Norway** the RSL used in the LCA calculations is taken from the representative EPDs, where the RSL is determined based on harmonised European standards, with rules put forth for service lives based on "...empirical, probabilistic, statistical, deemed to satisfy or research (scientific) data..." (EN15804). As such the RSL may be determined in a number of different ways.

An option exists for user-modified RSL of specific building materials and/or components, if the LCA practitioner deems it relevant, however it is only possible with proper arguments and documentation (Bingh, 2020). The same methodology is applied in the One Click LCA tool, where the RSL is based on values found in EPDs, and with the option for used-modified RSL should the need arise.

In **Sweden**, the RSL is not relevant for the Klimat-deklaration and Miljöbyggnad, as both schemes only declare the construction phase. For BREEAM SE the approach is to first check the service life in the EPD. If this is not available, or the RSL is not reported, then the construction product declaration (BPD), a common Swedish form for reporting environmental information, should be checked. If an RSL is not available there, then the supplier/contractor or building engineer should be contacted for an estimation (Palm & Linden, 2020).

In **Finland**, the Climate Declaration is based on the use of One Click LCA, which has pre-defined RSL values for different building constructions depending on the applied building materials. (Heikkinen, 2020).

4.5.3. Impact categories

Across all Nordic countries and analysed schemes, the impact categories receiving the most attention is global warming potential (GWP). However other categories can typically be included as either mandatory (only in Denmark) or voluntary (e.g. Ozone Depletion Potential, ODP, Photochemical Ozone Creation Potential, POCP, Acidification Potential, AP, Eutrophication Potential, EP, Abiotic Resource Depletion Potential, ADP, Primary Energy, PE). Weighting is not commonly performed, however it is applied in the Danish DGNB. Figure 3 illustrates the different impact categories which are included in the different voluntary certification schemes and legislations in the four investigated Nordic countries; Denmark, Finland, Norway and Sweden.

From Figure 3 it can be noticed that the impact category Global Warming Potential, GWP, is the only impact category which recurs as a requirement for the LCA results in every certification scheme and potentially upcoming legislation. Furthermore, **Denmark** is the only country where there is a requirement to include impact categories besides GWP for all studies schemes. For both the DGNB-DK 2016 and the DGNB-DK 2020 a weighting of the impact categories is applied and GWP has the highest contribution of 40 % to the total score, whereas the other impact categories contribute between 10 %-15 % each. For the voluntary sustainability class no weighting applies for the different impact categories, and as for now there is no concrete plan of introducing this at a later stage (Trafik- Bygge- og Boligstyrelsen, 2020). In **Finland** the upcoming legislation, the Climate Declaration, only has a requirement for reporting the GWP of the building, which is also the case for the RTS certification. However, in the long run the RTS certification scheme should include several impact categories (Heikkinen, 2020). The LEED certification scheme, which is used in Finland, requires GWP to be reported along with two optional other impact categories (see Figure 3) (U.S. Green Building Council, 2017). For BREEAM, BREEAM-NO and BREEAM-SE it is possible to obtain extra points for the LCA if two additional impact categories are included (Bøe, 2020; bre, 2016b). In **Sweden**, both the upcoming legislation, Klimat-deklaration, and the two national certification schemes developed by Sweden Green Building Council , NollCO_2 and Miljöbyggnad, only have requirements regarding the GWP impact category (Finansdepartementet, 2020; Sweden Green Building Council, 2020c, 2020b). In **Norway** Statsbygg follows the Norwegian standard NS 3720:2018 for which the primary indicator is GWP; other indicators may be required by Statsbygg in other parts of the sustainability assessment, but not as a specific requirement for the LCA (Bingh, 2020).

Generally, there is a tendency to have the largest focus on the impact category GWP in the LCA in the Nordic countries.

