Towards embodied carbon benchmarks for buildings in Europe

#1 Facing the data challenge

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DOI (link to publication from Publisher):
10.5281/zenodo.6120522

Publication date:
2022

Document Version
Publisher's PDF, also known as Version of record

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#1 Facing the data challenge

Project name	Towards EU embodied carbon benchmarks for buildings
Date	March 2022
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Disclaimer

In this report, the widely used term 'embodied carbon' is applied. It is considered to be synonymous with 'embodied GHG emissions' herein. The data and values presented in the following consider both CO2 and non-CO2 GHG emissions, the reference unit applied is kilogram CO2e (equivalent) expressed per m^2, per capita, or m^2 and year, respectively.

Acknowledgements

We would like to express our gratitude towards everyone that has accompanied the work in this project and helped improve the results with valuable input and critical comments. This includes:

The Built Environment team of Laudes Foundation, in person of Maya Faerch and James Drinkwater

The steering committee of the study, composed of Stephen Richardson (World Green Building Council), Josefina Lindblom (European Commission, DG Environment), Sven Bienert (International Real Estate Business School at Regensburg University), and Lars Ostenfeld-Riemann (Ramboll)

The data partners, for France: Florian Piton, Marine, Vesson, Sylviane Nibel (CSTB); for the Netherlands: Mantijn van Leeuwen, Marvin Spitsbaard, (NIBE) Ruben Zonnevijlle (Dutch Green Building Council); for Belgium: Karen Allacker (KU Leuven); for Finland: Matti Kuittinen (Ministry of Environment), Anni Viitala (Granlund), Sara Tikka (One Click LCA); (CSTB); Others: Anouk Muller, Markus Auinger (PORR); Mirko Farnetani (Hilson Moran)

Lastly, we would like to thank the Communications teams of Ramboll and Laudes Foundation for getting the message spread.

Cite as

Röck M, Sørensen A, Steinmann J, Le Den X, Lynge K, Horup L H,, Tozan B, Birgisdottir H. Towards Embodied Carbon Benchmarks for Buildings in Europe – Facing the data challenge, 2022, https://doi.org/10.5281/zenodo.6120522

Executive summary

Rationale – Why is this important?

"Embodied carbon" consists of all the greenhouse gas (GHG) emissions associated with the materials and construction processes used throughout the whole life cycle of a building[1]. While past efforts have mostly focused on increasing energy efficiency in building operation, recent research on the GHG emissions across the full life cycle of a building highlights the increasing importance of embodied GHG emissions in relation to producing and processing construction materials. The urgent state of climate change requires rapid action without any further delay.

The "Towards Embodied Carbon Benchmarks for buildings in Europe" project was set up by Ramboll Build AAU - Aalborg Universitet with the support of the Laudes Foundation. Through a series of four reports[2], the objective is to improve our understanding of embodied carbon in buildings and to set framework conditions for reducing it. In order to do so, the project explores the concept of embodied carbon baselines, targets, and benchmarks for buildings in Europe. In particular, the focus is on upfront embodied emissions which represent the largest share of embodied carbon and can be shaped at the design stage.

For this purpose, data on the GHG emissions from building construction is essential for calculating the current baseline levels of embodied carbon. Additionally, the current data landscape will shape the options available to us for monitoring future buildings against specific benchmarks, once these have been established. Therefore, this report describes the experience gained in collecting building-level embodied carbon data from life cycle assessments (LCAs).

Results – What did we find?

The objective of this part of the project was to compile LCA data from European countries, for which 50 cases or more could be found. Each case represents a building where LCA data was available which could be used to provide information on the current level of embodied carbon in buildings. This would allow relatively robust conclusions to be made regarding the baseline level.

However, the data collection process conducted across Europe resulted in only five countries being identified for which sufficient data could be used. These were Belgium, Denmark, Finland, France and the Netherlands. Figure 1 summarises and illustrates the situation across Europe.

The data collection process highlighted a series of data challenges which resulted in the low number of cases which could be used. These challenges are summarised in Table 1.

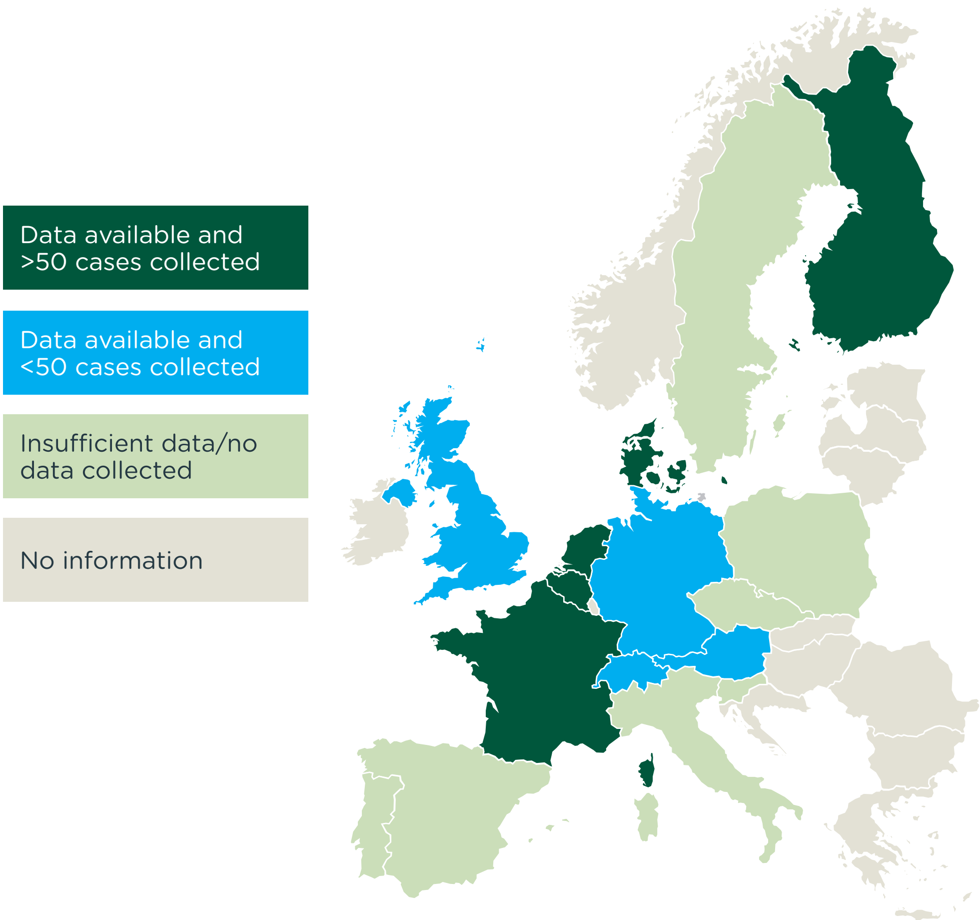
[1] Embodied carbon therefore includes: material extraction, transport to manufacturer, manufacturing, transport to site, construction, maintenance, repair, replacement, refurbishment, deconstruction, transport to end-of-life facilities, processing, disposal.

[2] Reports: #1: Facing the data challenge; #2: Setting the baseline; #3: Defining a carbon budget; #4: Bridging the gap

Table 1: Key challenges encountered in the LCA data collection

Challenge	Definition	Effect on building LCA data
Availability	Existence of data at the national level	In many European countries, the practice of conducting LCAs does not exist, or the results are not fed into a central repository.
Accessibility	Possibility to access existing data	LCA data may be collected into a central repository but is not shared by the owner because of data protection or intellectual property concerns.
Quality	Data meets accuracy, completeness, timeliness, validity, and uniqueness criteria	Entries in national databases vary in completeness, have unclear time origins or include duplications.
Comparability	Data scope and collection method are comparable with each other	The scope of life cycle stages, building parts or environmental impacts, or the data collection and results calculation methods differ. This is a particular challenge when comparing data across countries.
Representativeness	The data represents the building stock, in terms of new construction, well	Even if all the above factors are met, data can come from selected buildings with high environmental performance, for instance where obtaining sustainability certification is envisaged. This delivers a skewed and incomplete picture of the embodied carbon in new buildings. Sufficient data points are needed for each different building type to be able to draw representative conclusions. The larger the sample, the better it is in this respect.

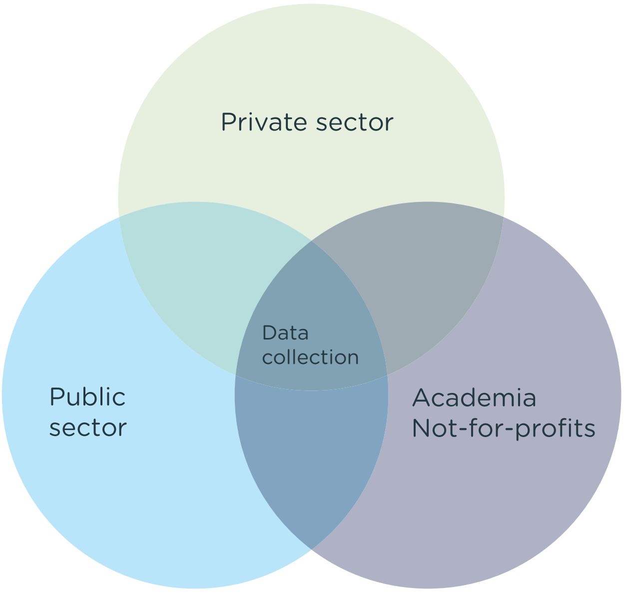
Figure 1: Overview of data availability in Europe



Conclusions – What does this mean?

