Baseline and carbon limit values A1-A3 for new buildings in Sweden Green Building Council's Net Zero Building certification system "NollCO$_2$" – version 1.1 2022

Pia Stoll, PhD[a, b]

[a]*Pia Stoll Konsult AB,* [b]*Sweden Green Building Council, Långholmsgatan 34, 117 33 Stockholm, Sweden*

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Abstract

New buildings contribute significantly to climate change and yet there is a lack of baselines and limit values for buildings' whole life carbon impact. This study presents a model that uses project specific and building type specific parameters in the calculation of carbon baseline and limit values for the life cycle modules A1-A3, expressed in the unit kgCO_2e/m^2 gross area. The model is used in the building certification system SGBC Net Zero Building ("NollCO$_2$" in Swedish) NollCO$_2$ requires building projects to reduce their climate impact with 30% and balance the remaining impact to net zero using climate actions. The baseline results are compared with benchmark values compiled by the Swedish National Board of Housing Building and Planning. In the comparison, the baseline values are found to be in the range of the national agency's mean values for the building types office building, multiapartment building and school, but differ for the building types preschool and one-family homes.

1. Introduction

1.1 The construction sector's carbon impact

The European Union (EU) has a carbon emissions reduction target of 55% by 2030 compared to 1990 year's level, and net zero by 2050. EU has pointed to the construction sector as one of the prioritized sectors for greenhouse gas reductions and included it in its taxonomy for sustainable investments (European Parliament, 2021).

1.2 Whole life carbon perspective

A building's whole life carbon (WLC) is divided into modules by the standard EN 15878 (European Committee for Standardization, 2011). The life cycle modules are illustrated in Figure 1. The carbon emissions from a building's life cycle are commonly divided into operational and embodied carbon. The division us used to discuss their different kinds of impact, even if the terms are not used in the standard EN 15978. The operational carbon emissions result from the energy production required for heating, cooling, and powering the building and is reported in the life cycle module B6. The embodied carbon emissions are reported in life cycle modules A-C with the exception of B6. The life cycle system boundary is determined by what modules are included in the calculation. Calculation result will differ depending on what life cycle modules are included.

The building element system boundary describes what building elements are included in the calculation. A calculation result where only frame and external walls are included cannot be directly compared with a calculation where all elements are included. It is therefore equally important to state the building element system boundary as it is to state the life cycle boundary for a building's climate impact calculation. It is worth noting that today, digital BIM models are often used to model the architecture and its building elements. It is then more difficult to exclude building elements when exporting data from the model than to have a full scope and export all the building element data.

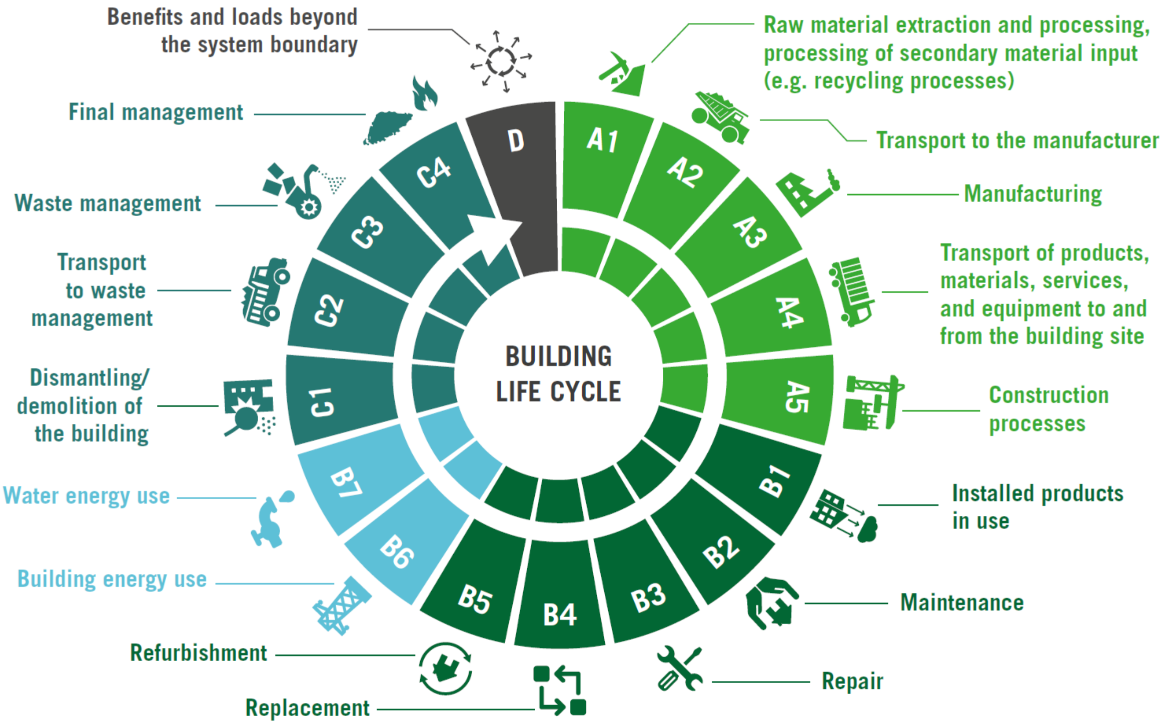

Figure 1 Whole life carbon cycle of a building according to the standard EN 15978. [Source: SGBC]

The third crucial component of a WLC calculation is the datasets representing the climate impact of the individual building elements. Generic datasets can be derived as average data of specific datasets in form of environmental product declarations (EPDs) of the most used products in a market or calculated from the most common processes to manufacture a building element. The generic climate dataset for producing a certain building element can therefore differ between countries depending on what generic datasets are available, what background data is used for the generic datasets, and – if the generic datasets are formed as average data – what products are used in the national market.

A building's climate impact A1-A3 is calculated as the sum of climate impact (kgCO_2e/kg) for each building element multiplied by its built-in quantity (kg). The building elements' A1-A3 modules is defined either by generic data or by product specific data. Product specific data is calculated according to the standard SS-EN 15804:2012 and product category rules (PCRs) and published as Environmental product declarations (EPDs) (Swedish Standards Institute, 2021). The EPDs are published on EPD platforms (Environdec, 2022).

1.3 Green Building Councils

The first Green Building Council was founded in 1993 and the World Green Building Council (WorldGBC) was founded in 2002 by eight Green Building Councils (World Green Building Council, 2022). Since its formation, WorldGBC has grown into a global network of around 70 Green Building Councils around the world. Sweden Green Building Council (SGBC) was founded in 2009 by thirteen companies and organisations. It has kept growing since then and has today around 410 members (Sweden Green Building Council, 2022). Common for all GBCs are that they are working for a sustainable built environment, but it differs in what degree they work through certification, education, and/or advocacy. SGBC has its focus on certification and education.

Advancing Net Zero (ANZ) is WorldGBC's global programme working towards total sector decarbonisation by 2050 (World Green Building Council, 2022). The ANZ vision is that by 2050, new buildings, infrastructure and renovations will have net zero embodied carbon, and all buildings, including existing buildings must be net zero operational carbon. Sweden Green building Council (SGBC) joined the ANZ programme in 2017 and within its framework, started the development of a net zero certification scheme for new buildings called "NollCO_2". The NollCO_2 system consists of criteria for reducing whole life carbon impact (the fossil part) in line with the Paris agreement 1.5° target. It also includes regenerative measures for contributing with carbon reductions and uptakes to the society, outside the project's boundary, with an amount that equals the project's remaining climate impact, see Figure 2, thus reaching a net zero impact (Sweden Green Building Council, 2020).