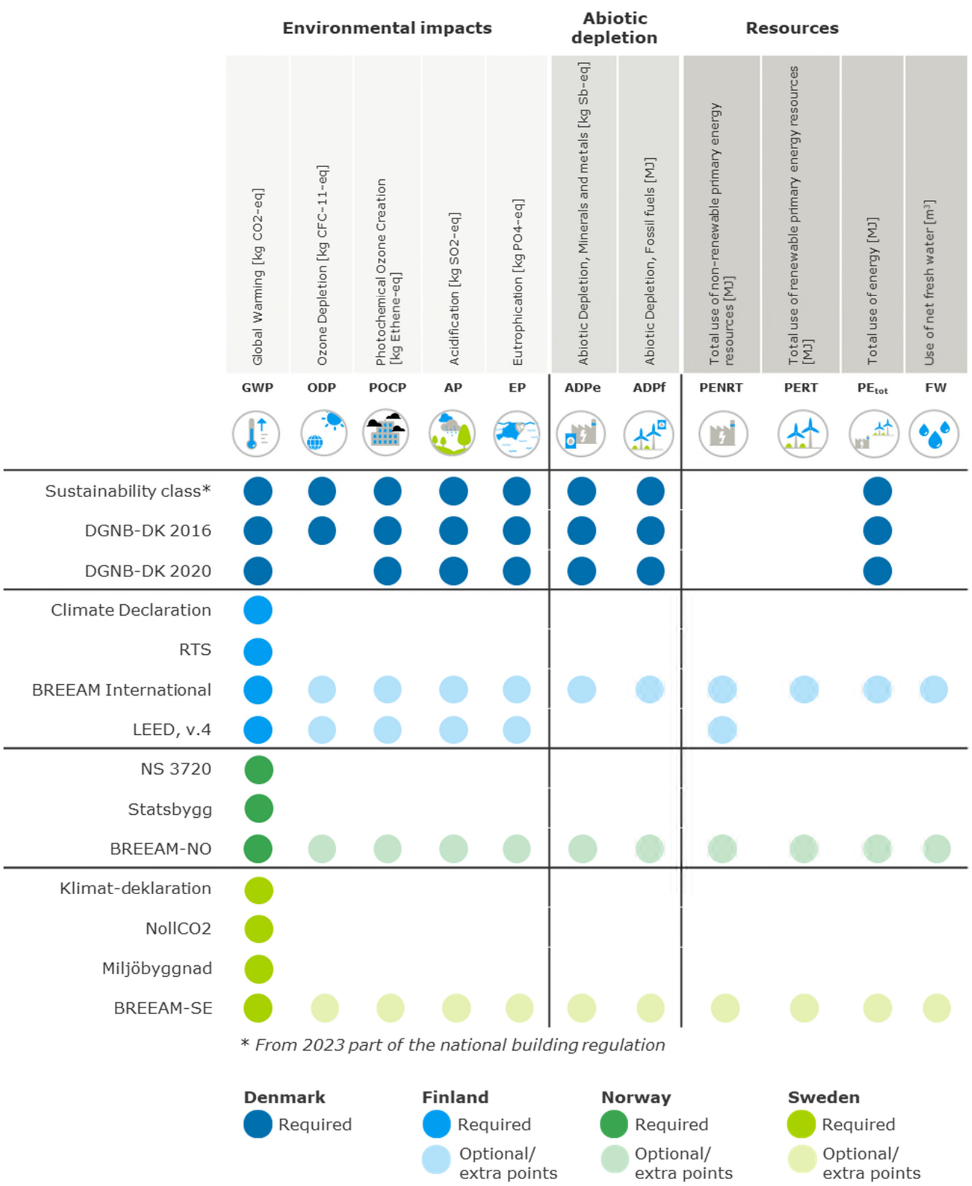

Figure 3 - Different impact categories included in the LCA calculation (required and optional) for the different certification schemes and legislation across the Nordic countries; Denmark, Finland, Norway and Sweden. For BREEAM International, BREEAM-SE and BREEAM-NO only GWP is required to document. Because it is optional which two additional impact categories are addressed it is possible that impact categories besides the above listed would be addressed.

4.5.4. Reference values, compliance, and verification

Different countries, schemes and legislations may base their building LCA requirements on different conceptual approaches regarding compliance or credit achievement. For example, the most basic requirement might simply be that an LCA is performed, without any further provision or condition about the very performance of the building. Another approach may be that a certain reference value has to be met in order to obtain a credit, or that increasing credit is awarded with increasing performance above a certain threshold. This reference-based approach can in turn be based on either *internal* baseline values, or *external* benchmark values, as described below.

The benchmark method involves the comparison of the LCA results against an externally set, fixed reference value, sometimes referred to as a benchmark or a limit value. This is the case in e.g. DGNB and RTS, and may potentially become the case for the upcoming legislation Finland (2025) and Sweden (2027). The drawback associated to this approach is the focus on the final design rather than on the optimisation process during the design. This barrier is accounted for in the newest version of the DGNB certification (DGNB-DK 2020) as well as in the voluntary sustainability class in Denmark. In DGNB-DK 2020 credits can be achieved for conducting LCAs during the design stages both for the entire building and for building components. In the voluntary sustainability class, it is mandatory to conduct an LCA at the early design, prior to the building application.

The baseline method requires on the other hand the definition of a baseline scenario in the early building design stages (and thus in the early LCA). This scenario, and the reference values associated with it, is thus project-specific and internally set. When the final design is set and the final LCA is performed, the LCA results have to be compared against the initially calculated baseline to obtain credits. This is the methodology used in e.g. LEED and BREEAM. One Click LCA has an integrated function for defining reference buildings based on the type, size and height of a building. The drawback of this method is the credibility of the baseline building scenarios, either implemented by a tool or by a practitioner, due to e.g. lack of LCA expertise, or simply due to the high uncertainty level during the design stages, the baseline model may be outdated. Sometimes the baseline models from tools like One Click LCA have very large ranges and must be modified to be used (Bøe, 2020).

In the **Danish** voluntary sustainability class the only requirement is actually that an early and a final LCA is performed, and this is currently checked by BUILD AAU. From 2023, documentation of a final LCA of the building as build, will be part of the legal requirements in the national building regulations similar to the current technical requirements. The municipality responsible for the building permit will check if the requirements are fulfilled (performed by 10% sample checks).

In the Danish voluntary sustainability class there is currently no limit or reference values to comply with. In March 2021, a political agreement was made with respect to the Danish National Strategy for Sustainable Construction. For buildings larger than 1000 m^2 a limit value for CO_2 will be introduced in 2023. From 2025 limit values will also be introduced for buildings smaller than 1000 m^2 (Contracting party, 2021). Similar to the requirement of performance of a final LCA, the limit values will be part of the national building regulations and will be checked by the municipality responsible for the building permit (performed by 10% sample checks).

DGNB does not strictly require an LCA, however if this is performed, its results have to be compared to an external limit value (benchmark approach), which is based on BR15 and calculations by BUILD AAU. Both third party verification and compliance check of the LCA results are carried out by BUILD AAU. If the criteria are not met, no points are awarded concerning the LCA.

In **Norway** both Statsbygg and BREEAM-NO require the creation of a “reference” building, which is a simplified model of the project building for which LCA results are calculated using generic values for the materials (following a baseline approach as described above). This reference building serves as part of the early LCA and establishes the baseline for the building. The actual requirements consist in the documentation of improved environmental performance of the building in the final LCA compared to the early, baseline LCA, through e.g. improved material choices, design choices, and other factors that may influence the LCA calculations. Therefore, while there is no actual external reference values to comply with yet, there is still a reference value of sorts (a baseline value) to adhere to through the reference-building calculation method. External reference values are however an ambition for the future (Bingh, 2020).

With respect to BREEAM-NO certification, the LCA results have to be verified by BRE Global, and failure to comply with the limit value for reduction compared to the reference building will result in a lower certification score (Norwegian Green Building Council, 2016b).

Statsbygg projects are also verified internally by Statsbygg experts, in order to ensure compliance with the set requirements for reductions compared to the reference building, performed post-construction to ensure the accuracy of the LCA and the compliance with limit-values. Failure to uphold the calculations of the LCA may result in financial sanctions, this has however not been necessary so far (Bingh, 2020).

The RTS certification in **Finland** requires that LCA results are compared to an external limit value (benchmark approach), which is yet to be defined. Third party verification of the LCA is performed by RTS auditors, who are trained experts authorised by the Building Information Foundation RTS. In LEED, the building’s structure and enclosure must show a 10 % reduction compared to a baseline building the project building should be compared against. Furthermore, none of the (minimum) three analysed impact categories may increase more than 5 % compared to the baseline building (U.S. Green Building Council, 2017). The LCA is third party verified by the USGBC. In the upcoming legislation it is expected that compliance will be based on a benchmark approach, and that sanctions for non-compliance will be introduced. It is still uncertain whether a verification of the LCA will be required (Heikkinen, 2020).