In conclusion, we found that the LCA data required for a benchmarking system to reduce embodied carbon in new buildings needs to be more extensive. Furthermore, the challenges identified in this report need to be addressed and overcome quickly in order to avoid any delay to action being taken.

The experience from those countries for which data could be collected shows that overcoming the challenges is the result of incentives to conduct LCAs and to make the results available being included in national legislation and other policy initiatives. Additionally, the effectiveness of data collection can be increased through triple-helix cooperation between the public and private sectors, as well as academia and not-for-profit partners.



Call to action – What should we do?

Based on the findings of this work, we arrive at the following recommendations:

National LCA methods and data collection systems are urgently needed to avoid any further delay in this fundamental step towards measuring and reducing embodied carbon as part of whole life carbon emissions.

To this end, legal or sectoral requirements that mandate the production of LCAs in accordance with standardised calculation and documentation methodologies are highly relevant at national level, as well as harmonisation at EU level through tools such as the Level(s) framework. Standardisation based on coordination between stakeholders in the building design and construction value chain should, for example, include: scope of life cycle modules, scope of building elements, reference study period, environmental data on building materials, etc.

Data collection and compilation efforts are needed from all those involved in designing and assessing buildings. For this purpose, collaboration and complementary activities between public institutions, building designers, investors, certification organisations and researchers are needed. This step requires a common language and standardised method for LCAs, as described in the first point above.

As this process may take some time, the challenge of gaps in data could also be mitigated through the following approaches. These should be considered complementary.

- **Data on recent and current building projects could be generated at a centralised level by applying a single LCA method in order to provide information on these specific cases, as it is likely that this data can still be obtained.** This exercise would benefit from input from the different actors involved, including the building industry, certification bodies, researchers and public bodies. This cooperation could be greatly facilitated through the use of standardised calculation methods and software tools to form a central database. A similar approach has provided a large database in France.
- **Existing data, that has been created in a scattered form using varying methodologies by different stakeholders, has the potential to be gathered together and harmonised to form a centralised database**. Harmonisation methods, adapted to the specific differences between the LCA methodologies, could be agreed upon by a coalition of actors to support this undertaking. Examples of such action are the international activities in Annex 72 to the IEA-EBC Programme, as well as the UK initiatives LETI and BRE.
- **Where empirical data faces the challenges described in this report, relying on results from modelled building archetypes could provide an insight into the life-cycle impacts.** Building archetypes offer the advantage of providing representative and comparable values. However, limits remain in translating building stock models into LCA data, which is challenging, particularly for the diverse landscape of non-residential buildings. Also, monitoring future buildings, in comparison with benchmarks, is not possible. Nonetheless, efforts to translate this data can help in the transition towards standardised empirical LCA data. This approach has been used successfully in projects such as the Tabula/Episcope project.

Contents

1. Introduction

As the effects of the accelerating climate and ecological crises are becoming evident, the need for transformational climate action is rising. Based on decades of climate science and driven by the increasing pressure from civil society, policymakers in the European Union (EU) and beyond are making bold claims to reduce greenhouse gas (GHG) emissions for their respective regions and activities.

Building construction and operation are amongst the most significant activities driving current GHG emissions, representing 37% of global GHG emissions[1]. At the same time, increasing the energy efficiency of both existing and new buildings, as well as shifting to sustainable construction practices, are considered to be major opportunities for decarbonising the economy in the coming decades.

Altogether, the total amount of embodied and operation emissions is referred to as whole-life carbon emissions. Reducing this total sum of emissions in a building is of the highest priority, to which this work aims to contribute.

While past efforts have mostly focused on increasing energy efficiency in building operation, recent research on GHG emissions across the full life cycle of buildings highlights the increasing importance of embodied GHG emissions, in relation to producing and processing construction materials. "Embodied carbon" refers to all the greenhouse gas (GHG) emissions associated with materials and construction processes throughout the whole lifecycle of a building[3].

These embodied emissions in buildings are rarely addressed in policy strategies and instruments. However, if embodied carbon is not included in building decarbonisation targets, a failure to meet global decarbonisation targets is highly likely. This is because the total climate impact of buildings would remain only partly addressed. Thus, the need and potential for reducing embodied emissions require attention and alignment as part of European and global efforts to combat climate change. Against the backdrop of increasing efforts to understand and reduce the whole life cycle of carbon in buildings, the project "Towards Embodied Carbon Benchmarks for the European Building Industry" was set up.

In particular, setting a performance system for embodied emissions at the building level can provide relevant guidance for policymakers and the building industry. Developing the foundations of such a performance system for new buildings has been the objective of the project "Towards Embodied Carbon Benchmarks for buildings in Europe", set up by Ramboll and Build AAU - Aalborg University, with the support of the Laudes Foundation. This includes a baseline of current embodied carbon levels in new buildings, as well as considerations of the available carbon budget for these emissions. Together with a review of data availability and quality, these elements form the basis of a performance system in the form of benchmarks for reducing embodied carbon.

This project focused on the European Union (EU). This is due to its position as a pioneer in GHG emission reduction policies with instruments such as the Energy Performance of Buildings Directive, the Taxonomy for Sustainable Activities and the EU Climate Transition Benchmark Regulation. Additionally, the life-cycle perspective of buildings is receiving increased policy awareness. These instruments and initiatives will have an increased impact on the building industry. This project seeks to inform the current debate involving policymakers and industry alike and to stimulate the development and application of benchmarks for embodied carbon in the EU and beyond.

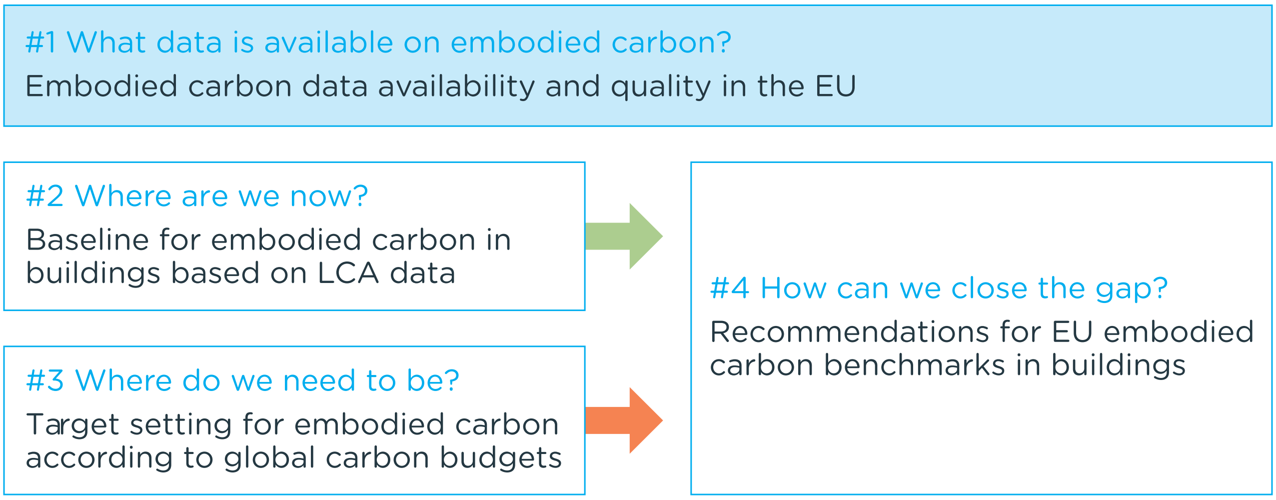
[3] Embodied carbon therefore includes: material extraction, transport to manufacturer, manufacturing, transport to site, construction, use phase, maintenance, repair, replacement, refurbishment, deconstruction, transport to end of life facilities, processing, disposal.

The series of reports produced as part of this project provides insights and developments on the following questions:

1. What data is available on embodied carbon in the EU?
2. Where are we now? What is the current status of embodied carbon in new buildings?
3. Where do we need to be? What level of embodied carbon is aligned with the available carbon budget?
4. How can we close the gap? How can benchmarks to reduce embodied carbon be set?

The report herein is the first report in this series.

Figure 2: Overview of the series of reports produced under the "Towards Embodied Carbon Benchmarks for buildings in Europe" project



The purpose of the report herein is to summarise the insights gained on embodied carbon data from life cycle assessments (LCA). A search for such data was carried out across EU countries (and the United Kingdom) to form a basis for the baseline setting process and for drawing up a benchmarking framework.

The report presents the current situation as encountered in the EU countries and the UK, points to the key issues in LCA data and provides solutions for overcoming these challenges. The findings in the report are supplemented with country sheets for the five countries for which sufficient data was available: Belgium, Denmark, Finland, France and the Netherlands.

2. What is the situation on building LCA data in Europe?

2.1 The ambition

Developing robust recommendations for a benchmarking system for embodied carbon in buildings requires an evidence base in order to be able to understand the status quo and to set the baseline for reduction efforts.