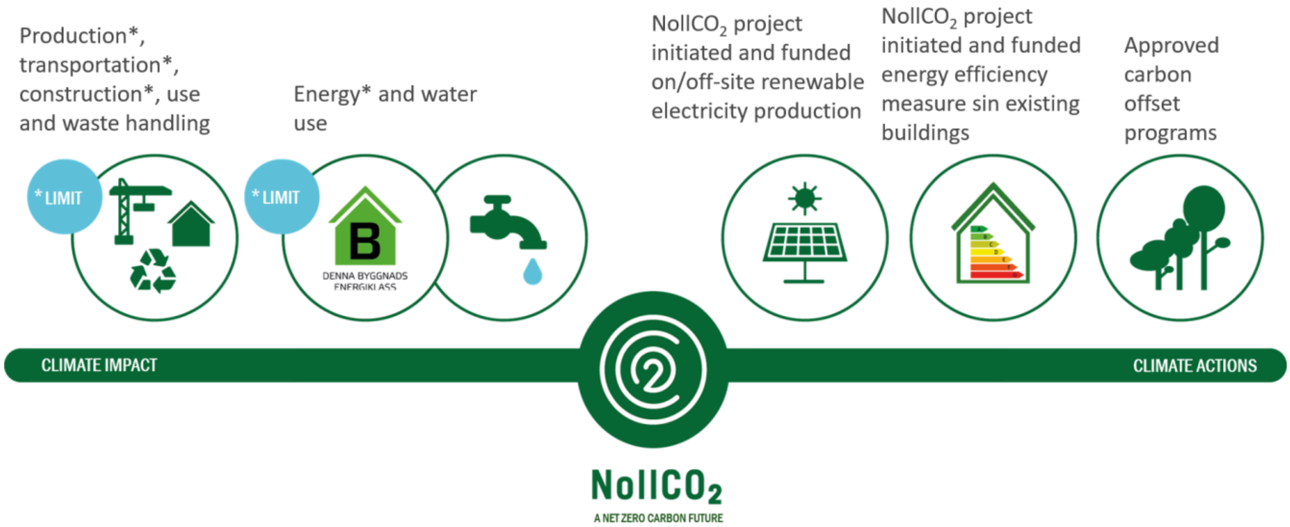

*Figure 2 NollCO$_2$ net zero model. *= Limit value [source: SGBC]*

In NollCO$_2$, B1-B7, is balanced to net zero on a yearly basis while A1-A5 and C1-C4 are balanced to net zero before 2045. To reduce carbon impact, NollCO$_2$ has set a project specific carbon limit for the modules A1-A3 and a static carbon limit for the modules A4-A5 and an energy performance limit for B6. NollCO$_2$ requires the climate impact of the building and its building elements to be calculated according to the standards SS EN 15978 and SS EN 15804. The NollCO$_2$ unit for the climate impact of one kg building element is 1 kgCO$_2$e/kg. For the transportation of a ton building element one kilometre, the unit is 1 kgCO$_2$e/tkm. The unit for the climate impact of a building is 1 kgCO$_2$e/m^2 gross area. The expected building service life is a 50-year span after the building is put into operation, as defined by the Swedish National Board of Housing, Building and Planning in the building code for climate declarations of new buildings. NollCO$_2$ includes the full life cycle A- C according to EN 15978 and all building elements above and below ground level, see NollCO$_2$ manual 1.0 (Sweden Green Building Council, 2020).

Since the certification scheme development started, one of its most important tasks has been to establish project specific limit values for the A1-A3 modules. A limit value for a building's carbon impact constitutes a carbon budget goal for the building development team. Realistic limit values are crucial since an unachievable limit value will discourage, and a value which is too easily achieved will not bring the necessary contribution required to limit global warming to 1.5°C.

1.4 Baseline and carbon limits

In a recast of the Energy Performance Building Directive, EU proposes Whole Life Carbon (WLC) reporting in 2030 as an addition to the EPC declaration (European Parliament, 2021). The European parliament writes that "*The 2050 vision for a decarbonised building stock goes beyond the current focus on operational greenhouse gas emissions. The whole life-cycle emissions of buildings should therefore progressively be taken into account, starting with new buildings*." However, the revised Directive gives no roadmap towards setting whole life carbon limits.

When constructing carbon limits, it is necessary to know what the typical carbon impact is today. For this purpose, benchmarks can be developed. A benchmark is defined by Merriam-Webster as something that serves as a standard by which others may be measured or judged, a point of reference from which measurements may be made, or a test that serves as a basis for evaluation or comparison (Merriam-Webster, 2022).

Ramboll has together with Aalborg university set up a carbon benchmarking project, reported on in the study "Towards embodied carbon benchmarks for buildings in Europe" (M, Röck; A., Sørensen; J., Steinmann; X., Le Den; K., Lynge; H., Horup L.; B., Tozan; H., Birgisdottir, 2022). The team has collected building level embodied carbon data from LCA case studies done in five European Union members states. The study uses the term "embodied" emissions throughout, which it defines as including the EN 15978 modules A1-A5, B1-B4 and C1-C4. The term "upfront embodied emissions" is used for A1-A5, and the study uses m^2 gross area as the area metric and presents results in the unit "kgCO$_2$e/m^2 gross area". The building elements are referred to as "building parts", and the included building parts in the study's scope are described as "ground; structure; envelope; internal; services; and appliances". The study has no detailed descriptions of what components are including in the five "building parts". It is unfortunate that the study does not present results per EN 15978 module. The only mentioning of the modules A1-A3 can be found on the study's page 12 as "the largest contribution of embodied carbon emissions occur during the production stage (A1-3), with a mean value of around 300 kgCO$_2$e/m^2 and ranging from around 70 to 520 kgCO$_2$e/m^2". Unfortunately, the study does not specify what building type(s) and design choices the

A1-A3 result 300 $kgCO_2e/m^2$ gross area refers to or what building types and geometries have an impact of 70 or 520 $kgCO_2e/m^2$.

The Swedish National Board of Housing, Building and Planning introduced a new building code in January 2022 stipulating that all new buildings are to declare their A1-A5 carbon impact for the building elements: external walls, roof, the frame, and the internal walls (Boverket, 2022). As part of the building code, the national board also developed a database with national generic climate data, which is average data based on EPDs for the most common used products on the Swedish market. In 2027 carbon limits will be introduced in the building code, and for this purpose a benchmark study was undertaken (Malmqvist, Borgström, Brismark, & Erlandsson, 2021). The report cites sixteen LCA articles, including the same LCA articles as the Ramboll study refers to, which provides the same background knowledge as the Ramboll study. Like the Ramboll study, the Swedish benchmark study constructs mean, median, upper- and lower quartile values, but it presents the results organised into EN 15978 modules and with detailed declaration of system boundaries and what datasets have been used.

The Ramboll and Swedish National Board of Housing, Building and Planning benchmark studies were not available when $NollCO_2$ version 1.0 was developed. Additionally, the $NollCO_2$ 1.0 pilot projects signalled that building type specific and project specific parameters influenced the carbon impact of their buildings in a way that a static carbon limit would be rather easy for one project to achieve and practically impossible for another. The decision was then taken to develop a baseline model for A1-A3 and to let the model use building type and project specific data as input for a calculation of project specific baseline and carbon limit values for A1-A3. Another reason for choosing A1-A3 as the scope of the limit is that it targets the producers of building material separately and their proof of lower impact can be found in their EPDs.

The carbon impact of A4-A5 very much depends on the modes of transport, the distances from the production plants to the construction site, and the fuels used on site and do not lend itself to be modelled in the same way as A1-A3. The carbon impact of the life cycle modules A4-A5 was therefor given the static limit value of 55 $kgCO_2e/m^2$ gross area on the recommendations of the involved experts.

