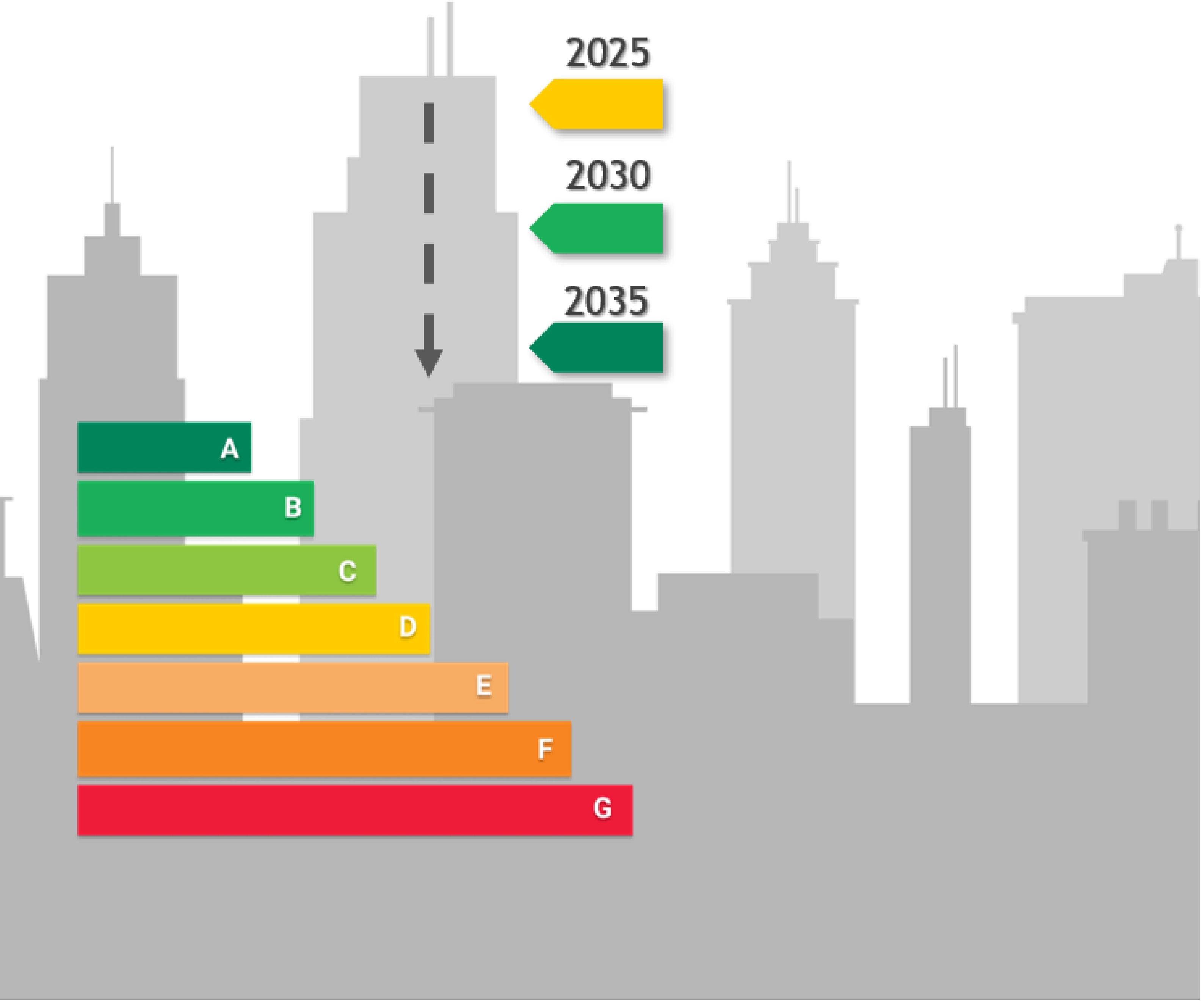
Carbon Footprint Limits for Common Building Types

Ministry of Environment, Finland

1 March 2021



Summary

This report was commissioned by the Ministry of the Environment from Bionova Ltd (better known under brand One Click LCA) to support the development of carbon footprint limit values for buildings – referred to in this report as building carbon footprints. This report is written for a subject matter expert audience and does not include introduction or definitions. Opinions and recommendations are those of the authors.

To establish a statistical baseline of building carbon footprints, 482 actual Finnish project construction materials carbon footprints were collected and analysed. Most of these projects were residential, school or office buildings. A further 3748 energy certificates for new buildings built since 2018 were analysed to establish average energy consumption per targeted building type. This provided a solid statistical basis for the average construction materials and energy carbon footprints for buildings.

For each targeted building type, a typical reference building was defined, applying solutions and parameters typical to the building type. For each reference building a materials carbon footprint was calculated and this was added to the average energy use carbon footprint from existing buildings of each targeted type. With the applied scope, which excludes foundations, parking structures and other external areas as well as fixed values for life-cycle phases A4-5, B3 and C1-C4, the results for all other building types were between 12,3 and 14 kg CO2e/m2/a, except for service buildings for which the reference carbon footprint was 19,2 kg CO2e/m2/a, owing to their significantly higher energy use.

This project considered a number of sensitivity analysis scenarios, some of which could be imposed on certain projects based on local zoning regulations. These included brick cladding, cast-in-place concrete, balconies and other scenarios. The zoning-dependent scenarios considered, increased the relevant building carbon footprint by 6-13 %, depending on the building type, and all scenarios increased the results by 11-22 %.

The reference buildings were calculated excluding foundation and parking, which potentially can have a significant impact on the carbon footprint. Their requirements vary very strongly based on the site, so these scenarios can only be considered indicative. The impact of unfavourable foundation and parking scenarios was an increase of between 12 and 20 % in the building carbon footprint; and soil stabilisation could cause a building carbon footprint increase of between 33 and 55 %, depending on the building type.

Five decarbonisation scenarios were created and analysed. These are: low carbon concrete; timber frame; CLT (cross laminated timber) frame; energy class A; and ground heat pump. The materials-neutral carbon reduction potential is 22-36 %, and maximum carbon reduction potential is from 28 to 43 %, depending on the building type.

The authors provide their conclusions and recommendations at the end of the report. The authors draw readers' attention to the fact that the expected changes in the government's methodology, calculation data and scope of assessment will require the conclusions to be updated. In addition to the core results, the authors provide their recommendations for carbon footprint methodology development for the government.

Tiivistelmä

Bionova Oy laati tämä raportin Ympäristöministeriön toimeksiannosta tulevien hiilijalanjäljen raja-arvojen valmistelua varten. Tämä raportti on kirjoitettu aihepiirin asiantuntijoista koostuvalle lukijajoukolle, ja se sisällä yleisesittelyä tai sanastoa. Esitetyt suositukset ja johtopäätökset ovat tekijöiden näkemyksiä.

Raportin pohjaksi kerättiin tilastollinen aineisto, joka koostui 482 suomalaisen rakennushankkeen materiaalien hiilijalanjäljestä ja 3748 vuodesta 2018 rakennuslupaa hakeneen hankkeen energiatodistusten energiankulutustiedoista. Suurin osa hankkeista oli asuin-, toimisto- ja koulurakennuksia. Näiden avulla saatiin laadittua tilastolliset keskimääräiset hiilijalanjäljet.

Jokaiselle hankkeessa tarkastelulle rakennustyypille määritettiin referenssirakennus, jonka ominaisuudet ja ratkaisut ovat rakennustyypille ominaisia. Jokaisen referenssirakennuksen materiaalien hiilijalanjälki laskettiin, ja siihen lisätiin tilastollinen energiankäytön keskiarvohiilijalanjälki. Referenssirakennus ei kata laskennan vakioarvoja, perustuksia, pysäköinti- tai piharakenteita. Näillä rajauksilla referenssirakennuksen hiilijalanjälki muille rakennustyypeille oli 12,3-14 kg CO2e/m2/a, paitsi palvelurakennukselle jolle hiilijalanjälki oli selvästi korkeamman energiankulutuksen johdosta 19,2 kg CO2e/m2/a.