In **Sweden** Boverket is very keen on emphasising that the most important point of the introduction of LCA requirement is to learn. Thus, there will be no requirements on reaching a certain reference value for the LCA in the first phase during the first phase of the Klimat-deklaration in 2022 (similarly to the Danish voluntary sustainability class). During this phase, only sample controls will be conducted on building LCAs, and this verification will be conducted by Boverket. In the second phase (in 2027) limit values may be introduced, in which case all LCAs will be checked by a 3rd party verifier. However, the actual introduction of reference values will be a political decision. In case of non-compliance with the LCA requirements, fees will be given as a sanction. It is possible that these sanction fees, which can be up to 500.000 SEK in the worst case, will already be introduced in 2022, however a final decision on this is still pending (Einarsson & Engström, 2020).

Also for NollCO_2 and Miljöbyggnad certifications a verification of the LCA is required to achieve the actual building certification. In Miljöbyggnad the LCA is 3rd party verified and the actual certification is to be based on project material which must be verified no longer than 3 years after the commissioning of the building. In the NollCO_2 different baseline buildings are used to calculate a limit value to be used in the specific project. From these baseline values a project specific limit value is calculated for the life cycle modules A1-3. This calculation is conducted in SGBCs "NollCO_2 Baseline"-tool. The limit value indicates that the baseline for the building without basement should be reduced by 30%, but if it is possible to reduce the baseline for only the basement by any percentage this reduction would be sufficient (Sweden Green Building Council, 2020d). In Miljöbyggnad there is no limit value which should be reached to achieve the certification, but in order to reach a gold certification, the environmental impact from A1-4 should be 10% lower compared to the silver level (Palm & Linden, 2020; Sweden Green Building Council, 2020b). BREEAM-SE also requires a verification of the LCA, where the calculations and the documentation are sent to a BREEAM assessor to be verified. After the building has been finalised, a follow-up of the LCA is done to assess that the inputs in terms of materials and quantities are still valid (Palm & Linden, 2020). Earlier for BREEAM-SE the final LCA had to be improved from early LCA, whereas today you only need to conduct the LCA calculation, so there are no limit or reference values to comply with, conducting the LCA is sufficient. However, to get the BREEAM-SE certification the LCA requirement is not strictly mandatory, i.e. there is no actual requirement of conducting the LCA. If an LCA is not conducted, it will just be necessary to achieve more points in some of the other criteria (Palm & Linden, 2020).

4.5.5. *Other methodological choices*

Across the Nordic countries different methodological LCA-related choices occur, which are important to be aware of when comparing approaches and results between countries.
A number of parameters have been investigated during desk research and interviews, and a few of them have been selected to be presented in this section based on their overall relevance. This section should thus not be seen as an exhaustive reporting of the work carried out, but rather as a short presentation of a few especially interesting parameters: unit for reporting of results, method for gross floor area quantification, included building parts, approach to biogenic carbon, inclusion of concrete carbonation, inclusion of surplus renewable energy, inclusion of leakage of cooling liquids and inclusion of construction-site waste.

- Several of the investigated schemes and pieces of legislations (especially in Denmark and Finland) adopt kg_{CO2eq}/m^2/year as the preferred **unit for reporting of LCA results** (CO_{2eq} have been chosen for the sake of exemplification in the case of GWP impacts). However, LEED (used in Finland) uses kg_{CO2eq}/m^2. In Norway Statsbygg the results are both reported in kg_{CO2eq} over the lifetime of the building as well as by the built area in kg_{CO2eq}/m^2. Sometimes it is also reported in kg_{CO2eq}/m^2/yr. All studied schemes and upcoming legislation in Sweden use kg_{CO2eq}/m^2.

- An essential variation to look out for when comparing building LCAs across countries is the **calculation method for gross floor area** which impacts the results heavily when these are presented in kg_{CO2eq}/m^2/year. In most countries this follows the energy calculations required by regulation, however local adaptations of the European standard may occur and thus this should be a point of focus. It has not been possible to gather more detailed information about this parameter so far, but this will be studied further.

- Regarding **included building parts**, no quantitative cut-off rules are generally given across the different schemes apart from the Norwegian standard NS 3720, where products that are present in small quantities in the building may be omitted, but the total omitted products within each building element at 2-digit level must not exceed 5% by weight of the buildings total weight. And the Finnish RTS system where a cut-off criteria allows the exclusion of parts under 1 % of total mass or energy use if the information is not available, as long as the total cut-off makes less than 5 %. The system boundary for the building (i.e. which components are part of the study) can vary to some extent (e.g. technical installations, balconies, lifts/escalators/fixed furniture, external structures), however, data availability is typically an issue, where data for e.g. technical installations are scarcely available and thus often not represented correspondingly to the actual building design.

- **Biobased carbon storage** is included but not reported in the Danish DGNB system, due to the database used (Ökobau.dat). The same is the case for the Danish voluntary sustainability class, however it is planned to be reported once EN15804:A2 is completely implemented. The possibility of reporting GWP_bio and GWP_luluc separately also depends on data availability from Ökobaudat: when EN15804:A2 is completely implemented, it will be possible to report GWP_bio and GWP_luluc separately, and it will be possible to import it into LCAbyg. In the Finnish Climate Declaration biobased carbon storage is included and reported however the biobased carbon (GWP-BIO) and the land-use and land-use-change (GWP-LULUC) are not reported separately (yet) due to the data not being declared separately. In the Norwegian standard NS 3720 the biobased carbon storage is included and reported separately in GWP-BIO and GWP-LULUC while in BREEAM-NO only the GWP-BIO is included and reported separately.

- In Denmark **concrete carbonation** during building use-phase is not accounted for, as the current method in both DGNB and the voluntary sustainability class does not include B1, where carbonation of concrete would be reported. Carbonation during end of life is not accounted for, as the most typical waste scenario (road-filling) does not allow for any significant carbonation during this phase. In Finland the Climate declaration accounts for carbonation in module B1 in accordance with EN16757 Annex BB and in the Norwegian standard NS 3720 it is also accounted for. In BREEAM-NO it is not reported (however currently under discussion), and in the Swedish Klimat-deklaration it is also not included.