For calculating the baseline of embodied carbon in new construction in the EU, this study aimed at gathering **national datasets consisting of at least 50 cases** of high-quality building LCA data per country from EU Member States and the United Kingdom. This target was set to create a sample for analysis that was as broad as possible, while taking into account the currently limited collection of building LCA data.

However, considering the overall number of construction projects, this target number was deemed sufficient for making feasible statements on the embodied carbon levels in new buildings.

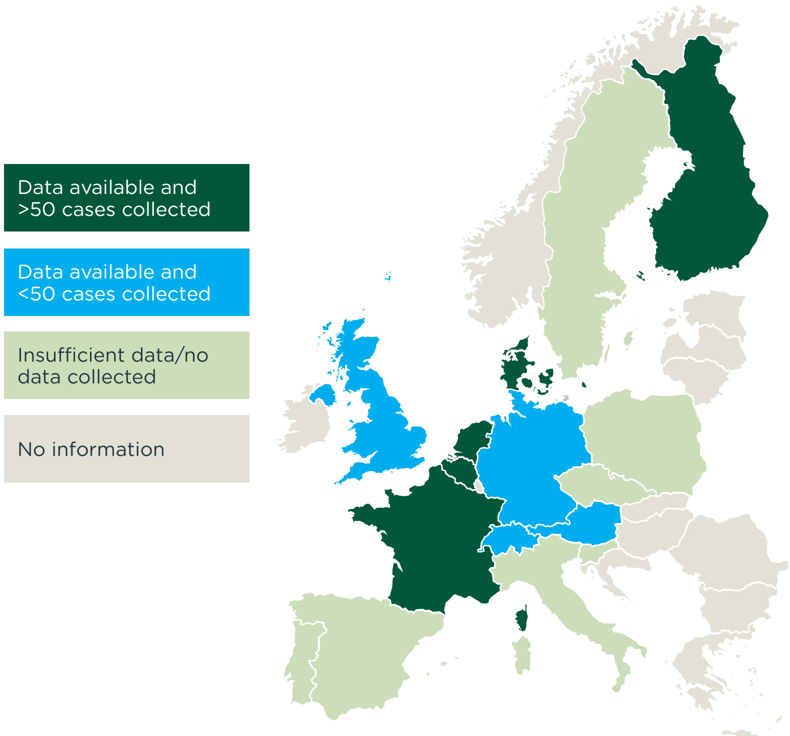
2.2 The reality

The research into the national methods and cases of available LCA data for all EU Member States revealed that obtaining a larger amount of data is impossible in the majority of countries. **The results show that the majority of EU Member States have low to no LCA data available for calculating bottom-up embodied carbon benchmarks**, with only five Member States identified as having 50 or more LCA cases available. The details for these five countries are compiled in the country sheets in Appendix 1, while an overview of the embodied carbon data landscape in all EU Member States is provided in Appendix 2.

Figure 3 summarises and illustrates the data available in European countries, as assessed during the data collection process for this project. It illustrates that, **within the countries included in the study, samples of sufficient size and quality could only be collected in Belgium, Denmark, Finland, France and the Netherlands**. In four additional countries, some data could be identified, but it did not pass the threshold of 50 cases.

This highlights a significant variation in the building LCA data available, which limited a broader coverage of countries to assess current embodied carbon levels. This impacted the calculation of the baseline and the carbon budgets, as well as the determination of benchmarks required to guide the reduction of said emissions. The variation in the data landscape and the need for this evidence base highlights the urgency for expanding and improving data collection, and suggests that lessons could be learnt from the Member States included in this study at the forefront of data collection. The following sections provide additional analysis and discussion of what drives data development and data accessibility in these countries.

Figure 3: Overview of data availability in Europe



3. What are the issues with LCA data?

This section summarises the key issues encountered in the data collection and analysis process. As suggested by the map of data availability in Figure 3, embodied carbon LCA data can be challenging to come by, as in most EU Member States there is no precedent or requirement to develop LCAs which include embodied carbon in buildings. However, other factors may also pose data challenges when using LCA data to develop embodied carbon benchmarks. This includes the following points (as summarised in Table 2 above) which will be discussed below, based on the experience gained from the data collection at national level.

Table 2: Key challenges encountered in LCA data collection

Challenge	Description
Availability	Existence of data at national level
Accessibility	Possibility to access existing data
Quality	Data meets accuracy, completeness, timeliness, validity and uniqueness criteria
Comparability	Data scope and collection methods are comparable with each other
Representativeness	Data represents the building stock, in terms of new construction, well

3.1 Data availability

As already outlined, finding existing LCA data for buildings has proved challenging in most countries. In many of the countries in which the expected sample size could not be reached, LCAs are not commonly performed in practice or are not collected. The reasons for this can be a lack of awareness, guidance on methodology, or incentives for LCAs for building projects. Two examples highlight the challenges of data availability from countries in which data could not be collected.

Firstly, in **Poland**, where there is no regulation on whole life carbon, the Polish Green Buildings Council expressed difficulties in accessing data on embodied carbon as the results of LCAs are not systematically gathered into a central repository. In this case, the development of LCA data was driven by investment companies and developers expressing an interest in conducting LCAs on construction projects to achieve voluntary sustainability certifications. Thus, the data was found to remain with the private sector (building owners, consultancy companies conducting the LCAs, the LCA tool owner, or certification bodies); and was not readily accessible by research institutions or the green building council. This case was found to be representative of the majority of EU Member States where the lack of a central LCA repository and private sector data holding were found to create barriers to developing nation-wide embodied carbon benchmarks. This case, therefore, is emblematic of the data availability and accessibility challenges.

In the **Czech Republic**, an active academic research project (CVUT) was identified on the topic of building LCA, its implementation in the design process, and the definition of carbon targets for buildings. However, the limited number of available building LCA case studies prevented the inclusion of these LCA cases in this study's analysis. This suggests that future support for local actors to build on this experience in order to increase the number of LCA cases could enable a suitable database to be established in the future. Consequently, this is representative of the lack of data availability.

3.2 Data accessibility

If data is collected through LCAs at the building level, this **data may still not be usable in a general assessment of embodied carbon in the country due to challenges in accessing the data**. In the countries for which data has been successfully collected for this study, the data partners were able and willing to share their data. In other countries, this was not possible. In such cases, the consideration of an EU level baseline for embodied carbon is not possible in the current situation.

For instance, in **Germany**, we found a different landscape. Here, due, on the one hand, to the requirement for federal buildings to conduct a BNB assessment including an LCA, and, on the other hand, a popular uptake of the DGNB buildings certifications, LCA data was found to be available and held by the DGNB. However, barriers were encountered in accessing it due to data protection and intellectual property considerations. This became such a challenge that the data could not actually be accessed for this study. By the end of this project, and as a useful and timely contribution to the overall discussion around embodied carbon benchmarks, the DGNB published their own report on benchmarks for embodied carbon in buildings in Germany [2]. The findings of this report proved to be consistent with the findings present in report #2 "Setting the baseline" of this study.

3.3 Data quality

To be able to use the data as an evidence base for a robust assessment of current embodied carbon levels, **quality criteria have to be met**. This relates to the accuracy of building data, the completeness of reported data for each of the cases in the datasets, the timeliness of reporting to reflect the current level of embodied carbon, and duplications in the dataset. Variations in these criteria impacted the results and reduced confidence in the findings and related recommendations.

For instance, the embodied carbon data collection in France provides a contrast as, in this case, the data was both easily accessible and plentiful. This can be attributed to the existence of a central data repository held by a public body, and the key role of the Ministry of Ecological Transition in ensuring data is collected as per the E+C- experiment, and forthcoming RE2020. However, as the data was being processed, challenges were encountered regarding the completeness of the entries, where incomplete cases had to be removed. Consequently, what started as 1,197 LCA cases had to be reduced to 486 due to quality considerations.