Tuloksia täydennettiin herkkyysanalyyseillä, joista osa voi perustua kaavamääräyksiin ja olla siten velvoittavia. Skenaarioita olivat mm. tiilijulkisivu, paikallavalettu betonirunko ja parvekkeet. Kaavamääräyksistä aiheutuvat skenaariot kasvattivat rakennuksen hiilijalanjälkeä 6-13 %, rakennus-tyypistä riippuen, ja kaikki skenaariot kasvattivat hiilijalanjälkeä 11-22 % rakennustyypistä riippuen.

Referenssirakennus ei huomioi perustuksia eikä pysäköintiratkaisuja, joilla voi olla huomattava vaikutus hiilijalanjälkeen. Perustukset ja pysäköinti ovat hyvin sijoituspaikkariippuvaisia, ja niille laadittuja skenaarioita voidaan pitää vain suuntaa antavina. Epäedullisen maaperän ja pysäköintivaatimusten vaikutus rakennuksen hiilijalanjälkeen oli rakennustyypistä riippuen 12-20 % kasvu, mutta jos tontin maaperä vaatii tämän lisäksi stabilointia, se voisi kasvattaa hiilijalanjälkeä jopa 33 – 55 %.

Rakennuksille arvioitiin viittä eri päästöjen vähennyskeinoa, jotka ovat vähähiilinen betoni, puurankarunko, CLT-runko, A-energialuokka ja maalämpöpumppu. Näiden keinojen materiaalineutraali hiilijalanjäljen vähentämispotentiaali oli 22-36 %, ja suurin näillä keinoilla saavutettavissa oleva päästöjen vähennyspotentiaali oli 28-43 %, rakennustyypistä riippuen.

Tekijät esittävät suosituksensa ja johtopäätökset raportin lopussa. Lukijan on syytä huomioida, että tulevat muutokset laskentamenetelmässä, päästökertoimissa ja arvioinnin laajuudessa tulevat edellyttämään tulosten ja johtopäätösten päivittämistä. Lisäksi tekijät esittävät raportissa suosituksensa rakennuksen vähähiilisyyden arviointimenetelmän kehittämisestä Ympäristöministeriölle.

Table of contents

1 Introduction

Finland's Ministry of the Environment is preparing future building regulations, which shall include limit values for the life-cycle carbon footprint of new buildings. Bionova Ltd was assigned to conduct this research to identify the preliminary carbon footprint limit values for residential and office buildings, service buildings (nursing and care homes only), educational and commercial buildings.

This report is authored for use by government specialists and is intended for subject matter experts. As such, it does not include definitions of terms or an introduction to the subject matter. The principles of the analysis meet the government's information needs. Results have been prepared using the currently available assessment method, *Method for the whole life carbon assessment of buildings (2019:23)*.

The Finnish government is expected to update the methodology and issue a national database for generic values to be used in carbon footprint calculations in 2021. The findings of this report, and suggested limit values shall consequently require a revision to reflect changes in underlying data and the methodology.

This project is based on a combination of three methods:

- Statistical analysis, which for carbon impacts linked to construction materials comprises 482 actual calculations, and for energy consumption carbon impacts comprises 3748 actual calculations. The former based on Bionova's Carbon Heroes Benchmark Program and the latter on government data.
- Reference building models, based on One Click LCA's Carbon Designer Finnish reference building scenarios, which are further documented in this report.
- Sensitivity scenarios, consisting of decarbonisation measures and other project specific scenarios which might increase or reduce a project's life-cycle carbon footprint and handprint.

It is worth noting that most projects calculated in Finland to date have not applied the full government issued scope of calculation. In the actual projects calculated to date, data relating to parking structures, soil stabilisation, foundations, external areas and building services in particular are underrepresented, when compared to calculations applying the full government mandated scope of assessment.

The project steering group consists of Laura Valkonen, Matti Kuittinen and Harri Hakaste. The project was delivered by Bionova Ltd between September and December 2020. The project team consisted of Panu Pasanen, Kostas Koukoulopoulos, Lotta Tarkkala, Veselin Mihaylov, Sara Tikka and Libby Bounds.

While every effort has been made to provide reliable results, Bionova Ltd does not guarantee that the results contained herein are free of errors and omissions.

2 Statistical analysis of new building materials carbon footprint

2.1 Source for the new building materials carbon footprint

The existing building calculations are extracted from One Click LCA's Carbon Heroes Benchmark Program. All calculations included in this program dataset have undergone a plausibility screening by Bionova's experts. While the screening does not guarantee the accuracy of underlying results, it excludes incomplete and outlier results, among others. The dataset used for this project contains 482 calculations.

All the benchmark calculations are anonymous, derivative data. These data are created using a consistent background calculation mechanism, which standardizes life-cycle phases and assumptions. The life-cycle phases it covers include A1-A3, A4, B4 and C1-C4, and it applies a fixed 60-year assessment period.

While methodology for benchmarking is consistent, the projects do not have consistent scopes. Most projects have no or very limited building systems data and some building elements are modelled in a more limited manner than is set out in the government's method. Also, in many cases, foundations are poorly modelled. The parking solution modelling practises are also very different. Furthermore, as soil stabilisation is part of pre-construction, information relating to it may not typically be available to the project.

2.2 Carbon Heroes Benchmark Program sample used for the analysis

The sample size per building type is documented below. While this project is aiming for creating limit values for five building types, the additional row houses and healthcare buildings are provided here separately for convenience only. The rest of the analyses will not be repeated for those building types. For clarity, all projects considered herein are exclusively Finnish projects and located in Finland.

Building class	Sample size	Building types included
Residential buildings	267	Residential buildings
Row houses	47	Row houses
Office buildings (excl. healthcare buildings)	41	Office buildings (excluding healthcare buildings)
Healthcare buildings	5	Healthcare stations only, not hospitals
Service buildings (nursing & care homes only)	11	Social welfare buildings
Educational buildings	100	Day care centres, primary schools and other education
Commercial buildings	11	Retail centres and cultural buildings

2.3 Construction product phase statistics (A1-A3) – without foundation

Statistical results, excluding foundation impacts, as kg CO2e / m2, without denomination per year.

Building class	Median	Average	95% conf. (T)	Interval
Residential buildings	252	247	8	238 – 255
Row houses	214	220	23	197 – 243
Office buildings (excl. healthcare buildings)	251	275	49	226 – 324
Healthcare buildings	224	241	82	159 – 323
Service buildings (nursing & care homes only)	198	209	29	180 – 239
Educational buildings	222	235	18	217 – 254
Commercial and cultural buildings	258	436	335	101 – 771

2.4 Construction product phase statistics (A1-A3) – with foundation

Statistical results, including foundation impacts, as kg CO2e / m2, without denomination per year.

Building class	Median	Average	95% conf. (T)	Interval
Residential buildings	276	278	10	268 – 287
Row houses	252	261	24	236 – 285
Office buildings (excl. healthcare buildings)	283	307	54	253 – 361
Healthcare buildings	306	281	105	176 – 386
Service buildings (nursing & care homes only)	230	243	41	202 – 285
Educational buildings	253	263	20	244 – 283
Commercial and cultural buildings	310	462	330	232 – 795