- Production of renewable energy from e.g. solar panels installed on the buildings is more and more common in modern buildings aiming for climate neutrality. In relation to this, most schemes and legislations allow the modelling of **surplus renewable energy** (i.e. extra energy generated by the building though e.g. PV technology and introduced to the electricity network). Only exceptions are the Norwegian standard NS 3720, and Miljöbyggnad (where this would not be relevant as only modules A1-A3 are included)

- No regulation or certification system accounts for **leakage of cooling liquids** as a part of the LCA, however some systems set requirements specifically for cooling liquids in other criteria to account for these emissions, e.g. DGNB, BREEAM-NO, BREEAM international, BREEAM-SE and LEED. For BREEAM International and BREEAM-SE it is possible to obtain 1-2 extra credits if the Direct Effect Life Cycle CO_2-eq emissions (DELC) in the Pol 01 criteria are calculated. In the calculation for DELC an annual leakage rate of cooling liquids is accounted for by applying average leakage values for different HVAC-systems (bre, 2016a; Sweden Green Building Council, 2017). Also in LEED International certification it is possible to obtain extra credits in a different criteria for including leakage of cooling liquid. Here an assumption of average leakage rate of 2% and an end of life refrigerant loss of

10% should be accounted for in all HVAC-equipment types (U.S. Green Building Council, 2017). In DGNB the CO2-emissions from leakage of cooling liquids is accounted for in a separate credit, by setting requirements to the specific refrigerants used e.g. GWP factor of less than 150 kgCO2eq.

- Regarding inclusion of **construction-site waste and leftovers**, the Danish sustainability class prescribes a generic wastage rate of 10% to be used for all building materials in lack of specific data (Trafik- Bygge- og Boligstyrelsen, 2020). The same estimation is also to be used in DGNB-DK 2020 if the life cycle modules A4 and A5 are included (Collin, 2020). In Norway construction-site waste is also included in NS 3720 and BREEAM-NO, where they are often based on generic values from One Click LCA. The background for the data used in One Click LCA is however uncertain, and the tool is in general affected by a certain lack of transparency (Bøe, 2020). In Sweden Boverket will develop a climate database with general assumptions, so it will become possible to calculate the waste from the construction site (Einarsson & Engström, 2020). So even though construction material wastage is widely taken into account in building LCA across the Nordic countries, no country has a solid and transparent method or data background.

In Figure 4 seven different parameters relevant when conducting building LCA are illustrated for the studied certification schemes and legislations in the Nordic countries. The figure shows that the methodological choices of *Biobased carbon storage included*, *Surplus renewable energy reported* and *Construction-site waste included* are those that are most likely to occur across many of the certification schemes and legislations in the studied countries.

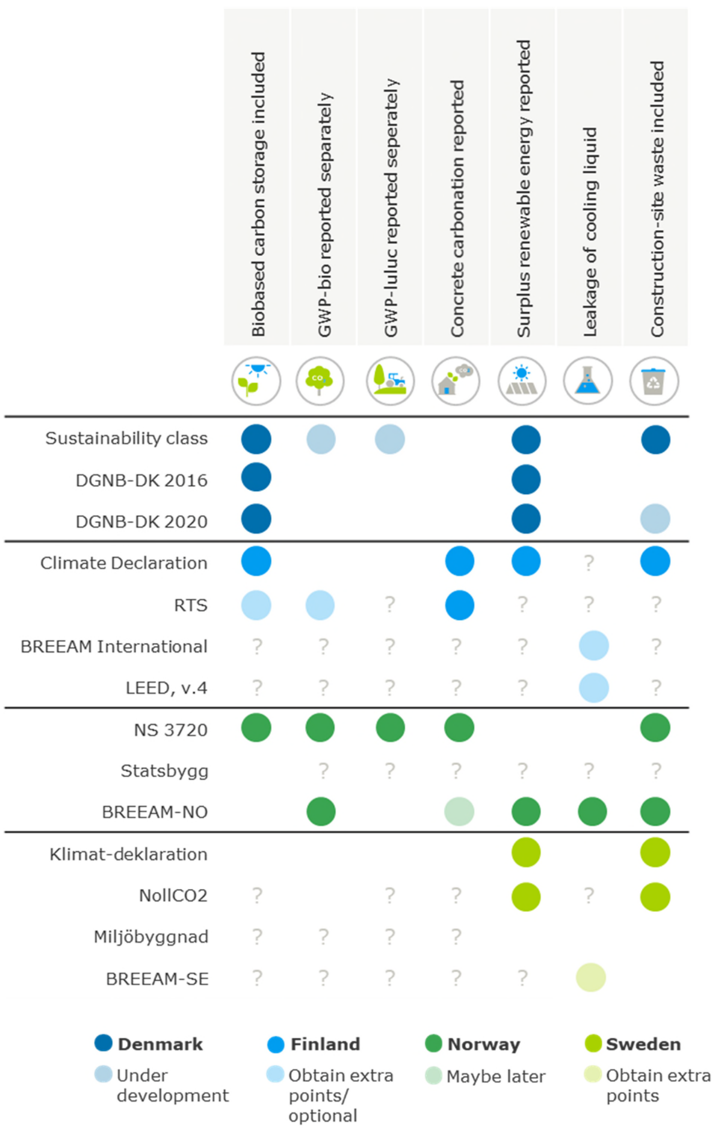

Figure 4 - Seven different methodological choices regarding LCAs for the different certification schemes and legislations across the Nordic countries. The question marks indicate that it has not been possible to collect data and answers on this yet, where a blanc space indicates that this not a requirement in the specific certification scheme or legislation in the current country.

4.5.6. Data sources and quality

Building LCAs - especially in the early design stages – are reliant on pre-existing data to perform the required calculations, both regarding material selections, production and consumption of electricity and heating, as well as various other included processes.

Thus it is necessary to evaluate data sources and their inherent quality, as there may be significant variations in the sources, for instance for materials; differences may be substantial not only between generic data vs. product specific EPDs, but also between the databases used in the various countries of this analysis.