This article presents the $NollCO_2$ A1-A3 baseline challenge, the modelling including updates made in 2022, the data usage, and simulation results of the updated baseline. The results are compared to the benchmark results in the Swedish National Board of Housing, Building, and Planning's research study. This article also includes a discussion of how the model and its results can be used and further developed.

2. Methodology

2.1 The challenge

How to construct a certain building type is impacted by functional requirements, local conditions, tradition, trends, and national building codes. A static carbon limit applied to, for example, an office building and a detached family home means that it is expected that the two building types use the same kind of materials in the same amount per square meter and that the materials are produced with the same climate impact. This is never the case. Early in the $NollCO_2$ development it was clear that two pilot projects, a detached grocery store and a large office building, had very different challenges. It was also impossible to say – if they met the static limit value – how much the different buildings had reduced their climate impact compared to their traditional carbon impact. In short, a baseline was missing.

Another discussion concerned whether it is right to base a limit value on the climate impact that a multiapartment building made from wood had per square meter, since that was the only research result available at the time to provide a limit value for Swedish conditions. All materials have their issues regarding climate impact, concrete must reduce the carbon emissions from cement production or replace cement; steel production has to replace the blast furnace using coke or only use recycled steel; glass and tile production has to use renewable energy; plastic based materials have to be fully recyclable and chemically harmless; and timber and wood cannot be sourced from unsustainable clear-cutting forestry and in parallel, the world has to preserve forests to meet the 1,5° target. Steering all construction work towards wooden buildings is not the answer to the construction industry's challenge. All material producers must work on their issues.

It might have been possible to base a limit value on benchmarking of different building types. But to get a high-quality benchmark of A1-A3, many LCA studies would have been needed. And the studies would have had to use the same system boundary regarding included building elements and to declare the A1-A3 impact. And they would have had to use the same climate data.

And even if these studies were available, which they were not in 2019-2020 when $NollCO_2$ was developed, the issue of the LCA studies using different architectural designs regarding exterior as well as interior elements would remain.

2.2 Baseline modelling

To meet the challenge, a baseline model would have to be based representing the contemporary way a certain building type is constructed in Sweden. And its building elements needed to be structured for a good overview – a building's climate impact calculation consists of several hundred of individual components. It also had to scale to the specific project's key parameters such as a certain number of floors and square metres above and beyond ground level. And it had to use climate datasets from databases in a defined priority order.

Microsoft Excel was chosen as the platform; changes can be done fast, and it is tailored to large data management and calculations which was needed for the baseline. Emphasis was put on using Excel variables and formulas so that one change to a parameter would update all the formulas containing the parameter. Summation was done in two different ways to find potential errors in the calculations. A strict layout and labelling were applied that made it easy to understand the stepwise calculations needed for the result. The building elements were structured according to the BSAB 96 codes from "Svensk Byggtjänst" (Svensk Byggtjänst, 2022). The structuring makes it easier to convey where the system boundary is set and it is, for NollCO$_2$'s baseline calculation, also a way to create an overview of the tool's calculations and simplify error finding during development.

To be able to scale the model according to building type and project specific parameters, different units per material/product needed to be applied. For example, the unit for EPS insulation and gravel in the foundation slab is kg/m^2 foundation floor slab. The unit is scaled according to the square meter foundation slab entered by the project (in the old version, above grade level BTA divided with number of above ground floors). The weight (kg/unit) is set according to the typical construction way for the building type. For the EPS insulation and gravel in the example, their weight is calculated as the typical thickness times typical density per square meter slab for the specific building type.

In the first version of the baseline, there was one Excel model for each building type and the baseline was constructed as a "shoebox" model, with the same gross area for all floors except the underground floors that was allowed to have a different area. The building type specific data was collected from the pilot projects and information material online and in books. The result was published at SGBC.se (SGBC, 2021).

In the updated baseline version, the results from the study "Climate impact of buildings - reference buildings for Swedish conditions" financed by the Swedish Construction Industry Development Fund (SBUF) was used (SBUF, 2021). Another significant change was that the shoe-box model was abandoned, the project now enters square meter gross area for each business activity and for each floor plan, from which the model automatically concludes the building type and adapts the calculations accordingly.

It is also possible to enter data for several interconnected building structures, and from their individual results do a total calculation. The project enters what side of one building structure that is interconnected with another building structure, for example the short side. The project then enters the percentage of the short side intersecting with an adjacent building structure. There is also the possibility to enter how many identical building structures that are adjacent to each other, which is useful for townhouses. Each building structure is calculated as a separate building but the area of external walls, roofs, foundation, facades, and windows etc. are reduced and changed according to how intersecting walls, roofs etc are constructed.

2.3 Data usage

NollCO$_2$ only uses the GWP-Fossil datasets in the baseline and in the project reporting, which means that NollCO$_2$ does not include the biogenic carbon emissions. Biogenic carbon emissions are those that originate from biological sources such as plants, trees, and soil. Biogenic carbon emissions relate to the natural carbon cycle where carbon dioxide emissions occur during the combustion or decay of biomass. NollCO$_2$ has investigated the option of reporting the biogenic carbon emissions separately, but this is only possible once the databases, described below, also include biogenic carbon data.

NollCO$_2$'s baseline model does not include any reused materials or products, but some of the materials and products have recycled content in the calculation of the generic climate data if the databases consider this as the common method of manufacturing, for example, steel rebars have a percentage recycled steel.

The baseline represents the most common contemporary way of constructing a certain building type in Sweden. Therefore, generic datasets are used as generic climate data is data representative of a certain construction product. Such representative data is usually based on averages for different construction products within one and the same product group. Generic climate data at the national level denotes generic climate data representative for a national market.

The baseline contains 139 individual products and materials. One product is used in several building elements, for example a certain type of insulation can be used for roofs, external and internal walls. The baseline model will therefore contain a larger number of building element components than individual products and materials.

All datasets for the 139 materials and products could not be sourced from one database, which is why the NollCO$_2$ baseline uses several databases. The databases are used in a certain priority order. This means that datasets from databases with priority 1 is used before datasets from databases with priority 2 and so on. As discussed, NollCO$_2$ only uses datasets that does not include biogenic carbon.

NollCO$_2$ was developed for the Swedish market, and therefore, the Swedish national board of housing, building, and planning's database with generic datasets is given priority 1 (Boverket, 2022). The baseline uses the national agency's specific generic datasets without their 25% add-on. The 25% is added on top of the specific generic dataset to get a conservative dataset to be used in the building code "Climate declaration of new buildings" (Boverket, 2022). The add-on should stimulate the development of specific EPDs, since just having an EPD will then guarantee a climate impact value 25% below the conservative data.

Priority 2 is given to the Ministry of Environment Finland's database "co2data.fi" (Ministry of Environment Finland, 2022). Also here, NollCO$_2$ uses the specific generic datasets without the add-on, which for the Finnish datasets is 20%. These datasets have been given priority 2 since the Swedish National Board of Housing, Building, and Planning and the Ministry of Environment Finland have collaborated when developing their respective databases. Both the Swedish and the Finnish database developers have created average generic datasets for GWP-Fossil from a selection of market representative EPDs developed according to the standard EN 15804. The Swedish and the Finish databases do not include biogenic carbon in their datasets.

Priority 3 is given to the German database "Ökobau.dat" and its generic datasets developed according to EN 15804+A2 by ThinkStep. NollCO$_2$ uses the GWP-Fossil data from Ökobau.dat's EN 15804+A2 datasets in the baseline. The Ökobau.dat's GWP-biogenic and GWP-LULUCF values are stored for possible future uses.