2.5 Replacement (B4) phase – whole project level figures

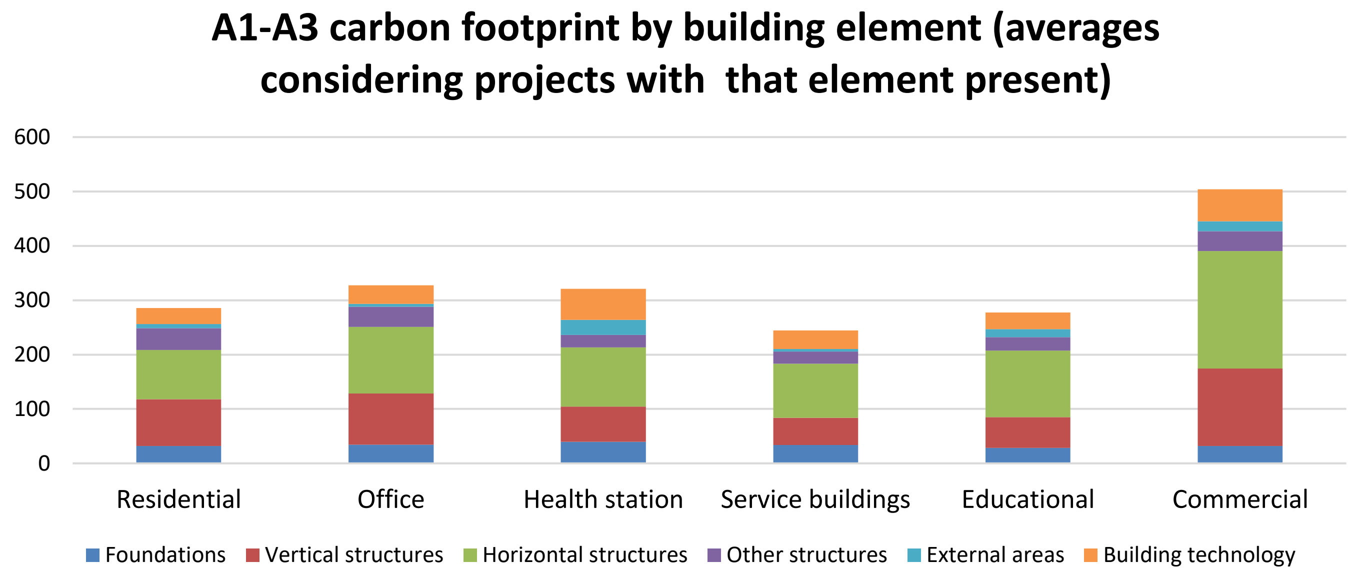
Statistical analysis of the samples, for all replacements provides the following results, expressed as kg CO2e / m2, for the material replacement (B4) phase only. The replacements are not calculated for foundations, so the figures remain the same for both the above scenarios. The replacement scope considers only the manufacturing impacts of the replaced materials, not their transport or waste handling.

Building class	Median	Average	95% conf. (T)	Interval
Residential buildings	71	72	4	68 – 75
Row houses	72	74	7	67 – 81
Office buildings (excl. healthcare buildings)	58	69	19	50 – 88
Healthcare buildings	70	71	73	n/a – 144
Service buildings (nursing & care homes only)	72	73	12	61 – 85
Educational buildings	62	71	8	63 – 79
Commercial and cultural buildings	107	144	149	n/a – 293

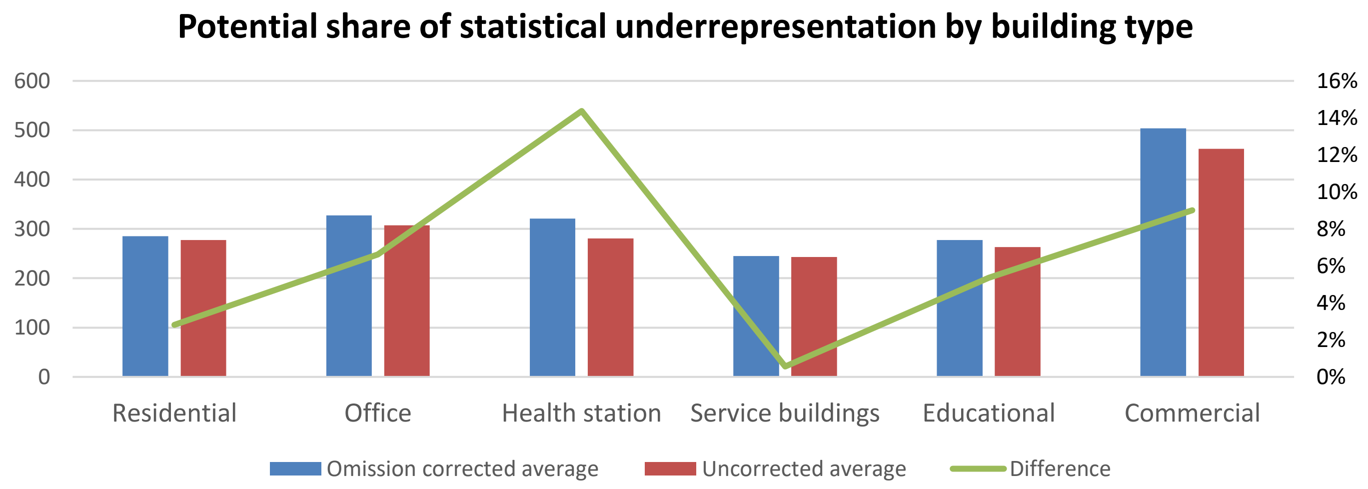
2.6 Potential statistical underrepresentation analysis

As previously stated, most projects have no or very limited building systems data and, in many cases, foundations are poorly modelled, among other possible underrepresentation/underreporting issues.

To identify the extent of this, we compiled a separate per structure analysis based on values from projects that actually report those building elements. In other words, a project that does not report building technology or external areas would not influence the average. While this isolates the impact of omitted elements, it does not reveal the scope of underreporting within an element that is reported. This approach can be used for foundations, external areas and building technology and is visualized below.



The below chart shows the share of underrepresentation. The identifiable gap across all types ranges from 3 to 14 %. The unweighted average of the underrepresentation is 6 %. This does not yet capture the share of limitations by partial omissions and by assessment simplification, especially for foundations.



3 Statistical analysis of new building energy consumption

3.1 Source data description for the energy consumption figures

The energy consumption data comes the Energy Certificate register maintained by the Housing Finance and Development Centre of Finland, ARA. The calculation method for all the energy data in the sample is the regulatory energy performance assessment method.

The source data request was specified to the buildings required here, aligned with the energy regulations in force since 2018, and for the building types covered by the research. Data from renovation projects was removed from the results. The final dataset for this analysis contained 3748 energy certificates. Since data for other building types was also supplied, that was processed and is shown here as well. Since this dataset can be considered to be very high quality only averages are shown, without other KPIs.

3.2 Average annual energy consumption by building type

The annual operating energy consumption, kWh / m2 / a per building type averages are as follows.

Building class	**Sample size**	**Elect-ricity**	**District heat**	**Fossil fuels**	**Renew. fuels**	**District cooling**	**Total energy**
Residential buildings	1950	44,7	59,8	0,0	0,0	0,1	105
Office buildings	395	67,5	28,6	0,0	0,6	1,0	98
Service buildings (nursing & care homes only)	167	83,5	105,3	0,3	0,0	0,0	189
Educational buildings	637	54,0	56,7	1,2	0,7	0,1	113
Commercial buildings	337	89,9	31,3	0,1	0,8	0,5	123
Hospitals and health care centres	97	66,7	103,0	0,0	0,0	0,1	170
Hotels and hostels	165	99,5	73,1	0,1	4,5	0,7	178

3.3 Average annual energy consumption - energy class A buildings only

Class A energy buildings clearly use less energy, but sample sizes were small, and in one case, zero.

Building class	**Sample size**	**Elect-ricity**	**District heat**	**Fossil fuels**	**Renew. fuels**	**District cooling**	**Total energy**
Residential buildings	208	44,4	37,8	0,0	0,0	0,1	82
Office buildings	29	52,4	20,2	0,0	0,0	3,7	76
Service buildings (nursing & care homes only)	0	-	-	-	-	-	-
Educational buildings	317	43,6	54,8	0,0	0,3	0,1	99
Commercial buildings	20	54,6	27,7	0,0	0,0	1,4	84
Hospitals and health care centres	2	45,4	42,2	0,0	0,0	0,0	88
Hotels and hostels	1	39,1	78,3	0,0	0,0	7,0	124

3.4 Average annual energy consumption –energy class B buildings only

Energy class B is the most common in the sample. The number of buildings with C or D class is negligible.

Building class	**Sample size**	**Elect-ricity**	**District heat**	**Fossil fuels**	**Renew. fuels**	**District cooling**	**Total energy**
Residential buildings	1726	44,7	61,9	0,0	0,0	0,1	107
Office buildings	357	67,0	29,7	0,0	0,4	0,8	98
Service buildings (nursing & care homes only)	163	82,6	105,6	0,0	0,0	0,0	188
Educational buildings	285	54,8	64,3	0,1	0,7	0,0	120
Commercial buildings	307	90,2	31,0	0,1	0,8	0,4	123
Hospitals and health care centres	92	67,2	97,7	0,0	0,0	0,1	165
Hotels and hostels	150	94,2	75,0	0,1	4,2	0,7	174

4 Statistical analysis of construction site data

4.1 Source data description for the construction site data

The sample data comes from a Finnish construction company, and contains a consistent set of data consisting of 28 construction projects completed in 2019. The sample is very strongly biased towards residential construction, which represents 20 of the projects.