In **Denmark and Norway**, the commonly used database for generic data is the German Ökobaudat database (Bøe, 2020; Collin, 2020), which is developed by the Federal Ministry of the Interior, Building and Community in Germany, with support by the German construction materials industry (https://www.oekobaudat.de/en.html). This generic database is used in the new Danish voluntary sustainability class, DGNB 2016 & 2020, LCAbyg, and One Click LCA. One Click LCA includes also processes from British database IMPACT (Bionova Ltd, 2020a; bre, 2018). Since Ökobaudat is based on material production data from Germany and IMPACT on material production from the UK, the implementation of EPDs is preferable and encouraged in all the aforementioned systems. Certification schemes apply – or plan to – varying penalties based on the data quality, ranking not only EPDs against generic data, but also various EPD-types against each other (e.g. sector vs. product specific EPDs), with decreasing penalty factors as the data becomes more specific (Green Building Council Denmark, 2016; Norwegian Green Building Council, 2016b).

In **Sweden** Boverket (in collaboration with the Finnish Ministry of Environment) is in the process of developing an open database for calculating LCAs to support the upcoming Klimat-deklaration, where building LCAs for new builds will become mandatory. The database is expected to be released by January 2021 (Boverket, 2020). For the Klimat-deklaration there is no requirement of applying EPDs for the LCA, however Boverket recommends using as product specific data as possible. The general tendency in Sweden is that data from EPDs typically have a lower environmental impact compared to generic data, providing another incentive for the use of EPDs, when available (Finansdepartementet, 2020; Palm & Linden, 2020). In Miljöbyggnad the requirement for data quality varies depending on the certification level. For the bronze level there is no requirement for EPDs, whereas a minimum of 50 % and 70 % EPDs are required for the silver and gold level respectively (Palm & Linden, 2020; Sweden Green Building Council, 2020b). In the NollCO_2 add-on certification, EPDs are also required if available. Besides One Click LCA which is widely used in Sweden, the Swedish Environmental Institute (IVL) has developed an LCA-tool called Byggsektorns miljöberäkningsverktyg (BM-verktyget), which contains data from IVL's generic database, IVL Miljödatabas Bygg (Boverket, 2019c, 2019a). Even though the BM-verktyget, which is free, can be used to conduct LCAs for Miljöbyggnad, One Click LCA is more commonly used (Palm & Linden, 2020).

In BREEAM (both BREEAM International in Finland and BREEAM-SE in Sweden), one extra credit is awarded if EPDs are applied for at least five products in the LCA for new builds, however it is not a requirement for conducting the LCA. Thus, generic databases may be applied (bre, 2016a; Sweden Green Building Council, 2017).

In **Finland** the upcoming generic database (developed in collaboration with Sweden) is planned to be used to conduct LCAs in the Climate Declaration from 2025, and will play a significant role in data quality, since a very small number of EPDs are available in Finland (Heikkinen, 2020). As a consequence, EPDs will not become a requirement in the Climate Declaration.

4.5.6.1. Operational energy consumption

The operational energy consumption is a critical contributor to the overall performance of the building, and the selected data for the production of electricity and heating is thus highly influential. During the reference study period of the building, the production-mix of electricity and heating changes year-by-year, and a scenario for the foreseen decarbonisation of the power grid and heating sources is necessary in order to model these changes.

In **Denmark** this scenario is outlined by a study carried out by COWI (COWI, 2020), which aims to quantify the expected impacts of 1 kWh electricity/heating until 2040. This study forms the basis for the energy consumption scenario in the voluntary sustainability class, as well as the DGNB certification.

In **Norway** the decarbonisation scenario is outlined in the standard for methods for greenhouse gas calculations for buildings, based on calculated production mix in 2015 and anticipated production mix in 2050, with the estimated production mix of 2050 being based on values from Eurostat, EEA, Statistics Sweden, and EU's Roadmap 2050 (NS EN 3720:2018). This method includes a production mix for the Norwegian scenario for 2015 and 2050, as well as a general European scenario for EU28 and Norway for 2015 and 2020. In addition to the scenario outlined in the standard NS 3720, further decarbonisation scenarios for Norway are developed by Bionova in One Click LCA, which take into account the geographical variations that may occur in the electricity and heating generation mix (Bøe, 2020).

In the upcoming Climate Declaration in **Finland,** the carbon emissions from the energy use during the use stage of the building's lifespan is to be calculated using standardised emission coefficients for different energy supplies. These take into account that the carbon emissions are expected to decrease in the future, in accordance to Finland's national Energy and Climate Strategy (Kuittinen, 2019).

In **Sweden** the NollCO_2 certification has an energy decarbonisation scenario which is based on an interpolation from the current emissions to the Swedish national climate neutrality target in 2045 and for other EU countries in 2050 (Sweden Green Building Council, 2020d). The energy consumption during use phase is not relevant in Miljöbyggnad, where phase B6 is not included. Thus, no decarbonisation scenario is defined for this certification scheme. For BREEAM-SE there is also no energy decarbonisation scenario defined to be used in the LCA if the operational energy use is accounted for. Furthermore, Klimat-deklaration does not account for use phase in the first introduction phase in 2022, hence there is no defined decarbonisation scenario. For the second phase of the Klimat-deklaration, it has not been decided if a decarbonisation scenario is to be included, if more life cycle stages will be included in 2027.

4.5.7. Environmental Product Declarations

Environmental Product Declarations (EPDs) are an essential part of the analysed schemes, standards, and pieces of legislation, either as a way of achieving credits in a certification, as the core of building LCAs, or as a requirement posed by the building commissioner (e.g. Statsbygg in Norway).

EPDs are a fundamental part of building LCAs as they replace generic data, and alleviate some of the inaccuracies inherent in these, which is why the use of EPDs is credited highly in the various certification schemes (Bøe, 2020; Green Building Council Denmark, 2016; Norwegian Green Building Council, 2016a). The inclusion of EPDs into approved LCA-tools generates an increased demand for EPDs, as they serve as the data-foundation for the material portion of the building LCA, and manufacturers without EPDs will not appear as selectable in the tools.

In **Denmark** the interest for EPDs is relatively recent, and mostly related to the introduction of DGNB as recommended building certification scheme in 2012, and even more recently with the long-awaited voluntary sustainability class for buildings. Regarding building sustainability, the focus in Denmark has for many years primarily been on energy class, rather than on the inherent environmental impact of building materials, thus with relatively little attention to EPDs. Danish producers of building products have often decided to publish their EPDs in other countries, e.g. Sweden, Norway, that actually had a demand for them (Andersen, 2020).