Simplified life cycle emission (LCE) calculations have priority 4. LCEs are done using a Construction product declaration (in Swedish "byggvarudeklaration, BVD"), which lists the proportion of the materials included in the declared product (Byggmaterialindustrierna, 2022). The proportions in the BVD are multiplied with the materials datasets according to the priority 1-3.

As priority 5, a proxy EPD developed using EN 15804 for a similar material/product is used. The EPD's GWP-Fossil is used, alternatively GWP-IOBC if the EPD is from the EPD platform "EPD-Norge".

A summary of what databases are used is shown in Table 1. The data quality of the datasets is decided by the developers of the datasets. Since all datasets are third party assessed, by EPD programmes and ThinkStep (for Ökobau.dat) the datasets are considered to have high quality. One could argue that the LCE is not third party assessed, but its climate datasets and construction product declaration are third party assessed, and a LCE for the baseline product constitutes a better generic dataset than a similar product's proxy EPD, which explains why the LCE is given a higher priority than the proxy EPD.

Table 1 Summary of databases priority and usage in NollCO$_2$ baseline datasets as of April 2022

Database	Priority	Usage percentage in baseline
Swedish national board of housing, building, and planning	1	44%
Ministry of the Environment Finland (co2data.fi)	2	16%
German Ökobau.dat (ThinkStep origin)	3	16%
LCE	4	19%
EPD proxy	5	6%

The baseline model automatically selects the datasets according to priority order since datasets are imported into the NollCO$_2$ baseline model tagged with its database. In the first version of the baseline, the data was transferred manually for each dataset from the databases to the model, but in the updated baseline, the entire databases are downloaded at a specific date, and imported into the baseline. This is to avoid manual transfer errors and to give the datasets a timestamp. The reporting tools are updated in the same way i.e., the downloaded databases are imported and incorporated in the reporting tools.

2.4 Building type specific data

At the time before the launch of NollCO$_2$ 1.0 (October 2020), there was no study on how different building types were constructed in Sweden. NollCO$_2$ did therefore, together with pilot projects, its own informal studies for a restricted number of building types. The results went into the 2020 version of the baseline.

In 2021, a report was published from a study financed by SBUF in which a great number of key actors from the construction industry in Sweden took part (SBUF, 2021). The study had consolidated information on how several building types are typically constructed in Sweden. The study's results were incorporated in the updated version of the baseline, resulting in higher baseline results, mainly due to thicker steel beams and pillars, thicker glass and more metals used in glass facades, and thicker concrete castings than was previously assumed in the first baseline model. The SBUF study has investigated the following building types: office, residential multifamily building, preschool, and school building, detached single family house, retirement home, and warehouse. For each building type the study listed how the following building elements are constructed: frame, façade, roof structure, roof cladding, heating and cooling system, ventilation system, floor slabs, external walls, percentage area windows in relation to total façade area, windows, suspended-ceiling, balconies and terraces, and the internal walls (load-bearing and non-load bearing). For example, “the internal non-load bearing walls in the office building typically consists of 20% glass internal walls, 10% tenant separating walls and 70% normal internal walls, where the tenant separating wall typically consists of 2*2*gypsum boards, steel sheet of 1 mm, steel profiles, and 45 mm stone wool”. Nearly all this information went into the NollCO_2 updated baseline model’s weight calculations per material/product for each building element. Some parameters were chosen to be project specific in the updated baseline, such as the type of façade and square meter surface-mounted balcony/attic corridor. The parameters that the study marked as uncertain, for example percentage of window area compared to the façade area for preschool buildings, were double checked and in some cases adjusted using certification projects’ drawings for the specific building type. NollCO_2 has also, after discussions with a municipality that builds many preschools, put a square meter limit to when a preschool is built with a concrete frame instead of a wooden frame. The reason is that preschool buildings serving low-density housing areas are built to blend in as smaller wooden framed buildings. In high density residential areas, the preschools are larger and built with a concrete frame. NollCO_2 also chose to use a solid concrete intermediate floor for the larger preschools.

Not all building type specific data was presented in the SBUF report. In fact, the NollCO_2 baseline model uses 192 building type specific parameters, but not all parameters are used for all building types. 116 of the 192 parameters are used for calculating climate impact of installation systems (heating, cooling, ventilation, lighting, fire protection, alarm and transportation systems, and electrical installations). Some of the needed building type specific parameters are specified by the national agency, for example minimum floor height for different business activities and recommended air exchange rate. Others are extracted from certification projects’ drawings, the BREEAM-SE manual, and manufacturers’ web pages. The book Neufert’s “Architects’ Data” is used to define what spaces the building types have and the spaces’ required square meters (Neufert & Neufert, 2019).

The façade material was one of the parameters that the SBUF report specified. Since the façade is an important architectural expression of a building, NollCO_2 has discussed whether this should be a building type specific data, as in the first version of the baseline, or a project specific data. For example, if NollCO_2 puts wood as the façade material for townhouses, using bricks can blow the project’s carbon budget. The conclusion was done that all construction materials have their carbon issues, and the purpose of NollCO_2 is to stimulate the work of reducing all materials’ carbon impact, not to exclude some of the materials. It was therefore decided that the updated baseline should have façade materials as project specific parameters.

2.5 Project specific data

The baseline model’s units and weights scale according to a set of project specific key parameter values and gross area entries, and the predefined building type specific data. Figure 3 and Figure 4 show the project specific key parameter values and gross area entries which the project specifies at registration. The “Laboratory” and “Hotel” cells are greyed-out since their modelling is not finished.

The project specific parameters have been chosen so that they are available early in the construction process. Therefore, the project can register, receive its baseline, and carbon limit, and use the carbon limit as a carbon budget throughout the construction processes. But the project can update its baseline free of charge once before preliminary certification.

If the project does not enter a maximum number of contemporary users in the building, the model estimates the number automatically using background data from BREEAM-SE (Sweden Green Building Council, 2022), Swedish building codes and the book Neufert’s Architects’ Data (Neufert & Neufert, 2019). The “number of users” parameter is used to derive the carbon impact per user of the building which could be an important KPI for some stakeholders.

Estimated maximum contemporary users in the building		
Building structure no.	1	
No of identical building structures	1	
Building structure's intersection with another building structure (not for hall buildings)	short side	
Shared part of the intersection	50%	
No. below ground level floors	0	
No. split-level floors	0	
No. above ground level floors	4	
No. passenger lifts	4	
No. goods/bed lifts	0	
Roof angle (0 if intersection is top floor)	0	grader
Roof ridge height above the highest ground level (detached house / preschool / hall building)		m
Facade type 1 (not garage floor)	Glass	
Facade type 1:s percentage of total facade (%)	100%	
Facade type 2 (not garage floor)		
Facade type 2:s percentage of total facade (%)		
Facade type 3 (not garage floor)		
Facade type 3:s percentage of total facade (%)		
Facade type 4 for garage floors aboveground		
Facade type 4:s percentage of total facade (%)		
Facade type 5 for garage floors aboveground		
Facade type 5:s percentage of total facade (%)		
Externally mounted balcony/attic corridor total area	0,00	m^2
Foundation floor slab concrete thickness	0,15	m
Reinforcement steel bar in foundation floor slab	100,00	kg/m^3
Piling		kg
Piling material	No piling	
Struts and anchorings (steel)		kg
Other foundations (concrete)	50,00	m^3
Maximum number of contemporary diners in restaurant/dining hall area	100	
Functional roof space area for ancillary use, not included in BTA (m2)	30	m^2

Figure 3 Project specific parameters

Gross area (m2) distributed by type of activity / accommodation, B. G. = BELOW GROUND, A. G. = ABOVE GROUND. Underground garages and / or above gr

	GROUND FLOOR	A. G.	A. G.	A. G.	
Floor no.	0	1	2	3	
Garage					
Industrial building					
Warehouse					
Grocery store					
Sports centre					
Office	1 700,00	2 000,00	2 000,00	1 500,00	
Health centre					
Preschool					
Shops, smaller					
School					
Retirement home					
Multiapartment building					
Laboratory					
Restaurant/dining hall	800,00				
Hotel					
One-family home					
Total gross area (m2)	2 500,00	2 000,00	2 000,00	1 500,00	
Externally mounted balcony/attic corridor (m2)					
Number of stairwells per floor	4,00	4,00	4,00	1,00	

*if split-level floorplan, fill in stairwells for the part where they are located, split-level b. g./split-level ground floor/split-level a. g.