While these figures are provided herein, we do not recommend relying on this data for any purpose.

4.2 Average waste data for the buildings

The sample does not contain data on soil replacements or pre-construction activity, which are performed by separate subcontractors and are not tracked in these figures. If they were included, the waste volume would be much higher.

These figures are very low, and can be assumed to have data gaps, even excluding the pre-construction.

The data are kg of waste fraction per gross square area (*"bruttoala"*).

Waste fractions	**Residential buildings**	**Other types**
General construction waste	20,65	15,48
Miscellaneous wood	12,42	12,78
Bricks and concrete	8,36	4,17
Sludge	0,56	0,12
Mixed waste	0,58	0,03
Energy waste	0,60	0,26
Clean wood	0,99	0,05
Total	**44,17**	**32,90**

4.3 Average energy consumption data for building sites

Datasets received for building site energy consumption data were not fit for this analysis. They contained only the electricity consumption that had occurred during the year, and not the cumulative energy use on the site during all the years the site had been in operation.

5 Reference buildings documentation

5.1 Key assumptions for reference buildings by building type

The table below summarizes the key assumptions for reference buildings. Foundations and parking structures were excluded from the reference buildings; and are instead presented as sensitivity analysis scenarios. All building types use a precast concrete default scenario for consistency and comparability. All reference building calculations exclude fixed government default values for phases A4-A5, B3 and C1-C4.

The average building sizes and number of floors by building types could not be established in the context of this project. The figures used below match those for Norwegian reference buildings.

Assumptions	Residential	Office	Service	School	Commercial
Calculation model	Finnish ref bldg. – all types	Finnish ref bldg. – all types	European reference building 2019.1	Finnish ref bldg. – all types	European reference building 2019.1
Building type	Apartment building	Office	Social welfare buildings	School, primary	Retail & whole-sale buildings
Net heated floor area m2	3 000	4 000	2 000	2 500	4 000
Above ground floors	4	4	2	2	2
Underground floors	0	0	0	0	0
Structures assumption	Precast	Precast	Precast	Precast	Precast
Other paved areas m2	150	200	100	375	200
Energy use	Statistical avg.	Statistical avg.	Statistical avg.	Statistical avg.	Statistical avg.
Heating solution	District heat	District heat	District heat	District heat	District heat
Number of staircases	1	2	1	1	1
Number of kitchens	49	9	2	2	2
Number of toilet spaces	49	24	18	15	12

5.2 Assumed reference building dimensions by building type

Parameter	Residential	Office	Service	School	Commercial
Gross Floor Area (m2)	3216	4231	2137	2638	4144
Height (m)	12	14,4	7,2	7,6	8
Width (m)	63,2	64,6	84	80,6	70,8
Depth (m)	14	18	14	18	32,2
Internal floor height (m)	2,7	3,3	3,3	3,5	3,7
Internal walls (non-load bearing) (m2)	2250	911	719	405	492
Windows (m2)	643	846	427	528	829

One reason for the comparatively low materials carbon footprint in the commercial building is the limited number of internal walls. This is of course subject to the actual layout of the building.

5.3 Key construction systems by building type

The key construction systems used by building type are documented below. For Service and Commercial buildings, no wet room tiles were considered. For the rest, ceramic tiles are 20% of internal wall finishes.

Building part	Residential	Office	Service	School	Commercial
External wall	External wall, concrete sandwich element, mineral wool, U = 0.17 W/m2K	External wall, concrete sandwich element, mineral wool, U = 0.17 W/m2K	External wall, concrete sandwich element, mineral wool, U = 0.17 W/m2K	External wall, concrete sandwich element, mineral wool, U = 0.17 W/m2K	External wall, concrete sandwich element, mineral wool, U = 0.17 W/m2K
Finishing	Render finishing, 10 mm	Render finishing, 10 mm	Render finishing, 10 mm	Render finishing, 10 mm	Render finishing, 10 mm
Load-bearing internal wall	Concrete internal wall assembly, incl. reinforcement and filler, 200 mm	Concrete internal wall assembly, incl. reinforcement and filler, 200 mm	Concrete internal wall assembly, incl. reinforcement and filler, 200 mm	Concrete internal wall assembly, incl. reinforcement and filler, 200 mm	Concrete internal wall assembly, incl. reinforcement and filler, 200 mm
Non load-bearing internal wall	Steel stud internal wall assembly, incl. mineral wool insulation, 70 mm and plasterboard 13 mm on both sides	Steel stud internal wall assembly, incl. mineral wool insulation, 70 mm and plasterboard 25 mm on both sides	Steel stud internal wall assembly, incl. mineral wool insulation, 70 mm and plasterboard 13 mm on both sides	Steel stud internal wall assembly, incl. mineral wool insulation, 70 mm and plasterboard 25 mm on both sides	Steel stud internal wall assembly, incl. mineral wool insulation, 70 mm and plasterboard 13 mm on both sides
Floor slab	Hollow-core slab floor assembly, 370 mm slab	Hollow-core slab floor assembly, 370 mm slab	Hollow-core slab floor assembly, 370 mm slab	Hollow-core slab floor assembly, 370 mm slab	Hollow-core slab floor assembly, 370 mm slab
Floor finishes	20% Vinyl floor covering, 20% Ceramic tiles, incl. underlay, 60% Laminate flooring	20% Vinyl floor covering, 20% Ceramic tiles, incl. underlay, 60% Laminate flooring	20% Vinyl floor covering, 20% Ceramic tiles, incl. underlay, 60% Laminate flooring	20% Vinyl floor covering, 20% Ceramic tiles, incl. underlay, 60% Laminate flooring	30% Parquet flooring 10% Vinyl floor covering 60% Ceramic tiles
Other paved areas	Light vehicle footway, concrete blocks	Light vehicle footway, asphalt	Light vehicle footway, asphalt	Light vehicle footway, asphalt	Heavy vehicle footway, asphalt

6 Reference building carbon footprint methodology and results

6.1 General calculation method

The calculation was performed using the One Click LCA software's Ministry of the Environment methodology compliant module and Carbon Designer's reference building structures.

The following assumptions were applied in the One Click LCA calculation methodology:

- Materials service life: technical service life.
- Materials localisation method: not applied.
- Assessment period: 50 years.
- All reference building calculations exclude fixed government set values for phases A4-A5, B3 and C1-C4. These can be added to the results at any time using the possibly revised set values.
- End of life calculation method: Market scenarios, user adjustable (defaults not changed)
- End of life energy recovery scenario: District heat Finland 2020-2070 (50 years)

Virtually all data used in the calculation were One Click LCA generic LCA profiles, with the exception of some kitchen and toilet fittings and furnishings, for which preliminary data from the upcoming SYKE database was used. The scope of the calculation follows the government methodology.

Carbonisation of cementious materials during the lifetime of the building was not considered. However, carbonisation after building demolition was included. Both of these are in the carbon handprint as per the government methodology.

6.2 Reference building scope and out of scope elements

The reference building scope is in line with the Ministry of the Environment requirements for assessment scope, barring the following building elements, which are provided as sensitivity analysis scenarios:

- Soil stabilisation and foundations
- External areas and other ground works
- Parking solutions
- Air raid shelters

Furthermore, building services data and all life-cycle phases that have a government provided default value use those default values. For clarity, it is noted here with the default values approach, there are no replacements to be calculated for the building services. These default values are not considered towards carbon handprints either.