In both DGNB and the voluntary sustainability class, EPDs are recommended as the preferred source of environmental data at product level. In the DGNB-DK 2020 scheme penalties are given for using generic data instead of EPDs, or even generic EPDs instead of product specific ones. For example, environmental performances of building products documented by generic datasets need to be multiplied by a factor equal to 1.3. This has constituted a powerful incentive for the development of EPDs, and the national EPD program operator, EPD Danmark, has seen a recent surge in the number of published EPDs (from 38 in 2019 to more than 70 expected by the end of

2020, including in total more than 200 datasets, i.e. including product variations). EPDs are published both in English and in Danish, and currently only in pdf format, i.e. data need to be manually imported to relevant LCA software, e.g. LCAbyg. A project is running, however, aiming at developing a solution for digitalising EPDs, thus making them directly compatible with LCAbyg. The project is expected to finish in the end of 2021. In Denmark the price for developing an EPD varies widely between 75.000 DKK and 300.000 DKK, depending on scoping, complexity, etc. (Andersen, 2020; Collin, 2020).

In **Norway** the implementation of the EPD-requirement has been ongoing for the past 15 years. The requirement has been progressively expanded to cover more aspects of the building, with the current step being the inclusion of building technical installations, providing an incentive for more EPDs within this field to be developed (Bingh, 2020; Nemitek, 2020). Statsbygg has been increasingly prioritising sustainability through their requirement for EPDs. Along with Statsbygg, some of the largest municipalities in Norway have also established similar EPD requirements, this is done in Oslo, Trondheim, and Stavanger (Marton, 2020).

More than 900 EPDs are published by EPD Norge, the national program operator, and 665 of those refer to construction products specifically (EPD Norge, 2020). EPD Norge has developed a digital platform: EPD-Norge Digi (digi.epd-norge.no) where 587 of their published EPDs are searchable and downloadable in either .xml or .csv formats, for easier integration into One Click LCA and hereby into Statsbygg calculations and BREEAM-NO certifications.

In **Sweden,** EPDs have previously not been used proactively as a tool for product development and optimisation. Manufacturers have mainly been focusing on simply having an EPD, rather than on minimising the actual environmental performance of the declared product through the development of an EPD. This has probably something to do with the various certification systems rewarding the *use* of EPDs, but not necessarily their *performance*. This is expected to change to a more performance-based focus in the future (Palm & Linden, 2020). The demand for EPDs in building projects mostly arises from client demand as it is a requirement in the certification schemes to use products with EPDs available. For instance, in Miljöbyggnad a minimum number of EPDs are required to achieve silver and gold certification.

Sweden has had an EPD-system since 1998, and local certification systems for sustainable buildings like Miljöbyggnad have been introduced since 2009 (Palm & Linden, 2020). Within a few years after their introduction, such schemes have begun to set requirements for LCA and later for EPDs. In addition, other types of certifications such as Byggvarubedömningen, although previously entirely focused on chemical content and hazardous materials, give points for EPDs. This has contributed to a significant diffusion of EPDs in Sweden, together with a more “structural” factor: Sweden has also had a history of using EPDs in other industries like the steel sector and

the wood/pulp/paper sector, which means that the EPD infrastructure was already in place. All these factors have contributed to a significant diffusion of EPDs. While Sweden does not have a national program operator, Environdec (the International EPD System) and EPD Norway are widely used, and generally published in English. Environdec has currently more than 750 EPDs published (Anderson, 2020). While EPDs are made available mostly in PDF, a digital format has recently been introduced for an additional fee (Palm & Linden, 2020).
In Sweden it has been experienced that products modelled with their own EPDs generally perform better than when modelled with generic data, which gives an incentive for the manufacturers to invest in an EPD for their products.

In **Finland** the Building Information Foundation RTS sr launched the first national EPD program in 1998 with updates in 2004 and again in 2016 (Sariola et al., 2019). The EPDs in the current program are approved by a workgroup of the PT18 RT EPD Committee of the Building Information Foundation RTS sr. EPDs compiled according to EN15804 + A1 are approved until June 2022, while from August 2022 PT18 will approve EPDs compiled only according to EN15804+A1+A2 (EN15804:2019) (Rakennustieto, 2020), Currently the RTS EPD database contains 79 EPDs. Finland and Sweden are currently also developing a generic database aiming at a first release in 2021, which should be used if EPDs are not available (Kuittinen et al., 2020). All building certifications used in Finland grant extra credits for the use of EPDs, which has been and still is an incentive for product manufacturers to compile EPDs.

Figure 5 contains an overview of the development in the number of published EPDs for three program operators active in the Nordic countries (EPD Danmark, Environdec, EPD Norge) based on data from Anderson, 2020. Data from the Finnish program operator were not included by Anderson (2020) and are therefore not reported.