3.4 Data comparability

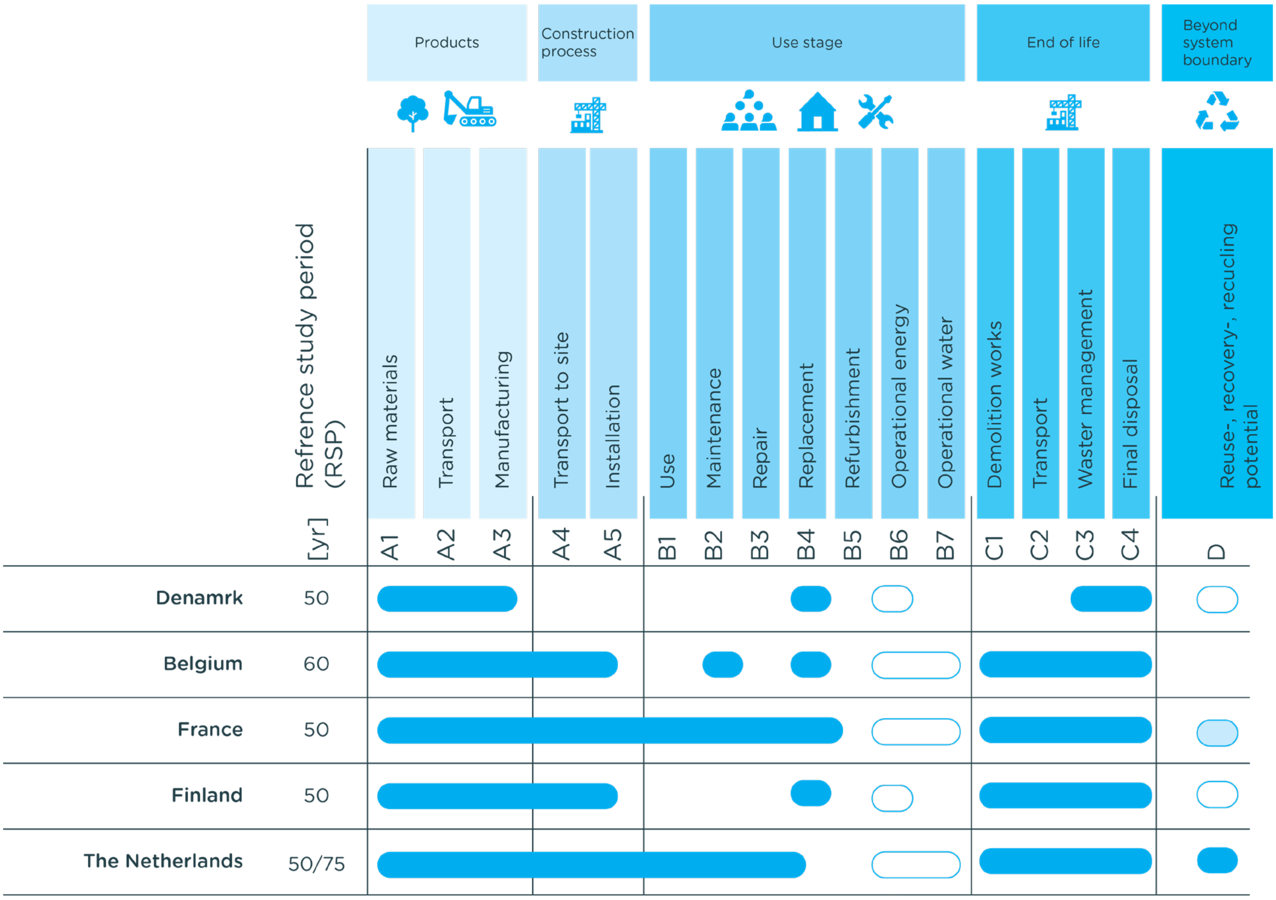
The consistency of the data quality is linked to the comparability of data based on the collection method. This challenge is particularly relevant when comparing and aggregating data from different countries in an EU-level baseline, or proposing actions such as a benchmarking system at EU-level. For these applications, the different approaches used further reduce the robustness of the evidence base.

Two main parameters can differ and impact the comparability:

- Scope of life cycle stages
- Assessment methods

Firstly, as Figure 4 shows, the inclusion of **life cycle modules in the scope** of the collected data differs between all of the five national LCA methods compared in detail in this project. The comparison illustrates that **France**'s LCA scope is the most encompassing, with **Denmark**'s being the least encompassing. Differences in the inclusion or exclusion of certain life cycle modules led to different baseline and LCA results. It is, therefore, important to consider, in the context of developing a harmonised baseline, which baselines can be used to set targets and benchmarks on embodied carbon, as the baseline for one country may be higher than another; not due to a higher embodied carbon footprint, but due to the inclusion of a broader scope.

Figure 4: Life cycle modules included in the scope of the collected data



Secondly, other elements in the assessment method can also vary and cause challenges in comparing the data. For example, the reference study period differs to some extent between the analysed cases (see Figure 4), which was also found to be the case for the scope of building parts included, and the background data used for modelling the building LCA. For instance, in France, the division of building parts was sometimes carried out using proxies, which could create biases as a result of their sources and the purposes they serve.

3.5 Data representativeness

Even if all of the aforementioned challenges are overcome, the data collected **may not be representative of the new buildings or building stock in total, and may therefore provide an incomplete and skewed picture of the embodied carbon situation**. For instance, this was discovered in the cases provided from Denmark and Finland, but also more generally for other EU Member States. The key challenge is that the majority of LCA studies are carried out for buildings which are already high-performance or new builds, and are less commonly carried out for average low-budget construction projects. This suggests that greater attention should be given to ensure the availability and accessibility of LCA cases for different building typologies to be able to ensure that the eventual national benchmark is representative of the general building stock. For this purpose, a large sample is highly beneficial, while smaller samples need to be particularly well-structured in order to be able to provide a full picture.

Conversely, there exist examples of alternatives. In **Belgium**, for example, KU Leuven could provide the required building case studies. There is a dedicated method for building LCA, called the MMG (Environmental Profile of Building Elements) method, and an open-access, online tool developed by the three regions in Belgium (Flanders, Walloon Region and the Brussels region) called TOTEM. KU Leuven had previously modelled the LCAs of various buildings as part of their research, these included studies of representative buildings, developed on the basis of the Belgian TABULA archetypes. KU Leuven could update their assessments and provide high quality case studies and detailed LCA results data.

4. What can be done about it?

The data challenges described in the previous chapter create a difficulty in establishing a robust benchmarking system for embodied carbon. On the one hand, this is caused by the challenges in establishing the baseline while, on the other hand, a comparison of future buildings against reference values also relies on a clearly defined methodology.

The data collection process and experience gained by the project team point to promising solutions in overcoming these barriers.

4.1 Incentives for LCA data collection in legislation and government initiatives

EU and national legislation or other forms of government initiatives can support LCA data collection by creating incentives, reducing barriers and promoting standard methods.

An assessment of regulatory measures covering embodied carbon across EU Member States found that very few Member States have developed legislation that includes requirements or standards for LCA methodology or embodied carbon in buildings (see annex 1). Thus far, Denmark, Finland, France and the Netherlands are the only Member States with existing or forthcoming regulatory measures covering embodied carbon.

However, to achieve an overview of embodied carbon legislation in the EU, the project team reached out to EU Member State infrastructure, development, and construction departments. The results indicate that additional Member States are in the process of planning legislation to set standards for both the level of embodied carbon emissions in buildings, and LCA methodology. For example, this is taking place in Sweden, where a second version of the Klimatdeklaration (a regulation to be enforced in 2022 making it obligatory to conduct LCAs on new builds [3]) is being planned for 2027, which will include limit values for LCA results.

In Switzerland, it was also noted that an LCA-based regulation is being planned, and a public official from Lithuania responded that plans are underway to prepare a methodology for modelling whole buildings life cycle emissions, including embodied carbon. Furthermore, in Ireland, a public official remarked that the international certification schemes for non-residential buildings LEED and BREEAM are driving interest amongst professionals wanting to calculate embodied carbon emissions, and that an increased interest from the investment community in embodied carbon has also been experienced. The official added that with these developments, alongside the Level(s) and the introduction of legislation in Finland, the Netherlands and France, they believed a plan for legislation would be forthcoming:The data collection and analysis in this study focused on the life cycle embodied carbon emissions of newly constructed buildings. In the context of the European renovation wave and the general need to revalue and further develop existing buildings stocks, there is an increased interest in understanding embodied carbon from retrofitting. We want to highlight a recent report by the European Academies Science Advisory Council (EASAC) on the 'Decarbonisation of buildings for climate, health and jobs' [9]. Therein, with regard to embodied carbon in both new building construction and building renovation, the author states:

> "There are currently no definitive plans in Ireland for regulations but there are a number of positive indicators that this is likely to happen over the next five years. Holland and France have already introduced regulations, with Finland introducing regulations in 2025 and other countries likely to follow.
>
> Changes to the EU Construction Products Directive will likely see a requirement for use of ecological footprinting of products through either EPD or Product Environmental Footprint (PEF) The EU commission has introduced the Level(s) framework"

Three key **types of regulatory measures on embodied carbon** and LCA methodology were identified. These are:

- A requirement to calculate LCAs on public buildings, as exemplified by Germany.
- A requirement to calculate LCAs on all buildings, as exemplified by France (progressively from 2022 onwards), the Netherlands and Denmark (from 2023 onwards for all buildings).
- A graduated standard for the level of embodied carbon allowed in buildings with the benchmark changing over time, as exemplified in Denmark and in France (both for whole life carbon, i.e. embodied and operational emissions).

The assessment suggests that requirements for LCA calculations on buildings leads to a greater number of LCA cases available per country and, as exemplified by the study, a greater number of available LCA cases allows for more accurate target-setting and benchmarking for policy making.

4.2 Effective data collection through triple-helix cooperation

In addition to government initiatives to promote and support data collection, greater effort is needed on implementing said collection. Here, the experiences from the five countries highlight that, where data is available, **triple helix cooperation between public, private, and research/not-for-profit partners** plays a significant role.

In **Denmark**, for example, the Danish Housing and Planning Authority could commission a study to calculate a baseline and an embodied carbon benchmark from the Build institute of Aalborg University, who were then able to use data collected by the Danish Green Building Council. This exemplifies the necessity for partnerships between the agencies driving action on whole life carbon in the building sector. In addition, it displays the key role of national governments in having a financial investment and internal motivation to develop embodied carbon benchmarks (in this case, for the purpose of regulatory development).