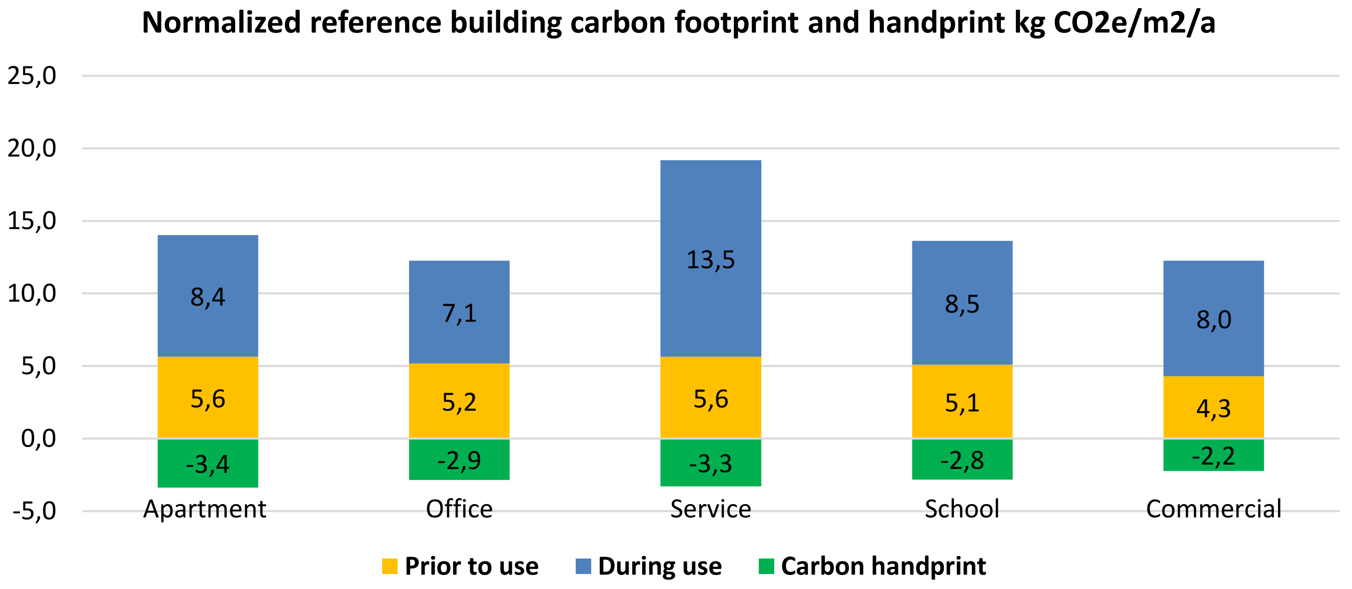
6.3 Reference building carbon footprint - before normalisation per year

The below table shows the reference building per m2 carbon footprint values before normalisation per year. All Ministry of the Environment fixed default values are shown in italicized font. All statistical non-annualized data produced in this project are rounded to integers to reflect their inherent uncertainty. Please note that the total figures may not add up due to rounding.

Results	Residential	Office	Service	School	Commercial
PRIOR TO USE					
A1-A3 Product manufacture	282	259	282	255	215
A4 Transportation to site	*10,2*	*10,2*	*10,2*	*10,2*	*10,2*
A5 Construction	*27,3*	*27,3*	*27,3*	*27,3*	*27,3*
DURING USE					
B3 Repairs	*2,16*	*2,16*	*2,16*	*2,16*	*2,16*
B4 Replacements	98	81	77	79	69
B6 Operational energy use	321	273	601	347	330
AFTER USE					
C1-C4 Disposal	*33,6*	*33,6*	*33,6*	*33,6*	*33,6*
CARBON FOOTPRINT	**774**	**686**	**1032**	**754**	**686**
Sum of fixed default values	*73,3*	*73,3*	*73,3*	*73,3*	*73,3*
Carbon footprint ex. defaults	701	613	959	681	613
CARBON HANDPRINT	**-169**	**-143**	**-165**	**-142**	**-112**

6.4 Reference building carbon footprint – per m2 and per year

The reference building carbon footprint per m2 and per year for different building types are shown in the below graph. This graph excludes fixed government default values for phases A4-A5, B3 and C1-C4 (total of 1,5 kg CO2e/m2/a). Total figures and further analysis are presented in the recommendations chapter.



7 Definitions of the analysis scenarios

7.1 Sensitivity analysis scenarios

The following scenarios were used to evaluate building carbon footprint sensitivity to different factors, some of which are outside the control of the project (such as what façade material is required, which can be dictated by zoning), and others which are clearly within the control of the project (such as energy class). The impact of energy class B in itself is not that significant a factor, as most new buildings achieve that level.

Frequent repairs are typical in buildings that are often reconfigured / refurbished for new tenants or users. Frequent repairs are to some extent also a feature of the methodology.

Name of the scenario	Applicable changes	Case in the reference building
Frequent interior renovation cycle	Non load bearing internal walls and gypsum boards are replaced once; kitchen cabinets and faucets are replaced twice. Bathroom cabinets are replaced three times and the bathroom faucets and showers twice.	No replacements for non-load bearing internal walls or gypsum boards. Kitchen cabinets and faucets are replaced once. Bathroom cabinets are replaced twice and the bathroom faucets and showers once.
Brick cladding	External wall rendering is replaced with 135 mm brick façade, including mortar. Energy use assumed unchanged.	Standard render finishing, made of glass fiber reinforcing mesh, 10mm mortar and paint.
Cast in place concrete structure	Walls and floors from cast in place concrete. Floor slabs 320 mm and roof slab 225 mm.	Hollow core slab, 370 mm for floors and hollow core slab, 265 mm for roof slab.
Air raid shelter	Added shelters with area equal to 1% of area for commercial buildings and 2% for the rest.	Not considered.
Balconies	Considered only for residential buildings. Balcony area was set to be 0,1m2 per m2 Heated net area. Standard balcony was assumed to be 7m2, and considered 260mm concrete slab, laminated wood flooring and 5mm laminated glass, aluminium-framed, to cover from bottom to top the 2 sides of the balcony.	No balconies were included.
Achieving energy class B	Energy class B was average operational energy consumption (no changes in materials).	Baseline scenario considers average energy consumption.

7.2 Out-of-scope element scenarios

The following scenarios were used to assess the impact of out-of-scope elements – that is, the elements which were not part of the reference building – to analyse their impact on the building carbon footprint.

Name of the scenario	Applicable changes	Case in the reference building
Plinth footing foundation	Plinth foundation with area 0,06 m2 per m2 GFA. Footing volume is 0,056 m3 per m2 GFA.	Not included.
Piling foundation	20m long steel piles, including steel core piles and steel casing, with 40% recycled steel. The casing is filled with concrete. Total weight of steel is 32 kg per m2 GFA.	Not included.
Soil stabilisation	20m long cement-lime piles with 600mm diameter and trench concrete slab 20cm. Depth to bedrock 15 m and trench depth 5 m. The scenario uses CEM I cement and slaked lime.	Not included.
Parking places outside	Parking area per heated net area as follows: - Residential: 0,31 - Office: 0,19 - Service Buildings: 0,17 - Schools: 0,0 - Commercial: 0,27	“Other paved areas” in baseline can also include a limited number of parking spots, which would be sufficient e.g., for schools.
Parking underground	Same areas as above but underground.	

7.3 Decarbonisation scenarios

The following scenarios were used to evaluate the potential decarbonisation of buildings using measures available on the market today. For this purpose, only scenarios with significant potential were considered.

All structures and elements used in the comparison are intended to provide a comparable level of performance, and they contain all layers and materials needed to achieve this. Building types for which the specification of wood-based elements could not be ensured were omitted from scenarios. The wood-based elements were defined with the Federation of the Finnish Woodworking Industries.