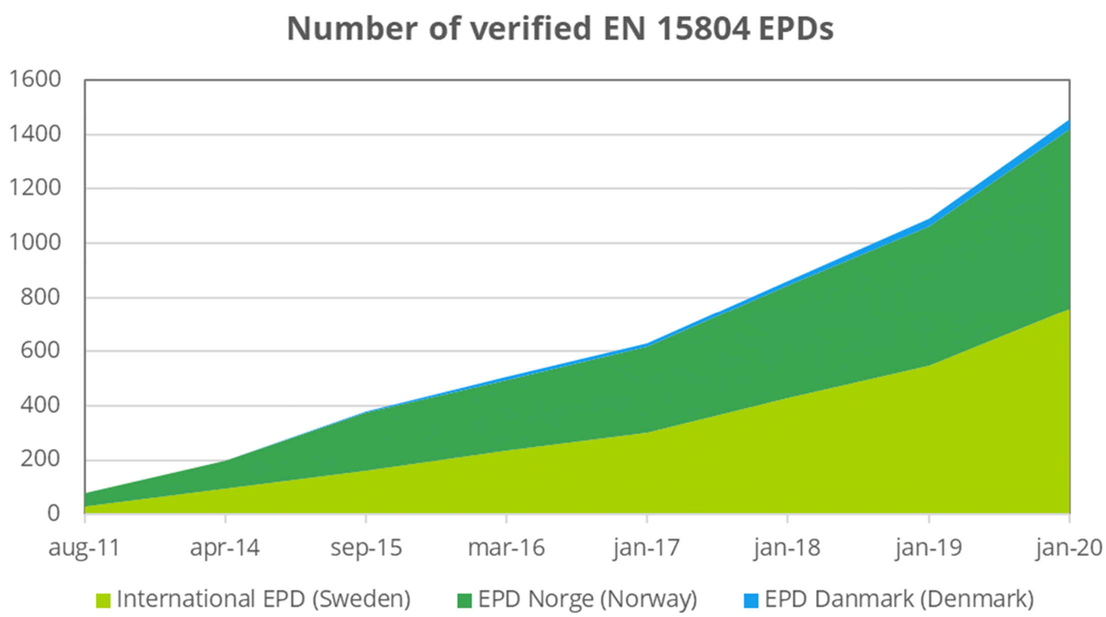

Figure 5 - Development in the number of available EPDs across the Nordic countries: Denmark, Norway and Sweden. Adjusted from (Anderson, 2020)*. Numbers for the Finnish RTS EPD program are not shown in the data from Anderson (2020), and are hence not part of the figure.*

4.5.8. Economic considerations

The cost of conducting an LCA for a building depends highly on the project type, size, complexity as well as on the certification or legislation requirement. For instance, whether the requirement is several LCA iterations conducted over the project design life or just a single LCA at the final design influences the cost. Similarly, further LCA studies focused on assessing specific building elements or materials, or optimising a specific design also require more time. Therefore, the gathered price ranges are to be considered as affected by a high level of uncertainty. However, through market trends in the industry such as certification systems requiring LCA, it is possible to gather rough estimates for conducting LCAs for various systems and across Nordic countries. Practitioners were asked to estimate LCA cost for an office building at 10.000 m^2 including all data gathering and with a certification level matching “Gold” level. The cost of an LCA is of course dependent on the specific project, level of detail and other project related conditions and the data availability. It is expected that the cost of an LCA will decrease to some extent as the industry adapts and get more experience but also that the LCAs will become more accurate and of higher quality.

All analysed markets are still prone to large deviations in cost estimations for the same type of project. In Sweden the project-model received cost estimations between 70.000-300.000 SEK (equivalent to 50.000-215.000 DKK) and has seen estimates on early LCAs of around 60.000 SEK (equivalent to 43.000 DKK). For a final LCA across the different certification schemes in Sweden an estimation of 100 hours could be set (Palm & Linden, 2020). In Norway the LCA credit of a BREEAM-NO certification can cost in the range of 60.000-70.000 NOK (equivalent to 41.000-48.000 DKK) depending on the scale and complexity of the BIM model, achievable credits range from 7-10 in the Mat 01 calculator (Bøe, 2020). A full BREEAM-NO certification of a project aiming at a high score will account for costs in the range of <2% of the total construction costs, this is however covering the entire certification process and not only the LCA sections (Bøe, 2020). In Denmark the workload to carry out an early LCA in connection with DGNB certification has been quantified as being in the range of 50-60 hours, corresponding to <1% of the total construction costs (equivalent to 45.000-55.000 DKK). The final LCA would on the other hand require in the order of 100 hours (equivalent to 95.000 DKK)., which would also typically remain under 1% of the total construction costs (Collin, 2020). In Finland an early LCA is estimated to be 20 hours and a final LCA 50 hours (Heikkinen, 2020), (equivalent to 25.000 and 65.000 DKK respectively). For LCAs conducted with a tool like One Click LCA additional costs for licenses are around 7500 DKK. The large deviations are possibly due to variations in methods and detail and level of expertise and experience. In Denmark the number of hours spend on an LCA has decreased significantly over the last couple of years and the quality has increased e.g. the LCAs are more exact and detailed now.

Prices seem to be quite aligned between Denmark and Sweden, while they could be slightly lower in Finland and more significantly lower in Norway, possibly due to the broader use of building LCA in e.g. mandatory Statsbygg requirements in the latter country.

Figure 6 below illustrate how the cost of conducting an LCA varies across the Nordic countries for the different certification schemes and legislations.

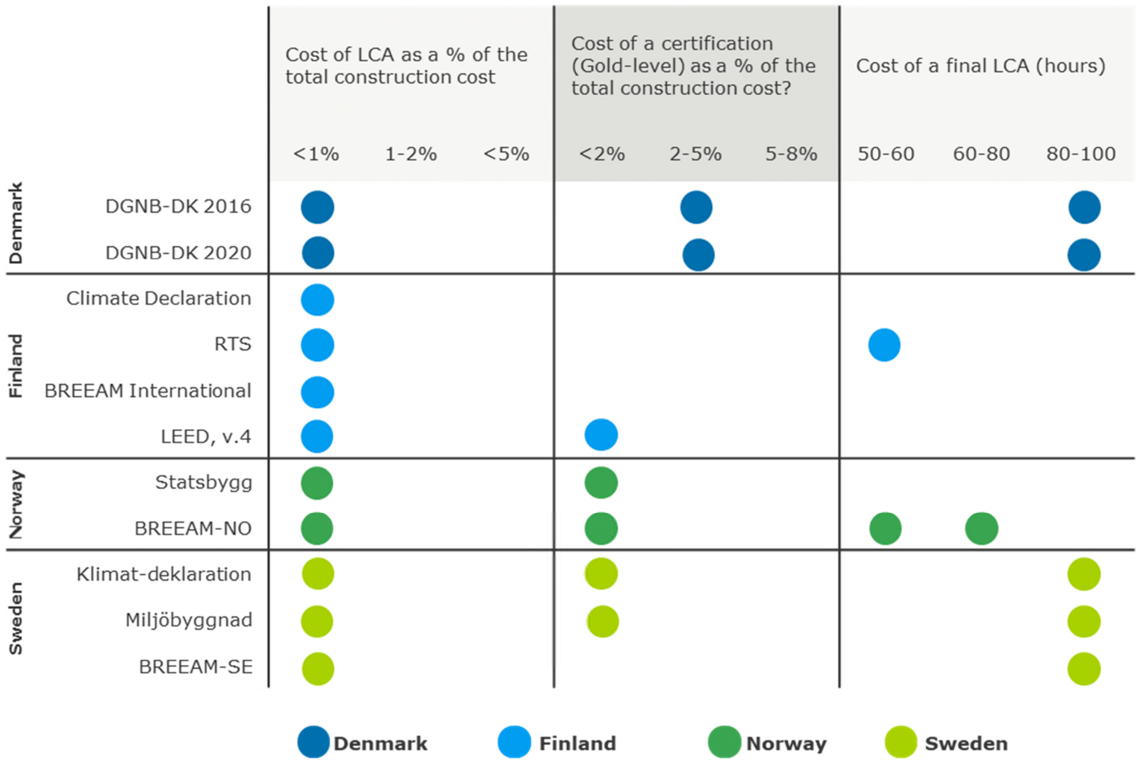

Figure 6 - Illustration of the cost in connection with conducting an LCA measured as a % of the total construction cost, as a % of the total construction cost for a gold certification and as hours for a final LCA. It should be noted that these costs illustrated in this figure contain some uncertainty as it can vary greatly between projects.