Figure 4 Project specific gross area entries

2.6 Completeness

The NollCO₂ baseline model's system boundary includes the BSAB 96 building elements codes, presented in Table 2, and their components. For example, the basic construction includes components related to the foundations, piles, pile plinths, pile slabs, pillar sockets, foundation soles, foundation beams, foundation walls, pile decks, and crushed rock. Table 2 lists the number of components per element code. Not all components are used by all building types, but all components are used by one or more of the building types. The components can use the same products and/or materials, which is why the baseline model has many more components than individual materials and products.

Table 2 BSAB 96 Building element codes and their components included in the NollCO₂ baseline model

BSAB 96 building element code	Number of baseline components for the code
15 Basic constructions	50
27 Bearing structure in the house frame	63
41 Climate separation components and extensions in roofs and floor joists	58
42 Climate separation components and extensions in the outer wall	86
43 Internal components for room construction	57
44 Internal surface layers	37
45 House extensions	25
49 Other components for room construction etc.	4
52 Water supply	29
53 Wastewater system	24
54 Fire extinguishing system	16
55 Cooling system	8
56 Heating system	45
57 Air handling system	24
6 Electricity and telecommunications systems	47
7 Transport system	7

NollCO₂ has included all components that could be modelled with a reasonable effort and for which information is available. Excluded products are screws, fasteners, joints, tapes and other similar "little things" hard to model. The installation systems' components might not be difficult to model as such, but it has been difficult to know what components should be included. SBUF has an ongoing project "Climate impact of installation systems in buildings" that might give a better basis for how to model the installation systems (SBUF, 2022). The results are expected at the end of 2022.

It is no longer the extraction of quantities of different building components that set up a limit for what building components can be a part of a calculation of climate impact. Today's BIM programs can easily export quantities for relatively simple composite components such as frames, but also for more complex composite components such as installation systems. It may even involve more work to exclude building components than to export them all from the BIM program. Instead, it is the availability of climate data for technical installation systems that is the challenge. Technical installation systems usually need to be broken down into their sub-components. By adding the climate impact of their sub-components, the project gets an approximation of the climate impact of the technical system.

The building structure weight per m^2 gross area is calculated by the model and is a good indicator of whether the calculations are correct and complete. For an office building, the number seems to be around 1000 kg/m^2 gross area for the typical way of constructing an office building in Sweden with five or more floor levels. A project using a more lightweight construction, such as a wooden frame, will obviously get a lower number.

Building-mounted renewable electricity generation systems are still not typically installed on buildings in Sweden and therefore not part of the baseline model. For the projects, the renewable electricity generation systems are part of the B6 reporting where they are reported as an up-front scope 3 climate impact in the year when the generation is taken into operation. If the renewable electricity generation system is integrated into a building element, the project makes an estimate of how much of the system is dedicated for electricity generation and how much is dedicated to act as a building element and report these parts in B6 and A1-A3 respectively.

2.7 Carbon limit construction

A limit value might be seen as easy to construct once the baseline results for the building types are in place. But the prerequisites of a project will influence its possibilities to stay below a limit value based on a percentage of a baseline. Figure 5 shows three examples. The baseline of example 1 is carbon impact of above ground elements (AG1) + carbon impact of below ground elements (BG1) divided with the total gross area (GA1). The baseline of example 2 is AG2/GA2 + BG2/GA2. For example 3, the baseline is AG3/GA3. If NollCO₂ required the examples to reduce their baselines with 20 %, then their respective carbon limits would be:

- 0,8* AG1/GA1 + 0,8*BG1/GA1
- 0.8* AG2/GA2 + 0,8*BG2/GA2
- 0,8*AG3/GA3.

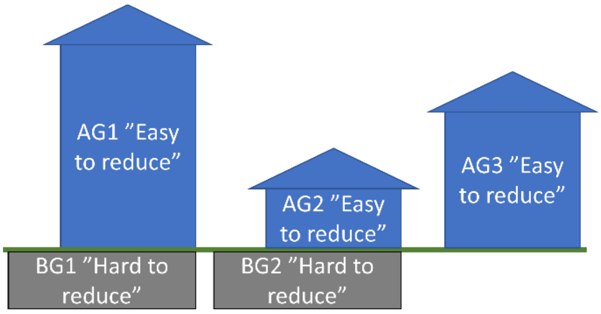

Figure 5 Carbon limit value setting, illustration

The below ground impact is harder to reduce than the impact of above ground elements since the below ground elements are made of concrete and steel, hard to replace with wood due to moist concerns, and their dimensions are set according to construction safety limits. For the AG1, the project can use a hybrid design of wood and concrete or even a full-scale wooden frame, the project can change the external walls, and so on. These strategies can help achieve the required 20% reduction in BG1 in addition to meet the reduction of 20% in AG1. Example 2 could use the same strategies to reduce AG2, but it will give a smaller reduction since AG2 itself is smaller than AG1. Example 2 will therefore get a tougher challenge when trying to meet its limit value. Example 3 would get the easiest challenge since it can use the strategies for reducing AG3 without considering the need of getting a surplus sufficient to cover a 20% reduction of the climate impact of any below ground elements. A certification system like NollCO$_2$, including all building elements above and below ground, would with such limit setting approach, give its projects very different challenges.

Another difficulty in using a percentage of a baseline as the carbon limit, is the fact that when dividing the carbon impact with the total gross area above and below ground, the result is:

$$(AG+BG)/GA.$$

Adding another floor to this building will change AG linearly with the added GA, but not necessarily change BG, so the baseline is not constant for the building type. The impact of BG on the result is higher for a low number of floors, since when AG is much higher than BG, the influence of BG decreases.

It was therefore decided to use another approach where the limit value is constructed as:

$$\text{Carbon limit A1-A3} = 0{,}7 * AG + BG.$$

This approach levels the field for the three examples since a project with below ground elements will get a higher limit value than the project without below ground elements. It also reduces the need of ensuring a surplus from reducing the carbon impact of the above ground, and all three projects will get the same challenge. They can of course use any reductions of the carbon impact of the below ground elements to meet the overall limit value, for example by using carbon impact reduced concrete. The limit is easily constructed since the baseline model uses a separate summarization of below ground and above ground elements.

3. Results

The example input used in Figure 3 and Figure 4, gives the result presented in Figure 6. In this case the baseline is 369 kgCO$_2$e/m^2 gross area and the carbon limit 271 kgCO$_2$e/m^2 gross area. NollCO$_2$ highlights the baseline and the carbon limit value with two separate lines so that it is easily detected. The results shown in Figure 6 is printed together with the input in Figure 3 and Figure 4 and uploaded into the project's folder in the certification project management system “Building Green Online (BGO)”.