Name of the scenario	Applicable changes	Case in the reference building
Using a ground source heat pump for the entire heat and cooling supply	The entire cooling and heat demand is replaced by ground source heat pump with COP of 3. Systems dimensioned to 150 kW for examined Residential building, 200 kW for Office and Commercial and 100 kW for Service and School buildings. Includes also the ground source heat pump system.	District heat and cooling supply and heat exchanger fully replaced
Achieving energy class A	Benefits from energy consumption reduction. Scenario considers only differences in energy consumption, not differences in embodied impacts deriving from the increased amount of insulation. Scenario is examined for all building types, except Service buildings which lack data.	Baseline scenario considers average energy consumption.
Using concrete that uses 40 % alternative binders (less clinker)	All reference building concrete elements (note: still excludes foundations)	0% alternative binders in concrete
Using stud frame timber structure	• External wall, wooden stud frame • Painted wood cladding, Wood cladding 20 mm + wooden lathes • Internal wall, wooden stud frame • Wooden stud internal wall assembly, 70 mm, incl. mineral wool insulation 75 mm and plasterboard 13 mm on both sides (25mm for Office and School) • Floor slab, timber joists • Flat roof, timber joists, U ≤ 0,09 W/m2K	• External wall, concrete sandwich element, mineral wool • Render finishing, 10 mm • Concrete internal wall assembly, incl. reinforcement and filler, 200 mm • Steel stud internal wall assembly, incl. mineral wool insulation, 70 mm and plasterboard 13 mm on both sides (25mm for Office and School) • Hollow-core slab floor assembly, 370 mm slab • Roof slab, for apartment building, concrete slab, U = 0.09 W/m2K

Name of the scenario	Applicable changes	Case in the reference building
Using CLT structure	For Residential / Office / School. Considered fire safety levels for examined structures are P2 R60 for Residential and Office and P2 R30 for School. Same structures as in “stud frame timber structure” scenario, except the following structures that change. Finishes are not included. • External wall, CLT: - Fire resistant gypsum board (K2 30, A2-s1, d0) 18mm for Residential and Office. - CLT element 120mm for Residential and Office and 100mm for School - Vapour barrier 0,25mm - Insulation (rockwool) 150mm - Windscreen (rockwool insulation / K2 10, A2-s1, d0) 50mm • Internal wall, CLT (for load-bearing walls): - Fire resistant gypsum board (K2 30, A2-s1, d0) 18mm for Residential and Office. - CLT element 100mm for Residential and Office and 60mm for School - Insulation (rockwool) 50mm for Residential and Office • Floor slab, CLT, including: - Levelling 50mm - Reinforcement mesh fabric (glass fibre) - CLT element 240mm - Acoustic insulation (mineral wool) 50mm - Fire resistant gypsum board (K2 30, A2-s1, d0) 18mm for Residential and Office.	As above

8 Sensitivity analysis scenarios

8.1 Overview of the sensitivity analysis scenarios

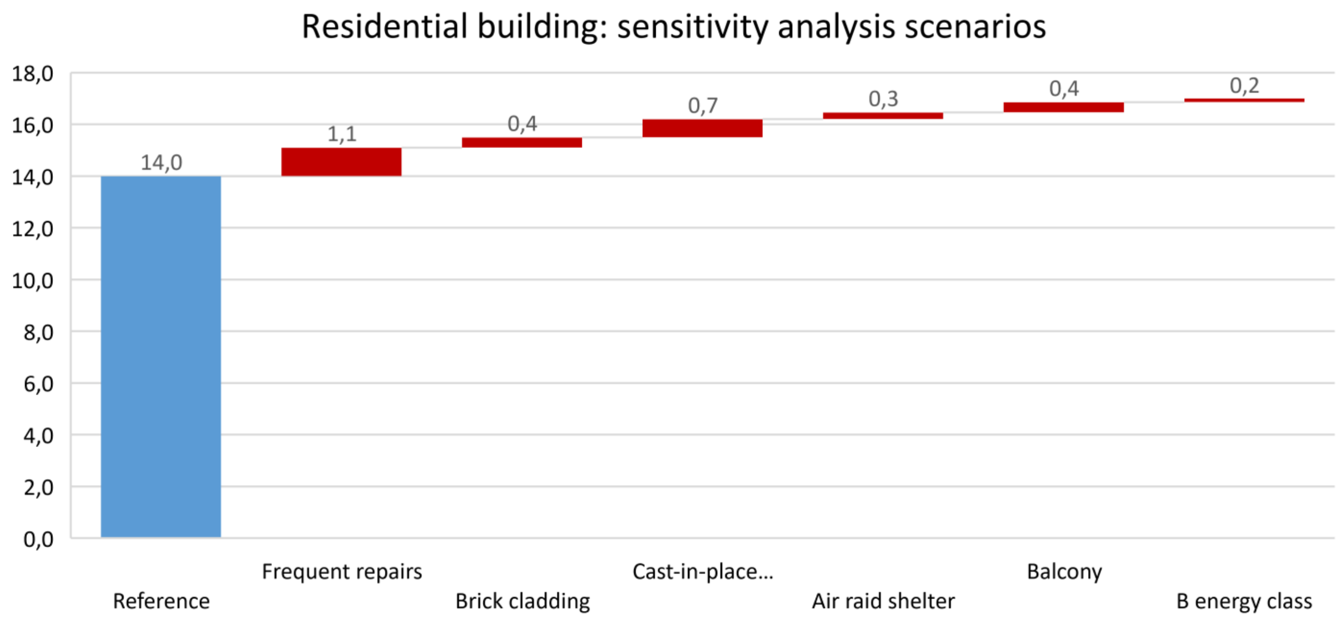
The sensitivity analysis scenarios, as studied here, impacted the whole building carbon footprint from +11 to +22 %. The zoning-dependent scenarios impacted the whole building carbon footprint from +6 % to 13 %. The following scenarios were considered to be zoning-dependent: brick façade, balconies, air raid shelters (which could be organised at a district level for some areas) and having to build with cast in place concrete owing to e.g., space constraints or other reasons. The reader should take note that it is very unlikely that a single project would have each of the adverse zoning parameters apply at the same time.

In some of the building types, using a B energy class average instead of an average of all projects would have improved the project energy performance and thus reduced the carbon footprint. In those cases, the impact of that scenario was set to zero.

None of the sensitivity analysis scenarios caused a meaningful change to the carbon handprint and, as such, those are not considered. The reader is advised that comparison scenarios here exclude the impact of fixed government default values for phases A4-A5, B3 and C1-C4, which are always immutable.

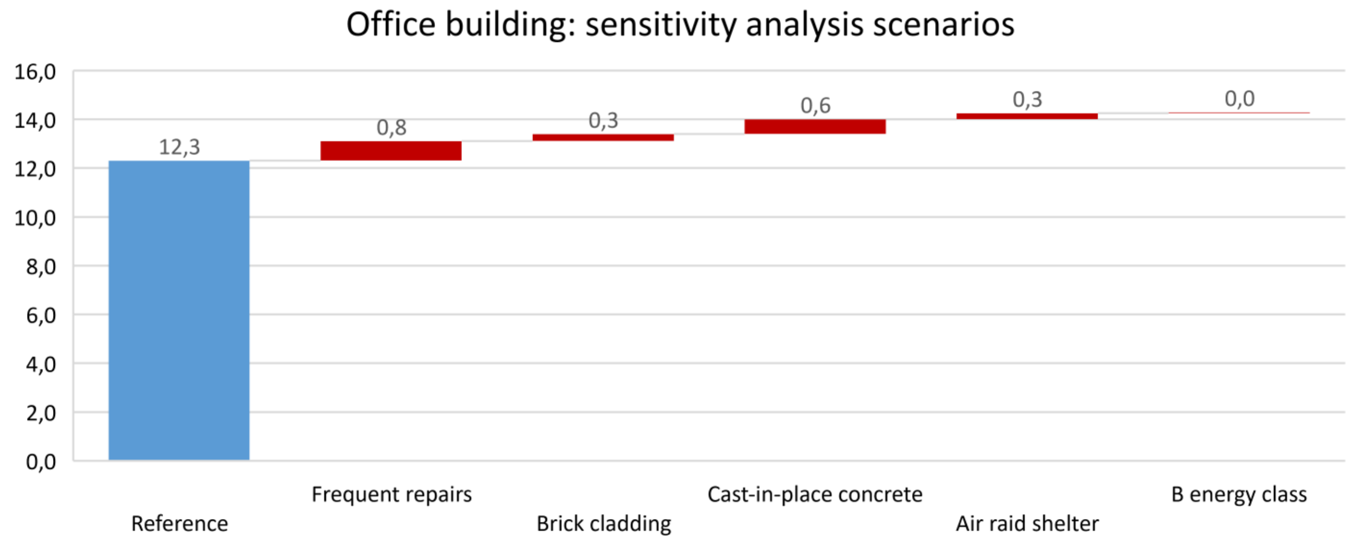
8.2 Sensitivity analysis – residential buildings

The studied factors collectively increased the carbon footprint of the building by 22 %. Of this, zoning-dependent factors added 13 % to the carbon footprint (8 % excluding cast in place concrete).