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5. Conclusions

In the Nordic countries building LCA is at different levels of development depending on when requirements have been introduced and in which form. None of the Nordic countries has legal requirements for building LCA, however both Denmark, Sweden and Finland are currently in the process of developing them (respectively the voluntary sustainability class in Denmark, Klimatdeklarationen in Sweden and Climate Declaration in Finland). Both in Finland and in Denmark, the upcoming regulations can already now be used as part of a test phase. In Denmark, a political agreement was made in March 2021, making performance of building LCA mandatory from 2023 for new buildings.

In Denmark, Sweden and Finland , the application of building LCA has so far mostly been driven by voluntary certification schemes, e.g. DGNB, BREEAM, Miljöbyggnad, RTS and LEED. Especially in Sweden, however, building certifications have been widely used.

Despite no concrete plan for the introduction of building LCA in the Norwegian legislation, Norway has been active in building LCA for the past 15 years. Statsbygg, the main public building owner, has been setting specific requirements for the sustainability of its buildings, which have typically translated in the requirement for an early and a final building LCA.

This is also reflected by the number of EPDs in each country. EPDs are extremely widespread in Sweden and Norway, as opposed to Denmark and Finland. For Sweden, the reason for this lies in the fact that building certification schemes promoting the use of EPDs, e.g. Miljöbyggnad, have been more widely applied, and that EPDs for non-building products were already widespread, providing an existing infrastructure for the rapid expansion of building products-EPDs. For Norway, Statsbygg has been requiring EPDs for building products for the past 15 years.

Regarding critical parameters for building LCA, the reference study period (RSP) is typically either 50 or 60 years, with an equal distribution between the two values. While 50 years is the value of choice in Denmark, 60 years is the value of choice in Norway, and Sweden and Finland use both values depending on the relevant scheme/regulation.

Most of the analysed countries and schemes prescribe that modules A1-A3 are included in the LCA study, as well as B4, B6, C3-C4. Other life cycle phases can be required by single schemes or be only optional. Exceptions are the Swedish certification scheme Miljöbyggnad, which only requires A1-A3, and Klimat-deklaration, where all allowed modules beyond A5 respectively are optional. Also in BREEAM (in both the Norwegian, Swedish and international version) all allowed modules beyond A3/A4 are optional. All Norwegian schemes require phase B8 as obligatory (transport during operation), which is only present in the Norwegian standard NS3720.

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Denmark is the only one of the Nordic countries where reference service life (RSL) used in building LCA are based on a technical report, where all building product types have systematically been attributed average values depending on their application in the building (thus independently from the specific producer). Systems in other countries rely primarily on EPDs, or alternatively on other technical information from the specific producer.

Across all Nordic countries and analysed schemes, the impact categories receiving the most attention is GWP, however other categories (e.g. ODP, POCP, AP, EP, ADP, PE) can typically be included as either mandatory (only in Denmark) or voluntary. Weighting is not commonly carried out, however it is applied in the Danish DGNB certification scheme.

External benchmark values or internal baseline values can be used as reference in the different schemes and legislations. However, for the Danish voluntary sustainability class no reference values have been introduced for the moment, meaning that the only requirement to comply with is the actual completion of an LCA, rather than a certain environmental performance to be achieved. From 2023, for buildings larger than 1000 m^2 a limit value for CO_2 will be introduced in the national building regulations. From 2025 limit values will also be introduced for buildings smaller than 1000 m^2

In Finland limit values are expected from 2025, maybe earlier. In Sweden, the integration of limit values depends on a political decision.
Several of the investigated schemes and pieces of legislations (especially in Denmark and Finland) adopt kg_{CO2eq}/m^2/year as the preferred unit for reporting of LCA results. However kg_{CO2eq}/m^2 and kg_{CO2eq} are used in some cases.

In most countries the calculation method for gross floor area follows the energy calculations required by regulation, however local adaptations of the European standard may occur and thus this should be a point of focus. It has not been possible to gather more detailed information about this parameter so far, but this will be studied further.

Regarding included building parts, the system boundary for the building can vary to some extent (e.g. technical installations, balconies, lifts/escalators/fixed furniture). However, data availability is typically an issue, e.g. regarding technical installations.

Construction-site waste and leftovers is a widely applied parameter in building LCA across the Nordic countries, however no country has a solid and transparent method or data background.

Regarding data choice, EPDs are consistently identified as the recommended data across all countries and schemes, and the choice of products with an EPD is generally awarded with extra credits (alternatively, the use of generic data is penalised with fewer credits). Additionally, all of the studied upcoming national regulations, as well as the Norwegian standard NS3720, define specific data quality requirements. Specific generic databases can furthermore be recommended, typically the German Ökobaudat (e.g. Denmark and Norway) or national ones when available (e.g. Sweden, Finland).

The cost of conducting an LCA for a building can vary widely depending on project type, size, complexity as well as goal. The gathered price ranges should therefore be treated as very rough estimations. In Sweden prices for an early and a final LCA are estimated as 43.000 DKK and 50.000-215.000 DKK respectively. In Denmark the corresponding tasks would normally have a cost of 45.000-55.000 and 95.000 DKK respectively, while in Finland an early and a final LCA are estimated to cost 25.000 and 65.000 DKK respectively. In Norway the LCA credit of a BREEAM-NO certification can cost in the range of 41.000-48.000 DKK. Prices seem thus to be quite aligned between Denmark and Sweden, while they could be slightly lower in Finland and more significantly lower in Norway, possibly due to the broad use of building LCA in the latter country.

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7. Appendix A: Excel sheet with results