NollCO2
NETTONOLL KLIMATPÅVERKAN

Språk/Language

SE

BASELINE OCH GRÄNSVÄRDE FÖR NOLLCO2 PROJEKT

Projektets namn: test **BGO ID:** NC2 2022-xxxx **Datum:** 2022-07-29

Huskropp no.1 :	**Kontorsverksamhet, kortsida 50 % snitt**	
BTA	**8 000**	**m^2**
Ljus BTA (Ovan marknivå)	**8 000**	**m^2**
Mörk BTA (Under marknivå)	**0**	**m^2**
Total klimatpåverkan A1-A3	**2 958**	**tCO_2e**
Klimatpåverkan A1-A3 ljus BTA	**2 612**	**tCO_2e**
Klimatpåverkan A1-A3 mörk BTA i form av fundament, stag, sockel, pålning, bottenplatta	**346**	**tCO_2e**
Klimatpåverkan A1-A3 av övrig mörk BTA	**0**	**tCO_2e**
Procentuell minskning av klimatpåverkan A1-A3 ljus BTA	**30%**	
Baseline A1-A3	**370**	**kgCO2e/m2 BTA**
Gränsvärde A1-A3	**272**	**kgCO2e/m2 BTA**
Minskning A1-A3, absolut	**784**	**tCO_2e**
Minskning A1-A3, procentuell	**26%**	
Byggnadens vikt per m2 BTA	**1 055**	**kg/m2 BTA**
Antal samtida brukare som mest	**340**	
Total klimatpåverkan A1-A3 per brukare	**9**	**tCO2e / brukare**

Figure 6 NollCO$_2$ Baseline model result for the input given in Figure 3 and Figure 4

A comparison was done of the NollCO$_2$ baseline A1-A3 results with the results of the Swedish National Board of Housing, Building, and Planning's commissioned research study (Malmqvist, Borgström, Brismark, & Erlandsson, 2021). The study included the building types: residential building; office building; commercial building; preschool building; school; detached one-family homes; and "others". By averaging the results of the LCA studies, the research team hopes to get a good representation of the carbon impact of the building types, so-called benchmarks. The national agency's study is done with two system boundaries regarding building elements, one for the 2022 boundary including external walls, roof, frame and internal walls, and another for the 2027 boundary including technical installations and internal surface layer. The national agency's system boundaries are organised according to the "SBEF byggdelstabell" based on an earlier version of BSAB, the BSAB 83 building element codes (Skanska, 2014). Table 3 shows a comparison of the system boundaries of the NollCO$_2$ baseline and the national agency's scope for 2027. Note that NollCO$_2$ does not include interior fittings such as shelfs, cupboards, or wardrobes in its 1.0 or 1.1 version.

Table 3 Comparison of building element system boundaries between NollCO$_2$ and the Swedish National Board of Housing, Building and Planning's 2027 scope

BSAB 96 building element codes included in NollCO$_2$ baseline and project reporting	**BSAB 83 building elements included in the 2027 system boundary of the Swedish National board of Housing, Building and Planning's building code "Climate declaration"**
15 Basic constructions	2 Building substructure
27 Load-bearing structures in the house frame	3. Frame (including lift shaft walls, stairs, and balconies)
41 Climate separation components and extensions in roofs and floor joists	4. Roof
42 Climate separation components and extensions in the outer wall	5. Façade
43 Internal components for room construction	6. Frame additions for room construction
44 Internal surface layers (excluding interior fittings)	7. Internal surface layers (including interior fittings)
45 Building additions (stairs, and balconies)	Stairs and balconies included in "3. Frame"
49 Other components for room construction (lift shaft walls)	Lift shaft walls included in "3. Frame"
52 Water supply	8. Installation systems
53 Wastewater system	8. Installation systems
54 Fire extinguishing system	8. Installation systems (included for wooden frame buildings except for one-family houses)
55 Cooling system	8. Installation systems
56 Heating system	8. Installation systems
57 Air handling system	8. Installation systems
6 Electricity and telecommunications systems	8. Installation systems
7 Transport system	8. Installation systems

The national agency's research team's 70 LCA studies lacked, partly or fully, reporting of BSAB 83 codes 7 and 8, and the team therefore constructed standardized values for these. For the remaining BSAB 83 codes, the projects were asked to report the coverage degree of their LCA studies, and then the research team used the coverage degree to increase the reported quantities (expressed in kg) correspondingly.

NollCO$_2$ calculates the quantities mathematically in a building type specific way. For the example above, the total quantity (kg) of the bricks is calculated using the project's reported gross area values per floor, and the model's building specific parameters floor height, façade brick volume and density, and percentage area of windows, doors, and ports for subtraction of opening areas in the façade area.

With these two different approaches to arrive at A1-A3 for the building types in mind, NollCO$_2$ baseline simulations were done and compared with the national agency's research study. To be able to do a comparison, NollCO$_2$ must "simulate" project specific parameters as floor levels, gross area per floor level, etc. Some of the baseline model's project specific parameters are not reported in the agency's study, and for the comparison set as:

- Building structure's intersection: detached
- Split-level floors: 0
- Foundation floor slab thickness office, residential building, school > 1000m^2: 0,20 m
- Foundation floor slab thickness office, residential building, school, preschool < 1000m^2: 0,10 m
- Foundation floor slab thickness preschool > 1000 m^2: 0,15 m
- Foundation floor slab thickness one-family home, and preschool < 1000 m^2: 0,10 m
- Rebar in foundation floor slab: 100 kg/m^3
- Piling: 0 kg
- Struts and anchoring (steel): 0 kg
- Other foundations (concrete) office, residential building > 1000m^2: 50 m^3
- Other foundations (concrete) office, residential building < 1000m^2: 20 m^3
- Other foundations (concrete) school and preschool > 1000 m^2: 20 m^3
- Functional roof space area for ancillary use (not included in gross area) office, school, and preschool > 1000m^2: 30 m^2

Façade materials are varied according to the agency's report's listed façade materials.

Preschools smaller than 1000 m^2 gross area, are in NollCO$_2$'s baseline modelled with a wooden frame like a one-family home. Schools and preschools have restaurants/dining halls, modelled as restaurant/dining hall areas within the school/preschool, see footnotes below Figure 7. One important remark is that NollCO$_2$ has not used the report's dataset 1,7 kgCO$_2$e/kg for construction steel with 50% recycled steel. Discussions with experts showed that this kind of construction steel is hardly available on the Swedish market and is not available from the agency's public database where only 100% primary steel or 100% recycled steel datasets can be found. NollCO$_2$ has therefore used the dataset for construction steel with 100% primary steel.

The comparison has recalculated the A1-A3 2027 Office building mean values in the agency's report, excluding wooden framed office buildings, to make the comparison with the NollCO2 results more appropriate.

The results of the comparisons are shown in Figure 7 and Figure 8.