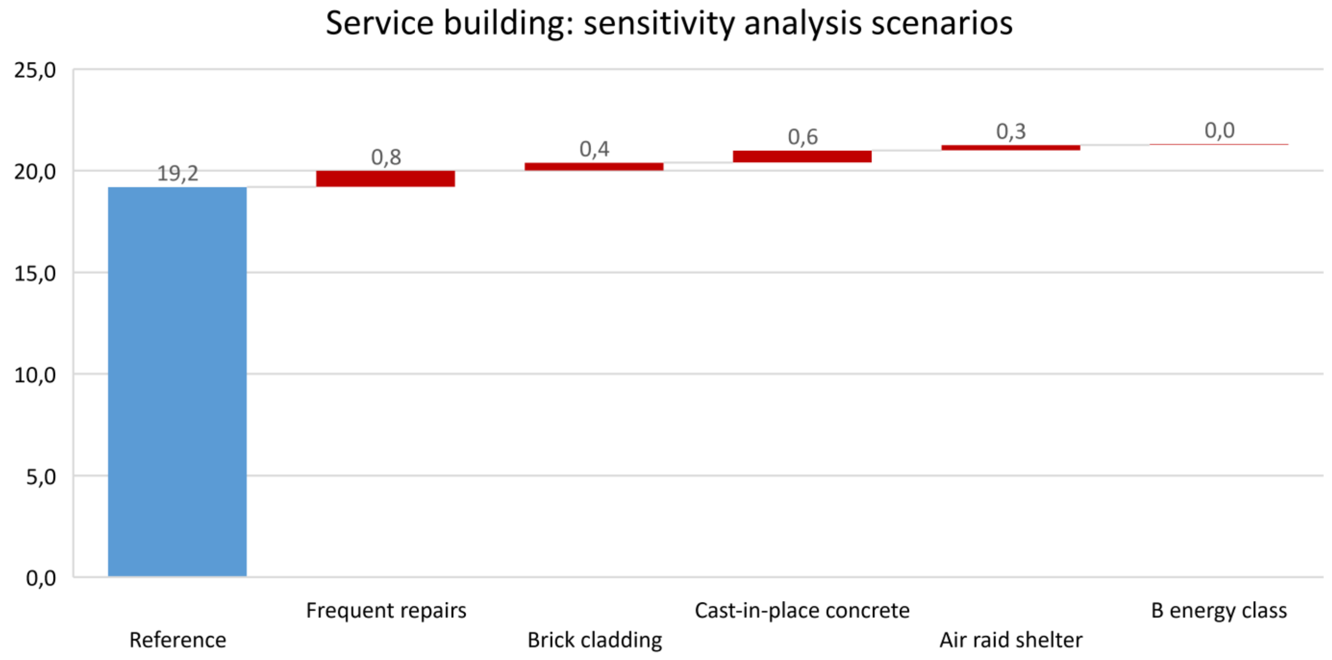
8.3 Sensitivity analysis – office buildings

The studied factors collectively increased the carbon footprint of the building by 15 %. Of this, zoning-dependent factors added 9 % to the carbon footprint (4 % excluding cast in place concrete). The B energy class impact in the case of office buildings was a slight improvement on the carbon footprint; as such it was not considered in these totals.



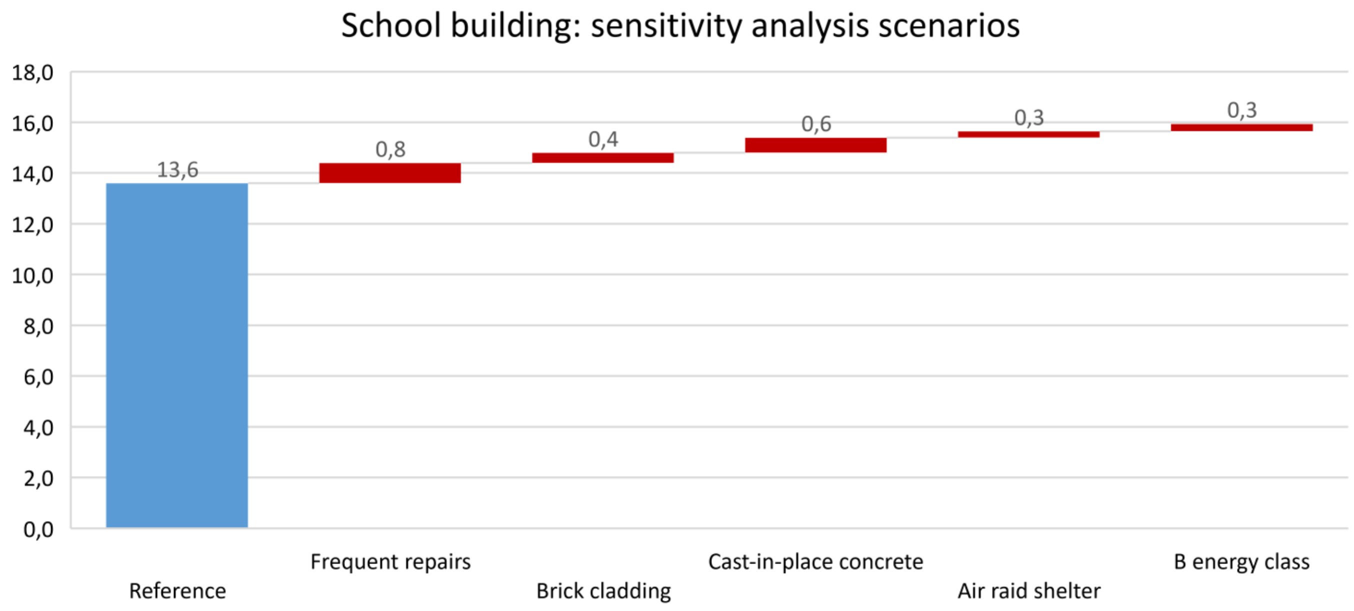
8.4 Sensitivity analysis – service buildings

The studied factors collectively increased the carbon footprint of the building by 11 %. Of this, zoning-dependent factors added 7 % to the carbon footprint (3 % excluding cast in place concrete). The B energy class impact in the case of service buildings would have been an improvement on the average energy performance; and it was not considered. The low percentage figures are caused by the higher starting point for the carbon footprint.



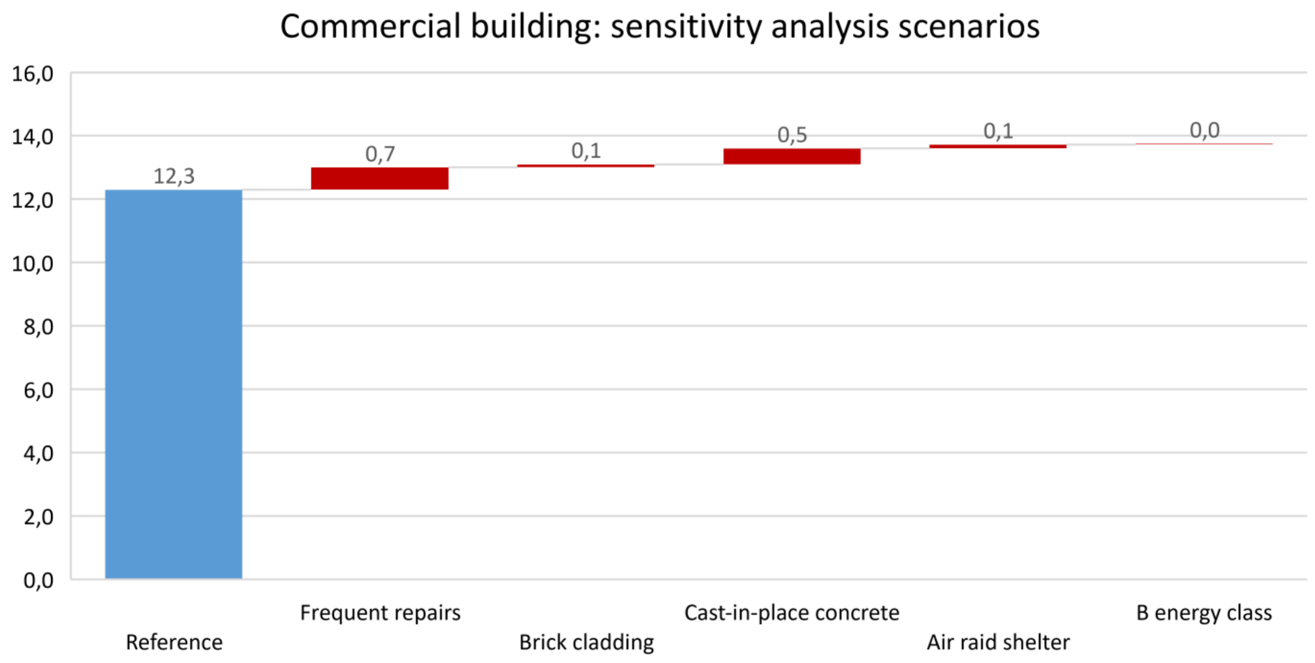
8.5 Sensitivity analysis – school buildings

The studied factors collectively increased the carbon footprint of the building by 17 %. Of this, zoning-dependent factors added 9 % to the carbon footprint (5% excluding cast in place concrete).