Similarly, in **Finland**, the 50 cases required were available due to a government-led initiative in 2016, where the Finnish Ministry of Environment began testing and planning for LCA-based regulation. In order to carry out such scoping and planning, technical assistance and data was provided by two Finnish consultancy firms: Granlund and OneClickLCA. The result was legislation that includes mandatory requirements for LCAs on new constructions including limit values on WLC.

In the **Netherlands**, data development was found to be driven by a mandatory requirement for LCAs to be conducted on new buildings in order to obtain a building permit. In addition, since 2018, the LCAs must also meet a limit value which includes a maximum impact from the global warming potential, in addition to other environmental impact categories (expressed in €/m2). The calculation tool and national database are maintained by the Stichting Bouwkwalitei foundation. However, for the purpose of the project, several data partners were also included in order to obtain the data required, with each having access to different building level calculations from private projects. The NIBE coordinated this process: collecting data at the level of the construction work and anonymising it. This case similarly suggests that it is the regulatory requirement which is driving the uptake of data development.

In **Belgium**, there is no requirement to produce LCAs or include embodied carbon in the certification schemes. In this case, data is available as three regional authorities, in collaboration with a research institution, developed an open-access LCA tool called TOTEM. As application of the tool makes the building eligible for BREEAM certification and achieving said certification is becoming more important to investors, use of the tool has become widespread. This has led to a database of MMGs (Environmental Profile of Building Elements) being created, from which, in this case, KU Leuven could develop building archetypes and model a baseline of embodied carbon for Belgium, based on the generic building archetypes provided by the Tabula archetype definitions.

In France, data availability can be attributed to the cooperation between the CSTB and the Ministry of Ecological Transition which, firstly through the E+C- labeling scheme, and very soon through the RE2020, have created strong incentives for LCAs to be conducted on new buildings. This encouragement has led to a sizable, open-access building LCA database, although with variable quality. A similar database will be set up for the RE2020 cases.

An additional case to note is that of the **UK**, where popular uptake of BREEAM and LEED has led to over 11,800 new buildings being certified, and 285 buildings already in use being certified [4].The wide use of BREEAM and LEED may explain why many of the bigger consultancy firms in the UK are familiar with conducting LCAs. Another example is London, where regional legislation lays down requirements for new residential buildings with more than 150 housing units or with a floor area exceeding specific limits, depending on the location in the London area. For these construction projects, an LCA must be conducted in order to gain a building permit. This has further increased the number of LCA cases in the UK. This was, in large part, attributed to the LETI public/private partnership. Additionally, advances in product-level environmental data in the BRE IMPACT database mean that data barriers to LCAs have been reduced.

In all cases, **governmental initiatives** and support, alongside **partnership approaches**, are highlighted as being key in driving data development. This suggests that methods to incentivise governmental buy-in to develop studies, or legislation to tackle embodied carbon, or standardising LCA methods may facilitate the calculation of future embodied carbon baselines, targets and benchmarks across the EU. Finally, the findings suggest that popular uptake of certifications and the new Level(s) framework, alongside increased investor interest in certified buildings (e.g. buildings with BREEAM certification), may further incentivise LCA harmonisation and thus data development on embodied carbon.

5. Conclusions and recommendations

5.1 Conclusions

This report has provided an overview of embodied carbon data availability from LCAs across EU Member States.

The process, and resulting dataset, show that LCA data on embodied carbon in the EU is sparse, and that there are data collection and analysis challenges to overcome in terms of accessibility, quality, comparability and representativeness. In Europe, it was only possible to obtain samples of more than 50 cases of buildings from Denmark, Finland, the Netherlands, Belgium and France.

The report herein highlights two relevant solutions for overcoming the current challenges, based on the experiences observed in the five frontrunner countries:

- Firstly, legislation in EU Member States that addresses embodied carbon and sets standards or requirements for LCAs is beneficial in creating the framework needed for harmonised data collection (e.g. the Level(s) framework), and it increases investor interest in certified buildings (e.g. BREEAM).
- Secondly, triple helix cooperation in the form of partnerships between governmental agencies, research and/or not-for-profit institutions, and private enterprise acts as a key component in the development of databases, legislation and benchmarks on embodied carbon in buildings. Governmental support in the commissioning of LCA-based studies to identify embodied carbon baselines, benchmarks or targets was found to be of particular importance.

5.2 Recommendations

Based on these findings, we arrive at the following recommendations:

National LCA methods and data collection systems are urgently needed to avoid any further delay in this fundamental step towards measuring and reducing embodied carbon as part of whole life carbon emissions.

To this end, legal or sectoral requirements that mandate the production of LCAs in accordance with standardised calculation and documentation methodologies are highly relevant at national level, as well as harmonisation at EU level through tools such as the Level(s) framework. Standardisation based on coordination between stakeholders in the building design and construction value chain should, for example, include: scope of life cycle modules, scope of building elements, reference study period, environmental data on building materials, etc.

Data collection and compilation efforts are needed from all those involved in designing & assessing buildings. For this purpose, collaboration and complementary activities between public institutions, building designers, investors, certification organisations and researchers are needed. This step requires a common language and standardised methods for LCAs as described in the first point above.

As this process may take some time, the challenge of gaps in data could also be mitigated through the following approaches. These should be considered complementary.

- **Data on recent and current building projects could be generated at a centralised level by applying a single LCA method in order to provide information on these specific cases as it is likely that this data can still be obtained**. This exercise would benefit from input from the different actors involved, including the building industry, certification bodies, researchers and public bodies. This cooperation could be greatly facilitated through the use of standardised calculation methods and software tools to form a central database. A similar approach has provided a large database in France.
- **Existing data, that has been created in a scattered form using varying methodologies by different stakeholders, has the potential to be gathered together and harmonised to form a centralised database**. Harmonisation methods, adapted to the specific differences between the LCA methodologies, could be agreed upon by a coalition of actors to support this undertaking. Examples of such action are the international activities in Annex 72 to the IEA-EBC Programme, as well as the UK initiatives LETI and BRE.

- **Where empirical data faces the challenges described in this report, relying on results from modelled building archetypes could provide an insight into the life-cycle impacts**. Building archetypes offer the advantage of providing representative and comparable values. However, limits remain in translating building stock models into LCA data, which is challenging, particularly for the diverse landscape of non-residential buildings. Also, monitoring future buildings, in comparison with benchmarks, is not possible. Nonetheless, efforts to translate this data can help in the transition towards standardised empirical LCA data. This approach has been used successfully in projects such as the Tabula/Episcope project.

Appendix 1- COUNTRY SHEETS ON EMBODIED CARBON LCA DATA

BELGIUM

Overall data situation in the country, and the relation to the data collected for this project.

To date, Belgian building practitioners use the TOTEM tool[1] for the life cycle assessment of buildings. The TOTEM tool is an open-access online tool developed by the three regions in Belgium (Flanders, Walloon Region and Brussels region) and that uses the MMG (Environmental Profile of Building Elements) method. The tool has been available since February 2018 and is frequently updated to include new features, enlarge the database, include new methodological developments, etc. Although the use of the TOTEM tool in practice is not mandatory, it is being used by many practitioners and is often referred to in design contests.

Since March 2020 TOTEM is available for BREEAM certification[2]. It concerns the standards "BREEAM International New Construction 2013 and 2016" and "BREEAM International Refurbishment and Fit Out 2015 calculators", in the material criterion "MAT 01". TOTEM allows buildings to obtain a rating of "5+ EXEMPLARY", which is the maximum number of credits for this criterion.

GRO is a sustainability meter that the Facilities Company of the Flemish government uses for all construction projects, regardless of scale and function, in order to realize its ambition in the field of sustainability and circular construction. The GRO refers to TOTEM for the assessment of the environmental impact of materials and hence TOTEM is also used by building practitioners using the GRO.

KU Leuven was, and still is, involved in the development of the MMG method and the TOTEM tool and has provided this project with 105 cases. The MMG method has been used for the data in this project.

Status on LCA methodology

The MMG methodology embedded in the TOTEM tool is common and widely accepted in the Belgian construction sector. All life cycle modules are included, except for module D. The MMG method version as used in this project, follows the EN 15804:A1 and a set of additional environmental impact categories (in line with ILCD[3]). The environmental impacts are reported both in characterized values and as a single score, expressed in EURO (external environmental cost).

The method has fixed transport scenarios, cleaning scenarios and waste scenarios for the construction materials. The service life of the building is fixed to 60 years.

Status on LCA-based regulation

There is no LCA-based regulation yet for construction in Belgium. It is expected that this will be the case in the near future, although no exact timing is given by the authorities yet.

Identified key actors on the topic

- KU Leuven: The Design and Engineering of Construction and Architecture unit at KU Leuven has taken part in developing the MMG method.
- VITO: has taken part in developing the MMG method.
- BBRI: has taken part in developing the MMG method.
- Public Authorities of Wallonia: Supported the development of the TOTEM tool for the life cycle assessment of buildings.
- OVAM, the Public Waste Agency Flanders: Supported the development of the TOTEM tool for the life cycle assessment of buildings.
- Brussels' Environment Office: Supported the development of the TOTEM tool for the life cycle assessment of buildings.