	Project specific parameters								NollCO$_2$ baseline and carbon limits				Swedish National Board of Housing, Building, and Planning agency's research study	
Building type	Gross area per floor level (m^2)	Floor levels above ground	Floor levels below ground	Passenger lifts	Stairwells per floor (one for top floor's access to flat roof)	Roof angle (°)	Facade (100%)	Externally mounted balcony area per floor above first floor (m^2)	Baseline A1-A3 (kgCO$_2$e/m^2 gross area)	Carbon limit A1-A3 (kgCO$_2$e/m^2 gross area)	Baseline A1-A3 (tCO$_2$e/user)	Weight (kg/m^2 gross area)	Mean value A1-A3 2027 (kgCO$_2$e/m^2 gross area)*	Mean value A1-A3 2027 using climate improved materials/products (kgCO$_2$e/m^2 gross area)
Office building	2000	8	0	8	4	0	Brick	0	318	228	7	890	317	250
Office building	2000	8	0	8	4	0	Glass	0	348	249	8	863	317	250
Office building	640	5	0	4	2	0	Brick	0	424	308	10	1114	317	250
Office building	3500	10	0	12	6	0	Brick	0	293	210	7	833	317	250
Office building	2000	7	2	8	4	0	Steel	0	287	217	7	896	317	250
Multiapartment building	1300	6	0	4	4	15	Brick	58	319	232	11	1566	323	259
Multiapartment building	1300	6	1	4	4	15	Brick	58	303	228	11	1499	323	259
Multiapartment building	472	2	0	1	1	15	Plaster	21	411	307	14	1963	323	259
Multiapartment building	2100	9	1	6	6	15	Brick	94	284	209	10	1408	323	259
Multiapartment building	2600	7	2	7	7	15	Plaster	116	263	202	9	1328	323	259
School[1]	2900	3	0	1	3	0	Wood	0	298	224	3	1073	287	251
School[1]	2900	3	0	1	3	0	Brick	0	313	234	3	1134	287	251
School[2]	1100	2	0	1	2	0	Wood	0	350	268	3	1303	287	251
School[3]	3400	2	1	1	3	0	Wood	0	275	225	2	1172	287	251
One-family home[4]	171	1	0	0	0	38	Wood	0	285	236	10	1274	139	130
One-family home[4]	171	1	0	0	0	38	Brick	0	326	265	11	1436	139	130
One-family home[4]	200	1	0	0	0	38	Wood	0	280	233	9	1267	139	130
One-family home[5]	80	2	0	0	1	38	Wood	0	200	159	6	749	139	130
One-family home[5]	80	2	0	0	1	38	Wood	0	242	188	8	787	139	130
One-family home[5]	98	2	0	0	1	38	Wood	0	234	183	8	771	139	130
Preschool[6]	612	2	0	1	1	0	Wood	0	407	308	3	1184	263	240
Preschool[6]	612	2	0	1	1	0	Brick	0	428	304	3	1269	263	240
Preschool[6]	925	2	0	1	1	0	Wood	0	361	272	3	1018	263	240
Preschool[7]	350	1	0	0	0	25	Wood	0	324	263	3	1308	263	240
Preschool[7]	350	1	0	0	0	25	Brick	0	358	287	3	1443	263	240

Figure 7 Comparison between NollCO$_2$ baseline and carbon limit results and the Swedish national board of housing, building, and planning's reference values research study

*Wooden framed office buildings excluded from mean value A1-A3 2027

1 Dining hall area: 500 m^2, maximum contemporary users of dining hall area: 200

2 Dining hall area: 300 m^2, maximum contemporary users of dining hall area: 120

3 Dining hall area: 590 m^2, maximum contemporary users of dining hall area: 230

4 Roof ridge height: 5.8 m, roof angle 38°

5 Roof ridge height: 8.5 m, roof angle 38°

6 Dining hall area: 200 m^2, maximum contemporary users of dining hall area: 100

7 Roof ridge height: 5.8 m, roof angle 25°, dining hall area: 50 m^2, maximum contemporary users of dining hall area: 25

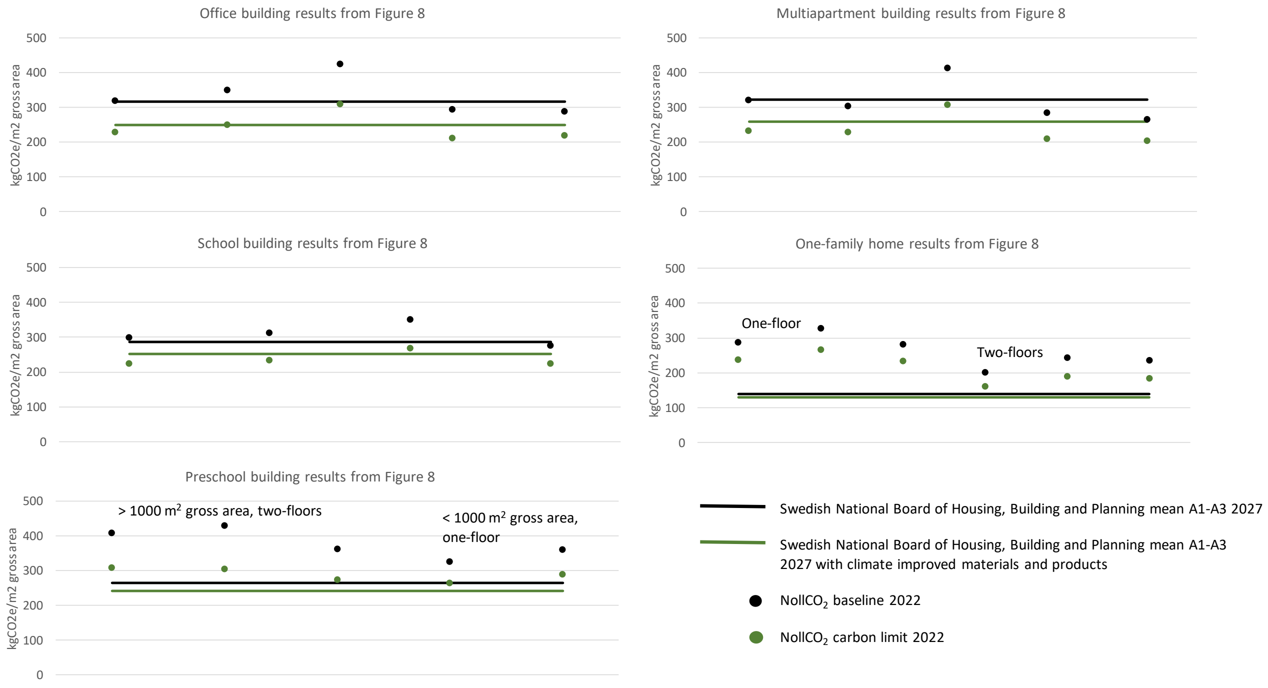

Figure 8 Graph visualization of comparison in Figure 8

4. Discussion

NollCO$_2$ models a baseline A1-A3 mathematically, using building type specific and project type specific parameters. The result is a representation of how the project's building would be built using the contemporary way of constructing the corresponding building type in Sweden in 2020-2021. The results from the simulations in Figure 7 shows a large variation in baselines and carbon limits which was expected and one of the reasons why NollCO$_2$ chose to construct a baseline model.

The NollCO$_2$ model has a complete calculation, as very little is left out, and is not the result of averaging buildings with varying carbon impacts. Consequently, if the contemporary way of constructing a certain building type comes with a high carbon impact, then the NollCO$_2$ model will deliver a high baseline for that building type. Averaging carbon impact calculations for buildings of a certain building type, including buildings built with a lower carbon impact than what is the contemporary way of constructing that building type, will give a lower mean value. It is therefore expected that the NollCO$_2$ baseline simulations are higher than the national agency's mean values.

From the simulations, it can be noted that the NollCO$_2$s baseline and carbon limits for the building types office building, multiapartment building, and school are reasonably well scattered around the mean values A1-A3 2027 and the climate improved values A1-A3 2027. One might think that it is then reasonable to set the limit as the mean value, but the difference between the baseline simulation's highest carbon limit for an office building, 424 kgCO$_2$e/m^2 gross area, and the lowest, 287 kgCO$_2$e/m^2 gross area, is significant. A static limit value for these two projects could be very hard for one of them to reach and very easy for the other.