Data collected for this project

Number of cases and data source	**Number of cases:** 105 **Source:** Cases from KU Leuven (Karen Allacker, Martin Röck) based on the modelling of the Belgium TABULA[4] cases in the MMG LCA Tool with adaptation to contemporary energy performance requirements. The cases were initially conducted as part of the work of the research group in the context of master thesis and PhD research. Cases are based on the modelling of the Belgium TABULA cases in the MMG LCA Tool with adaptation to contemporary energy performance requirements for the purpose of the Laudes/Ramboll project.
Scope of data	**Modules:** A1, A2, A3, A4, A5, B2, B4, B6, B7, C1, C2, C3, C4 **Reference study period:** 60 years **Square meter definition:** Gross floor area (Belgian definition) **Tool:** MMG-Building-LCA-Tool developed by KU Leuven (identical methodology as the TOTEM tool) **Background data:** Ecoinvent 2.2 database **Other comments on scope:** Module D not included

[1] https://www.totem-building.be/

[2] BREEAM is an environmental assessment method and rating system for buildings, with 200,000 buildings with certified BREEAM assessment ratings and over a million registered for assessment since it was first launched in 1990.

[3] https://publications.jrc.ec.europa.eu/repository/handle/JRC58190

[4] The TABULA/EPISCOPE projects developed Building Typologies for Energy Performance Assessment of National Building Stocks for various European countries - https://episcope.eu/welcome/

DENMARK

Overall data situation in the country, and the relation to the data collected for this project.

Until today the main incentive to conduct a building LCA in Denmark has been in relation to DGNB certifications of buildings. The DGNB certification is operated by Green Building Council Denmark, who has developed a Danish version of the DGNB system, that originates from Germany. The method description of Danish LCA criteria and reference values used differs slightly from the German version.

In 2020 The Danish Green Building Institute reported that 90 DGNB projects had been conducted over the past 8 years [4]. It is not mandatory to conduct an LCA as a part of a DGNB project, but as it counts so much in the final DGNB score, in practice, all projects get one done.

BUILD at Aalborg University conducted an analysis of the climate impacts of 60 building cases suggesting benchmark of whole life carbon in Denmark [5] . About 40 of the 60 building cases where DGBN certified buildings that all had been through conformity check in relation to the certification process. BUILD and Ramboll have provided this project with 60 and 12 cases, respectively.

Status on LCA methodology

The most LCAs in Denmark has been generated as a part of DGNB-projects. The Danish version of DGNB has been developed by the Danish Green Building Council with involvement from the industry and expertise form BUILD. The scope of the LCA includes the following life cycle modules: A1, A2, A3, B4, B6, C3, C4 and D. BUILD has been developing a Danish LCA tool called LCAbyg, which is most often used in DGNB projects today. The same scope is expected to be used in the forthcoming whole life carbon requirements in the building regulation from 2023.

In addition to DGNB and the forthcoming requirements in the building regulation, a Voluntary Sustainability Class for buildings was introduced by the authorities in May 2020 with a two-year test phase from mid-2020 to mid-2022. LCA is one of nine criteria in the Voluntary Sustainability Class. It builds upon the DGNB-scope, but with two further modules included: A4 and A5. The Voluntary Sustainability Class contains detailed guidelines for methodology and key assumptions, e.g. that must be performed in accordance with EN15978, EN15804 and relevant product category rules (PCRs).

Module A4 and A5 are also included as voluntary modules in the new DGNB-DK 2020 manual from 2021.

When reporting for the Voluntary Sustainability Class, it is recommended to use LCAbyg, but this is not mandatory. There is a strong acceptance in the industry of the LCA scope and method described in DGNB and the overlapping method described in the rather new Voluntary Sustainability Class.

Status on LCA-based regulation

A Voluntary Sustainability Class for buildings was introduced by the authorities in May 2020, and which now is in a testing phase with a two-year test phase from mid-2020 to mid-2022. LCA is one of nine criteria. The LCA criteria includes expansion of the scope compared to previous practice (including A4 and A5), but test phase of the Voluntary Sustainability Class includes no limit values.

In March 2021, the Danish government with cross-parliamentary support issued a new national strategy on sustainable construction including requirements on whole life carbon in new constructions in the building regulation enters into force in 2023. The forthcoming changes in the building regulation require that whole life carbon is assessed in all new constructions, and that buildings larger than 1000 m2 shall fulfill a mandatory limit value of 12 kg CO2/m2/year and that they have the possibility to fulfill a more ambitious voluntary CO2 class with a limit value of 8 kg CO2/m2/year. The strategy also includes phasing and tightening CO2 requirements in the period 2023 to 2029. From 2025 buildings smaller than 1000 m2 will also have to comply with limits on whole life carbon. The regulation will be reviewed every second year to set new, stricter requirements. The sketched pathway for tightening the regulation ends with limits in 2029 at 7,5 kg/CO2-eq/year for all buildings and 5 kg/CO2-eq/year for the voluntary CO2 class.

Identified key actors on the topic

- The Danish Housing and Planning Authority: Administrates and develops building regulation.
- The Danish Green Building Council (DK-DBC): Advocates for action on embodied carbon and provides certifications to buildings based on certain standards.
- BUILD, Department of the built environment, Aalborg University: Influential department on building research and on developing suggestions for future building regulation. BUILD is responsible for verifying the LCAs conducted as a part of the Voluntary Sustainability Class.

Data collected for this project

Number of cases and data source	**Number of cases:** 72 (60 from Build and 12 from Ramboll) **Source:** The Ramboll cases have initial been conducted as a part of DGNB-DK projects. The 60 cases from build have been conducted or updated as a part of a report by BUILD for The Danish Housing and Planning Authority (BUILD, 2021). 37 of the 60 cases are also DGNB projects.
Scope of data	**Modules:** A1, A2, A3, B4, B6, C3, C4 and D **Reference study period:** 50 years **Square meter definition:** Gross floor area (Danish definition) **Tool:** LCAbyg (developed by Build AAU) **Background data:** LCAbyg includes the Ökobau database as generic data and possibility to use EPD's when appropriate. BUILD cases are mostly calculated with generic data based on Ökobau 2020. The updated version of the 60 building cases from 2021 also includes use of average sector EPD's for Danish concrete and wood (BUILD, 2021). **Other comments on scope:** Module D is calculated separately

FINLAND

Overall data situation in the country, and the relation to the data collected for this project.

At present, there is no systematic collection of buildings-level LCA data in Finland. However, in the future, the government aims to develop requirements for collecting, analyzing, and aggregating generic reference data based on normative climate declarations of buildings.

Regarding product-level LCA data, there is an EPD operator (RTS) in Finland. This is, however, not run by authorities. The government has developed a generic database (www.CO2data.fi) for typical construction products and processes.

The data used for this project was created as a part of the test phase of upcoming regulation, the Climate Declaration for Buildings. Two different consultants (Granlund and OneClickLCA) were assigned by the Finnish Ministry of The Environment to deliver cases for this project.

Status on LCA methodology

The Ministry of The Environment published the 2nd version of the whole life carbon assessment of buildings in June 2021. It is based on European standards and Level(s), as well as feedback from the first public consultation round from the summer of 2020. The method is a draft developed for the upcoming LCA regulation and will be updated after the ongoing public hearing round in autumn 2021. Reporting following this method includes the following life cycle stages: A1-A5, B4, B6, C1-C4 and D.

Status on LCA-based regulation

In Finland the initial planning and testing of LCA-based regulation began in 2016 by the Finnish Ministry of The Environment, who developed a roadmap for reducing the carbon footprint of buildings. An upcoming regulation is currently being developed under the name of 'The Climate Declaration' and includes mandatory LCA-studies on all new construction as well as limit values to whole life carbon. The regulation will be implemented at latest in 2025.

Identified key actors on the topic

- The Ministry of The Environment: Responsible for developing the upcoming regulation and the related methods and reporting standards behind it.
- SYKE (Finnish Center of the Environment): In charge of CO2data.fi, the national generic database for building products and processes.
- Green Building Council Finland: In charge of Embodied Carbon Commitments (voluntary commitments for companies to decrease the embodied carbon of their products).
- OneClickLCA: An influential consultancy company and LCA tool provider with large amounts of data from Finish LCA studies (as well as data from other countries).

Data collected for this project

Number of cases and data source	**Number of cases:** 59 **Source:** 40 cases from Bionova and 19 cases from Granlund Oy.
Scope of data	**Modules:** A1, A2, A3, A4, A5, B4, (B5), B6, C1, C2, C3, C4, D **Reference study period:** 50 years **Square meter definition:** Heated floor area (Finnish definition) **Tool:** One Click LCA **Background data:** Various sources **Other comments on scope:** Cases from Granlund Oy do not include module B5 in the scope of the LCA while cases from OnceClickLCA do include module B5. Module D is calculated separately for all cases.

FRANCE

Overall data situation in the country, and the relation to the data collected for this project.

The collected LCA data from France comes from the Scientific and Technical Centre for Buildings (CSTB) database, which has been generated as a part of the voluntary reporting on whole life carbon encouraged in an experiment launched by the French Ministries in charge of construction and environment in 2016, in parallel of the second period of the RT2012 regulation. The database, called E+C- Observatory, is open source and contains 1197 cases. The LCA cases all follow the guidelines presented in the E+C- framework which has been used as an experimental precursor to the coming embodied carbon regulation for new buildings RE2020 (E as environmental) which enters into force from January 2022 (with several steps). CSTB has made an assessment of the quality of the LCAs in the database and found that they are of varying quality. For this project, CSTB has pointed us to 712 cases of good high quality. For the analysis in the Embodied Carbon Benchmarks project, these have been further filtered down to 486 cases, removing cases with missing data.

Status on LCA methodology

The LCA methodology defined in E+C-, which is based on the methods described in the European Standard EN15978 (2012), with minor variation, is common and widely accepted in the French construction sector and will help the transition to the mandatory RE2020 regulation in 2022. Nevertheless, the RE2020 LCA methodology differs from the E+C- one and from EN15978 on several points, and the GWP results obtained with RE2020 are not directly comparable to the one obtained with E+C- because a "dynamic" LCA method was introduced in RE2020 for GWP indicator.

Status on LCA-based regulation

In 2022 a substantial revision, called RE2020, enters into force. This replace the RT2012 regulation. It is applicable for new residential buildings from January 2022 and for new offices and schools from July 2022. So far conducting an LCA was optional, encouraged by voluntary certifications, but the new regulation introduces mandatory LCA-studies on these 3 building types. The next revision of the RE2020 regulation is expected to include LCA-requirements for all building types. The regulation also includes other sustainability measures, such as requirements to report on transportation of building materials, energy- and water use on the building site, as well as waste from the construction site. The regulation has been developed by the Ministry for Ecological Transition with technical support from CSTB and the involvement of many stakeholders.

For residential buildings (single homes and apartment buildings), regulatory thresholds were defined for operational energy-related carbon and embodied carbon, first for 2022 and becoming gradually stricter (smaller) until 2031. For embodied carbon, the 2031 value will be the 2022 one minus 1/3.

For other types of buildings, carbon thresholds are not defined yet, but they will probably follow a similar approach.

Identified key actors on the topic

- Scientific and Technical Centre for Building (CSTB): A public industrial and commercial company that supports the Ministry for Ecological Transition in collecting LCA data through certifications and classifications for buildings.
- HQE^{TM}: Certification that rewards buildings sustainable design, construction, operation and responsible management as well as urban planning projects. Accredited operators are Certivéa and Cerqual Qualitel Certification.
- Alliance HQE-GBC: French Green Building Council.
- Ministry for Ecological Transition: The governmental department responsible for the development and enforcement of the RE2020.

Data collected for this project

Number of cases and data source	**Number of cases:** 487 **Source:** Cases from the French database "E+C- Observatory". The cases have been selected with assistance from CSTB.
Scope of data	**Modules:** All life cycle modules **Reference study period:** 50 years **Square meter definition:** GFA (French definition, "surface de plancher") **Tool:** 9 tools were allowed in the E+C- experiment, among them the LCA tool ELODIE developed by CSTB. **Background data:** INIES database (including specific EPDs complemented by generic datasets) **Other comments on scope:** for materials, 1/3 of Module D is included if beneficial

NETHERLANDS

Overall data situation in the country, and the relation to the data collected for this project.

In the Netherlands, LCA data on product level is generated by industry, and after mandatory review, it can be uploaded to a National database known as the "Nationale Milieudatabase". From the national database, the data is provided to an approved software for calculations on the level of construction work (both building and infrastructural works). A team dedicated to the National Environmental Database maintains the system and the database and provides access (under license) to the data. The database contains both LCA on specific products (EPD's) and generic data.

The data for this project is collected on the level of construction works. The data was provided by several data partners that have access to building level calculations from their customers, or from the projects they have worked on. The data is made anonymous so it cannot be traced back to the specific building. NIBE has conducted the data collection and has a proprietary list of the individual buildings and data owners that have provided the data.

Status on LCA methodology

Conducting an LCA is mandatory for obtaining a building permit in The Netherlands. The requirements for the LCA are described in "Bepalingsmethode Milieuprestatie Bouwwerken" (method for calculating the environmental performance from buildings). All life cycle modules are included in the obligatory method. The "Bepalingsmethode Milieuprestatie Bouwwerken" follows the EN 15804:A2 and provides additional information regarding scenarios and default environmental profiles for transport and energy.

The method has fixed waste percentages for building materials. These are respectively 3% for prefab elements (e.g. concrete elements), 5% for in-situ applied materials (e.g. bricks) and 15% for 'assisting materials' (e.g. paint).

Status on LCA-based regulation

In the Netherlands it is required to conduct an LCA in order to get a building permit. This was introduced in 2012. The results from the LCA must live up to a limit value (since 2018), that sets a maximum of impact from GWP as well as other environmental impact categories. The limit is expressed in €/m2 and is calculated by a weighting of all impact categories (shadow prices). This implicates that one cannot derive the resulting GWP/m2, if one only has the results in €/m2.

The limit value is tightened periodically and is announced to decrease from 1,0 (introduction value)€/m2 in 2018 to 0,5 €/m2 in 2030. The Dutch software for performing calculations on Building level also provides the underlying environmental effects (like GWP). Consequently, the user can also obtain environmental effect data, per LCA module for the complete building.

Identified key actors on the topic

- Stichting Bouwkwaliteit (The Building Quality Foundation): In charge of developing the national LCA methodology. The members are both governmental representatives and industry players.
- NIBE: An influential, private consultancy firm specialized in services related to sustainable construction.
- Dutch Green Building Council: Advocates for action on embodied carbon and provides certifications to buildings based on certain standards.

Data collected for this project

Number of cases and data source	**Number of cases:** 50 **Source:** NIBE.
Scope of data	**Modules:** A1, A2, A3, A4, A5, B1, B2, B3, B4, C1, C2, C3, C4, D **Reference study period:** 50 or 75 years **Square meter definition:** Gross floor area (Dutch definition) **Tool:** SimaPro **Background data:** Ecoinvent 3.6 **Other comments on scope:** Module D is subtracted (credit)

Appendix 2 - EMBODIED CARBON LANDSCAPE IN THE EU

Country	Standardized LCA method/ scope (Y/N)	Embodied carbon regulation (Y/N)	Embodied carbon front runners (govt/ academia/ industry/ certification bodies)	Details / comments
Austria	No, but there is a nationally accepted methodology	No **Relevant regulations:** IBO ÖKOPASS	IBO – Österreichisches Institut für Baubiologie und -ökologie	While there is no formal government-set methodology, IBO – Österreichisches Institut für Baubiologie und -ökologie has published what constitutes the nearest to a national embodied impact evaluation methodology. The name of this methodology is Ökoindex 3 (Ökologischer Kennwert der thermischen Gebäudehülle). This methodology is a weighted score of global warming potential (carbon footprint), primary energy depletion, and acidification, expressed as an A to E rating. The scale of performance has been fixed by IBO. The calculation data applied for these analyses are provided by Baubook, which is a limited company owned by a regional energy association and IBO. Austria has a governmental environmental rating system called klimaaktiv, which applies the Ökoindex 3 as the methodology for the building materials environmental impact assessment. Materials assessment is a mandatory part of the certification. Performing well in this certification can make residential buildings eligible for an additional environment-related subsidy. This certification has been applied to over 500 buildings.
Belgium	No, but there is a nationally accepted methodology	No **Relevant regulations:** Circular Flanders: Green Deal Circular Building, Open Call Innovative Circular Economy Projects Brussels: 'Guide de gestion des déchets de construction, Programme Régional en Economie Circulaire (PREC) Wallonia: TOTEM: instrument to evaluate the environmental impact of buildings	See section above	See section above
Bulgaria	No	No	Data not obtained	Regulation soon to include operational energy "The upcoming legislation transposing the EPBD at national level will ensure that energy performance requirements are part of the building codes. It is also required by the EPBD to relate energy performance requirements to primary energy consumption, in order to have a more accurate picture of the energy quality and related CO2. No requirements for compulsory use of renewable energy in new buildings. However, in the Energy Efficiency Law it is mentioned that the renewable energy use should be considered as a possible option during the design phase of the buildings"

Country	Standardized LCA method/ scope (Y/N)	Embodied carbon regulation (Y/N)	Embodied carbon front runners (govt/ academia/ industry/ certification bodies)	Details / comments
Croatia	Data not obtained	Data not obtained	Data not obtained	
Cyprus	Data not obtained	Data not obtained	Data not obtained	
Czech Republic	No	No	Technical and Testing Institute of Civil Engineering Prague, sp (TZÚS Praha, sp) Research Institute of Civil Engineering – Certifikační společnost, sro (VÚPS)	**embodied carbon is optionalà SBToolCZ is Czech method for complex quality assessment of building performance in which the characteristics of the building and its surroundings are evaluated with respect to the sustainable development. Building's impacts on the environment, social-cultural aspects, functional and technical quality, economic and management issues and location of a building are included in the assessment. The method contains a set of criteria which is evaluated based on the basic characteristics of the building and its surrounding; and based on this evaluation the building obtain one of the three certificates (bronze, silver or gold)
Denmark	Yes	Yes **Relevant regulations:** The National Strategy for Sustainable Construction	Danish Ministry of Environment and Food; Ministry of Industry, Business and Financial Affairs; Danish Energy Agency Build Institute, Aalborg University Danish Green Building Council	See section above
Estonia	No	No **Relevant regulations:** Estonia's 2030 National Energy and Climate Plan (NECP 2030)	Ministry of Economic Affairs and Communications TalTech expert level knowledge working on the development of national methodology and creating LCA materials database (for CO2eq emissions).	Currently there is an ongoing study by TalTech, which should establish suitable method and scope, is carried out. The results of the study will be finalized by the end of the year 2021. The proposed method is carefully aligned with the European Standards EN 15804+A2:2019 and EN 15978, the European Level(s) framework, and with international best practice. Scope: A1-A5, B4, B6, D. Scope of functional systems: Ground, Wall, Slab, Roof. Impact of use stage operational energy (B6) is considered via EPC (EPBD) requirements. As Estonia has very high grid electricity emissions factor, it is important and can be considered as part of LCA assessment. An official from Estonia notes that the number of experienced individuals and enterprises capable of performing LCA assessments is low, and that less than 10 individuals/enterprises could be identified with such skillsets. It is estimated that less than 5 cases are available.
Finland	Yes	Yes	See section above	See section above