NollCO$_2$'s carbon limit values 2022 are scattered around the national agency's expected carbon improved buildings in 2027. NollCO$_2$ requires the projects to reduce their carbon impact compared to a baseline based on yearly updated generic data. The generic data represents the market. If Sweden's construction product market evolves in a way that complies with the Swedish government climate target of net zero 2045, the generic data will be lower in 2027. This means that the NollCO$_2$ carbon limits 2027 will be lower than those of 2022 and lower than the national agency's climate improved values A1-A3 2027, which is as it should be. Certified buildings should be market leading.

Design choices, for example different room heights, different amounts and qualities of steel and concrete, thinner or thicker window glasses, and varied types of intermediate floors influence a building's carbon impact. For the one-family home and small pre-school, the thickness of and the material in the foundation floor slab has a very high impact on the result. The installation systems also have a significant impact for these building types. The reason is the relatively large percentage of steel for ventilation channels and electric wiring in comparison with the percentage of more low-carbon impact building element materials, like wood, gypsum, and mineral wool, in the one-family homes and preschools.

NollCO$_2$ has verified its baseline for one-family homes with the preliminary certification result for the NollCO$_2$ pilot project "VillaZero" (Fiskarhedenvillan, 2021). The one family home VillaZero uses a cross laminated timber foundation, wooden frame, wooden internal and external walls, and a wooden roof. In addition, they have used organic insulation instead of mineral wool insulation. With all these measures in place the VillaZero project arrived at a climate impact of 176 $kgCO_2e/m^2$ gross area. The agency's 2027 mean value of 139 $kgCO_2e/m^2$ gross area for one-family homes can therefore be considered as very low.

Two of the preschools, larger than 1000 m^2 gross area, in the agency's research study have a wooden frame, and one has foam glass instead of concrete in the foundation floor slab. These design choices lower the mean value for preschools. $NollCO_2$ models preschools larger than 1000 m^2 gross area with a steel and concrete frame and therefore has a higher baseline and carbon limit for these than for smaller preschools. The smaller preschools are modelled with a wooden frame as this is the more common approach for small preschools in one-family home residential areas. Gothenburg city has built a climate impact improved preschool "Hoppet" and published the results (Göteborgs stad Lokalförvaltningen, Derome, 2022). "Hoppet", which has a gross area of 1850 m^2 and two floor levels, has a climate impact A1-A3 of 195 $kgCO_2e/m^2$ gross area. Gothenburg city compares "Hoppet" with a preschool "Grönskan", built as preschools are usually built in Gothenburg. "Grönskan" has a climate impact A1-A3 of approximately 370 $kgCO_2e/m^2$ gross area. The climate impact A1-A3 of "Grönskan" is much higher than the national agency's 2027 mean value 263 $kgCO_2e/m^2$ but is in line with $NollCO_2$'s baseline for a preschool of similar gross area and with two floor levels.

Building type specific parameters, in terms of what materials are used, can change soon due to requirements to build with lowered carbon impact. Also, the manufacturing of future materials and products will be done differently. Steel will be produced with green hydrogen, concrete with substitutes for cement or with cement produced in a plant using carbon capture technology, glass will be produced with renewable energy, and so on. And all buildings cannot be constructed out of wood since the forests must be managed sustainable which means the harvests will not be significantly higher than today. Thus, regardless of method used to construct baselines, benchmarks, and limit values, there will be a need for new studies and updated models and generic climate data for construction products in a few years' time.

5. Conclusions

In this article, a model for calculating baseline and carbon limit mathematically for a variety of building types has been presented. The model is based on the Swedish contemporary way of constructing a set of building types, architectural lay-out parameters, generic climate datasets selected in a certain priority order, and project specific parameters. The mathematically constructed baseline model gives a precise A1-A3 baseline and carbon limit which gives projects a fair chance to meet their carbon budget.

6. Acknowledgements

The development of $NollCO_2$ and its baseline model could not have been done without the help of the $NollCO_2$ pilot projects, the Sweden Green Building Council's drive to push for a new science- and standards-based certification system, and all the experts and members of the Sweden Green Building Council participating in discussions contributing to the system. The World Green Building Council's network "Advancing Net zero" has also been a valuable support and discussion partner.

References

Boverket. (2022, January). *Klimatdeklaration - en handbok från Boverket*. Retrieved from boverket.se: https://www.boverket.se/sv/klimatdeklaration/

Boverket. (2022, April). *Sök i Boverkets klimatdatabas*. Retrieved from https://www.boverket.se/sv/klimatdeklaration/klimatdatabas/klimatdatabas/

Byggmaterialindustrierna. (2022). *eBVD*. Retrieved from https://byggmaterialindustrierna.se/byggvarudeklaration-ebvd1-0/ebvd-english/

Environdec. (2022). *The International EPD system*. Retrieved from www.environdec.com

European Committee for Standardization. (2011). *Sustainability of Construction Works–Assessment of Environmental Performance of Buildings–Calculation Method; EN 15978:2011.* Brussels, Belgium: European Committee for Standardization.

European Parliament. (2021). *Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast).* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02010L0031-20210101: EUr-Lex.

European Parliament. (2021, June 18). Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088 (Text with EEA relevance). EUR-Lex.

Fiskarhedenvillan. (2021, October). *Ett välbesökt seminarium*. Retrieved from https://fiskarhedenvillan.se/villazero-byggdialog-dalarna-seminarium/

Göteborgs stad Lokalförvaltningen, Derome. (2022). *Klimatarbete Hoppet.* Göteborgs stad Lokalförvaltningen.

M, Röck; A., Sørensen; J., Steinmann; X., Le Den; K., Lynge; H., Horup L.; B., Tozan; H., Birgisdottir. (2022). *Towards embodied carbon benchmarks for buildings in Europe.* Denmark: Ramboll.

Malmqvist, T., Borgström, S., Brismark, J., & Erlandsson, M. (2021). *Referensvärden för klimatpåverkan vid uppförande av byggnader.* Stockholm: KTH.

Merriam-Webster. (2022). *Dictionary>Benchmark*. Retrieved from https://www.merriam-webster.com/dictionary/benchmark

Ministry of Environment Finland. (2022, April). *Emissions database for construction*. Retrieved from https://co2data.fi/

Neufert, E., & Neufert, P. (2019). *Neufert Architect's Data Fifth Edition.* WILEY Blackwell.

SBUF. (2021). *Byggnaders klimatpåverkan - Referensbyggnader för svenska förhållanden.* SBUF.

SBUF. (2022, April). *Klimatpåverkan av installationssystem i byggnader*. Retrieved from https://www.sbuf.se/Projektsida?project=92ad568a-303a-4058-9869-45f644438468

SGBC. (2021). *NollCO2 BASELINE OCH GRÄNSVÄRDEN JUNI 2021.* SGBC.

Skanska. (2014). *Skanska Sveriges Byggdelsregister enligt BSAB83.*

Svensk Byggtjänst. (2022). *Byggdelar Byggdelstyper total*. Retrieved from https://bsab.byggtjanst.se/bsab/byggdelar_byggdelstyper_total

Sweden Green Building Council. (2020). *NollCO2 - A NET ZERO CARBON FUTURE - MANUAL 1.0.* Stockholm: SGBC.

Sweden Green Building Council. (2022). *BREEAM-SE*. Retrieved from https://www.sgbc.se/certifiering/breeam-se/

Sweden Green Building Council. (2022, April). *Om oss*. Retrieved from https://www.sgbc.se/om-oss/

Swedish Standards Institute. (2021). *SS-EN 15804:2012+A2:2019/AC:2021 Hållbarhet hos byggnadsverk - Miljödeklarationer - produktspecifika regler.* Stockholm.

World Green Building Council. (2022, April). *About us*. Retrieved from https://www.worldgbc.org/our-story

World Green Building Council. (2022, April). *Advancing Net Zero*. Retrieved from https://www.worldgbc.org/advancing-net-zero