Country	Standardized LCA method/ scope (Y/N)	Embodied carbon regulation (Y/N)	Embodied carbon front runners (govt/ academia/ industry/ certification bodies)	Details / comments
France	Yes	Yes	See section above	See section above
Germany	No, but a nationally accepted method exists	No **Relevant frameworks**: Bewertungssystem Nachhaltiges Bauen or BNB Deutsche Gesellschaft für Nachhaltiges Bauen (German Sustainable Building Council, DGNB) BNB Assessment System for Sustainable Building.	DGNB BNB The Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety	In Germany there is no national LCA-based regulation. However, an official method for assessing the sustainability of a building, BNB (Bewertungssystem für Nachhaltiges Bauen), has been developed and introduced in 2009. Conducting an LCA is a part of this assessment, and the results from the LCA will be a part of the final score. The score determines whether the building obtains a bronze, silver or gold level. Since 2011 it has been obligatory for all federal buildings to conduct an BNB assessment, and as a part of this, an LCA. Federal buildings must obtain a silver level in order to get a building permit. Although there are no requirements at national level for the execution of building LCAs, there are some states that set regional requirements where they have also chosen to follow the BNB system, and also require a minimum of silver level. Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB) is the most popular sustainability certification scheme in Germany. The results from an LCA counts in the overall score, and DGNB is therefore a driver in normalizing the use of LCAs in the German construction sector.
Greece	No	No **Relevant regulation:** National circular economy strategy	Not assessed	
Ireland	No, but a nationally approved method exists	No **Relevant regulation:** EN15978		EN15978 sets out how the full life cycle carbon and other environmental impacts should be calculated setting out the modules relevant to each part of the building lifecycle. There are currently no definitive plans in Ireland for regulations but there are a number of positive indicators that this is likely to happen over the next five years. Ireland's national certification scheme for homes – Home Performance Index awards credits for embodied carbon calculation and LCA. The international certification schemes for non-residential buildings LEED and BREEAM also award credits for the calculation of Life Cycle Assessment and embodied carbon. This is driving interest amongst professionals in calculation. However, there is also an increasing interest from the investment community in embodied carbon and this is likely to grow over the coming years.

Country	Standardized LCA method/ scope (Y/N)	Embodied carbon regulation (Y/N)	Embodied carbon front runners (govt/ academia/ industry/ certification bodies)	Details / comments
Italy	No	No **Relevant legislation:** Towards a Model of Circular Economy for Italy - Overview and Strategic Framework	Casaclima Nature, Casaclima Nature, GBC Home Ministry of Environment	No systematic collection of data on embodied carbon from of the Italian systems evaluate embodied carbon. There are is regulatory measures on embodied carbon. No national, common agreed LCA method or tools has been identified.
Lativa	Data not obtained	Data not obtained	No data obtained	
Lithuania	No	No	Environmental Protection Agency in Lithuania which is subordinate to the Ministry of Environment of the Republic of Lithuania is one of the main institutions involved in Lithuania's greenhouse gas (GHG) emissions inventory preparation.	There are plans to prepare the methodology for modelling whole building life cycle and to model all stages of life cycle it is important to have this information about construction products. The preparation should begin in 2023. One of the plans of the Ministry for the future is to prepare the methodology for modelling building life cycle to evaluate the impact of structures, buildings, construction products/materials on the environment, climate change, health, the opportunities of waste recycling, second use, circular economy principles in all stages of building life cycle (planning, design, construction, use, demolition). To evaluate these things like formation of waste, greenhouse gas emission in the whole cycle of the building in the early stages of planning and design would be very helpful and useful for all participating in the fields of waste and construction sectors. The preparation of the methodology is planned to start in 2023.
Luxembourg	No data obtained	No data obtained	No data obtained	
Malta	No data obtained	No data obtained	No data obtained	
Netherlands	No, but a nationally approved method exists	No **Relevant regulation:** A Circular Economy in the Netherlands by 2050 + Dutch Building Code (Bouwbesluit 2012), Article 5.9.	See section above	See section above

Country	Standardized LCA method/ scope (Y/N)	Embodied carbon regulation (Y/N)	Embodied carbon front runners (govt/ academia/ industry/ certification bodies)	Details / comments
Poland	No	No	Polish Green Building Council Institute of Innovation and Responsible Development Polish Circular Hotspot	There is no regulation of whole life carbon in Poland. Large investment companies and developers are showing interest in conducting LCAs on construction projects as a part of voluntary sustainability certifications. The Polish Green Building Council expressed difficulties on getting data on the topic of embodied carbon, since the results of the LCAs are not systematically gathered in a central repository. As in many other countries, the data stays with the building owners, the consultancy companies conducting the LCAs, the providers of the LCA tools or the certification bodies.
Portugal	No	No regulation includes embodied carbon. **Relevant regulation:** Action plan for circular economy in Portugal: 2017-2020 Green Growth Commitment	Certification: LiderA	LiderA: acronym for Leading for the Environment for sustainable construction, is the designation of a Portuguese voluntary system that aims to carry out.
Romania	No	No regulation includes embodied carbon. **Relevant regulations:** Romania's strategy for the transition to a circular economy (ROCES) 2020-2030	Romania Green Building Council and the Green Homes Certification Owners Association Office	In Romania, the energy performance certificate has been compulsory for new buildings since 2007. Romania has building code requirements only for new buildings and no whole building energy performance-based requirements for new buildings and renovations. Romania has prescriptive/ element-based criteria for thermal insulation and an overall heat transfer coefficient G-value. From 2011 energy certificates are mandatory whenever a flat or house is sold or rented, thus creating an awareness raising wave that could be used to push for a stronger refurbishment and a new nearly zero-energy construction programme.
Slovakia	No data obtained	No data obtained	No data obtained	
Slovenia	No	No **Relevant regulations:** Roadmap towards the circular economy in Slovenia	Ministry of the Environment and Spatial Planning ZAG	The majority of LCA in Slovenia is still done on product level (for EPDs). It is estimated there are less than 5 cases.

Country	Standardized LCA method/ scope (Y/N)	Embodied carbon regulation (Y/N)	Embodied carbon front runners (govt/ academia/ industry/ certification bodies)	Details / comments
Spain	No	No **Relevant regulations** *Climate Change law* (recently approved in 2021), "encourages the use of materials with the smallest possible carbon footprint" *VERDE certification* (GBC España), a volunteer Spanish sustainability rating system that used a qualitative LCA based approach in the assessment process.	• GBC (España) (https://gbce.es/blog/proyecto/buildinglife/) • ITEC(Catalunia) BEDEC database (https://metabase.itec.es/vide/es/bedec) • Instituto Torroja (Madrid) (https://www.opendap.es/) • Asociación Ecómetro (Madrid) (http://ecometro.org/evaluar-un-proyecto/) • University of Sevilla (TEP 130 and TEP 986) (Andalusia) • Other Spanish universities such as University of Granada (TEP 968), University of Zaragoza, UPM, UPC, UNESCO Chair in Life Cycle and Climate Change	Some academic studies have been made on embodied carbon in the Spanish building stock, but with variation in scope and method, since there is no agreed national standard on how to conduct an LCA (Soust-Verdaguer, 2021). It might be possible to collect enough data from these studies to do a baseline, but it would take a lot of effort to make the data comparable due to the different methodological approaches. There are no regulatory measures on embodied carbon in Spain, nor any official methods or tools. More than 50 Spanish LCA case studies indexed publications are detected in Scopus in the last 5 years, however, different methods and tools are used for the LCA implementation.
Sweden	Yes	Yes **Relevant regulation:** The Climate Declaration Act for new buildings	Boverket The National Board of Housing, Building and Planning	In 2022 regulation targeting sustainable construction called *Klimatdeklaration* (the climate declaration) will come into force in Sweden. As a part of this, it will become obligatory to conduct building LCAs on new build (Boverket, 2020). A second version of the regulation is to be implemented in 2027, where limit values for the results from the LCA will be introduced.
Switzerland	No	No	• LCA studies related to the SIA • PORR (construction company)	There is upcoming LCA-based regulation (BPIE, 2021). The construction company PORR provided a cross-country dataset of 22 cases for AT, DE, CH for the study.

Appendix 3 - REFERENCES

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