8.6 Sensitivity analysis – commercial buildings

The studied factors collectively increased the carbon footprint of the building by 12 %. Of this, zoning-dependent factors added 6 % to the carbon footprint (2 % excluding cast in place concrete).



9 Out-of-scope element scenarios

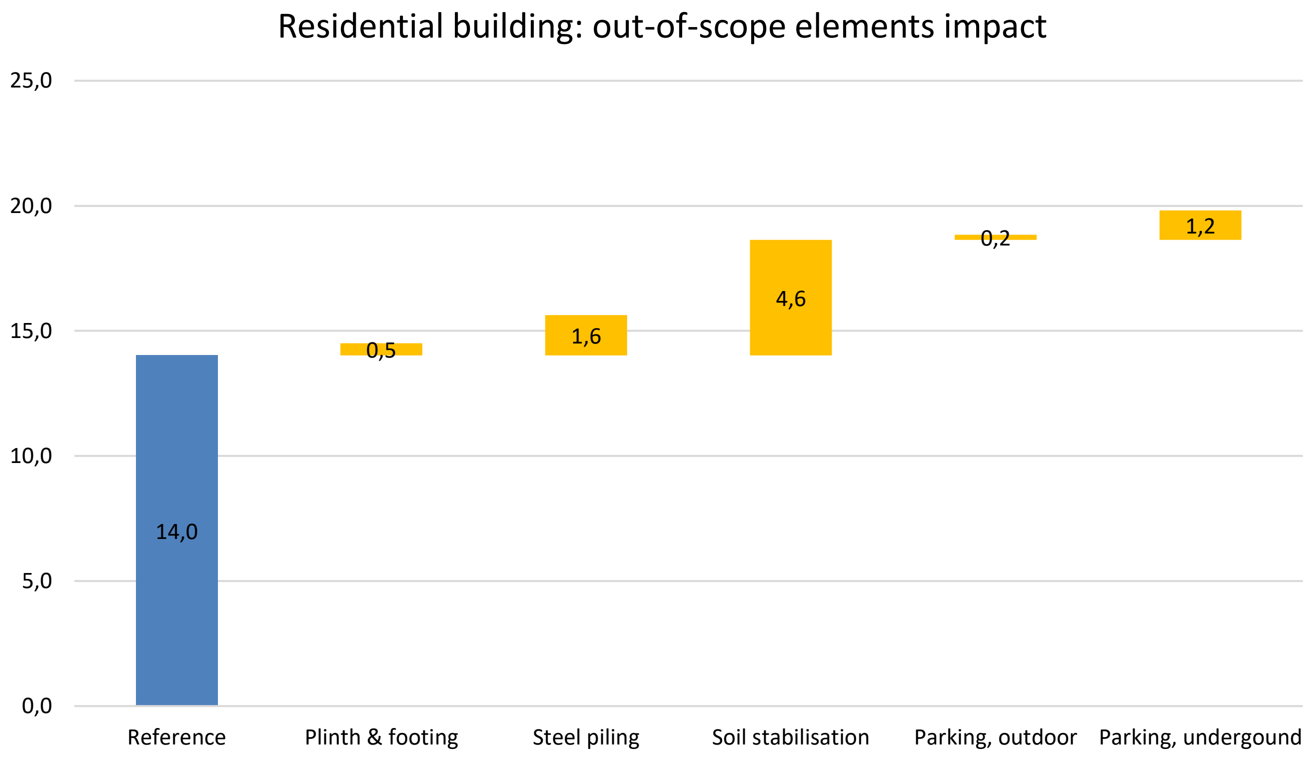
9.1 Overview of the out-of-scope element scenarios

The out-of-scope elements include different types of foundation scenarios and different types of parking solutions for each building type (excluding schools, which are not assumed to need more parking). The results should therefore not be read as a cumulation of all potential scenarios, but rather as the potential cumulation of one of the foundation scenarios and one of the parking scenarios.

The actual parking requirements and foundation conditions and figures provided here can be considered indicative only, as any need for soil stabilisation and sheet piling would be very site dependent. The cumulative impact of unfavourable foundation and parking scenarios (other than soil stabilisation) with the used assumptions would be an increase of between 12 and 20 % in the building carbon footprint, depending on the building type. Stabilising site soil could result in an increase of between 33 to 55 % in the building carbon footprint, depending on the building type. The reader is advised that comparison scenarios exclude the impact of fixed government default values for phases A4-A5, B3 and C1-C4.

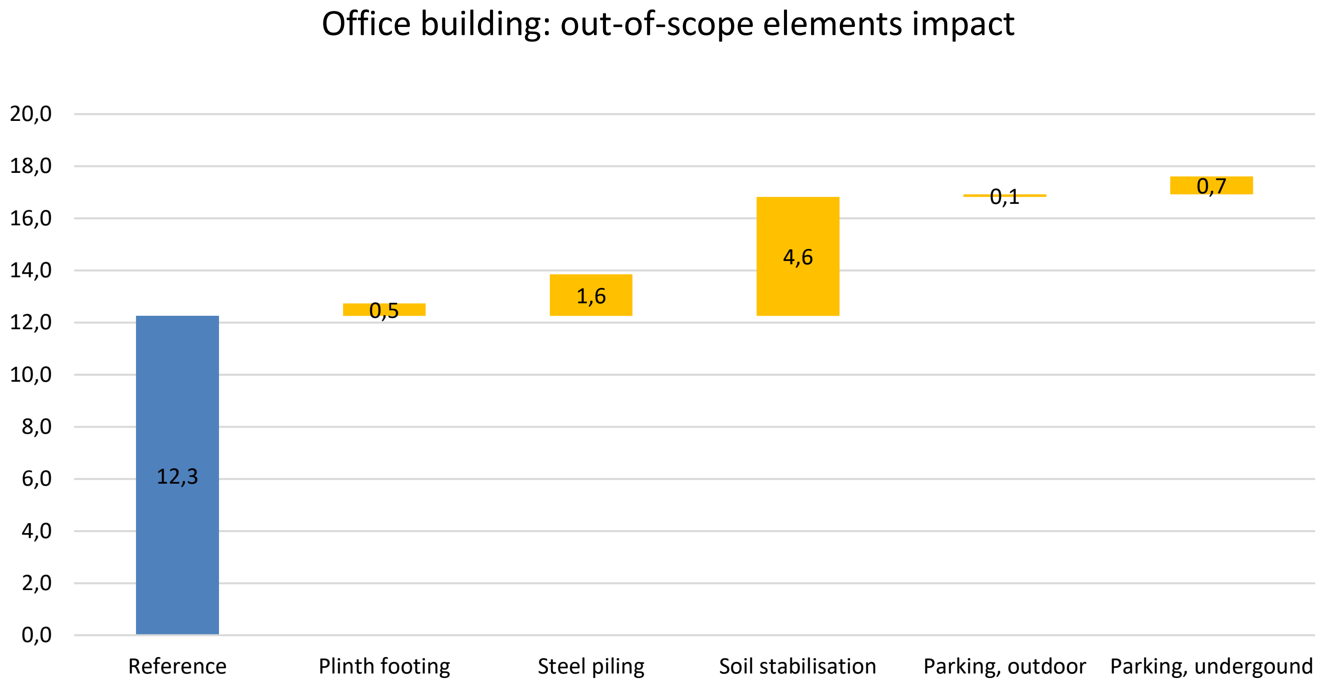
9.2 Out-of-scope elements – residential buildings

The cumulative impact of unfavourable foundation and parking scenarios is a 20 % increase in the building carbon footprint. The impact of soil stabilisation could increase the carbon footprint by up to 33 %.



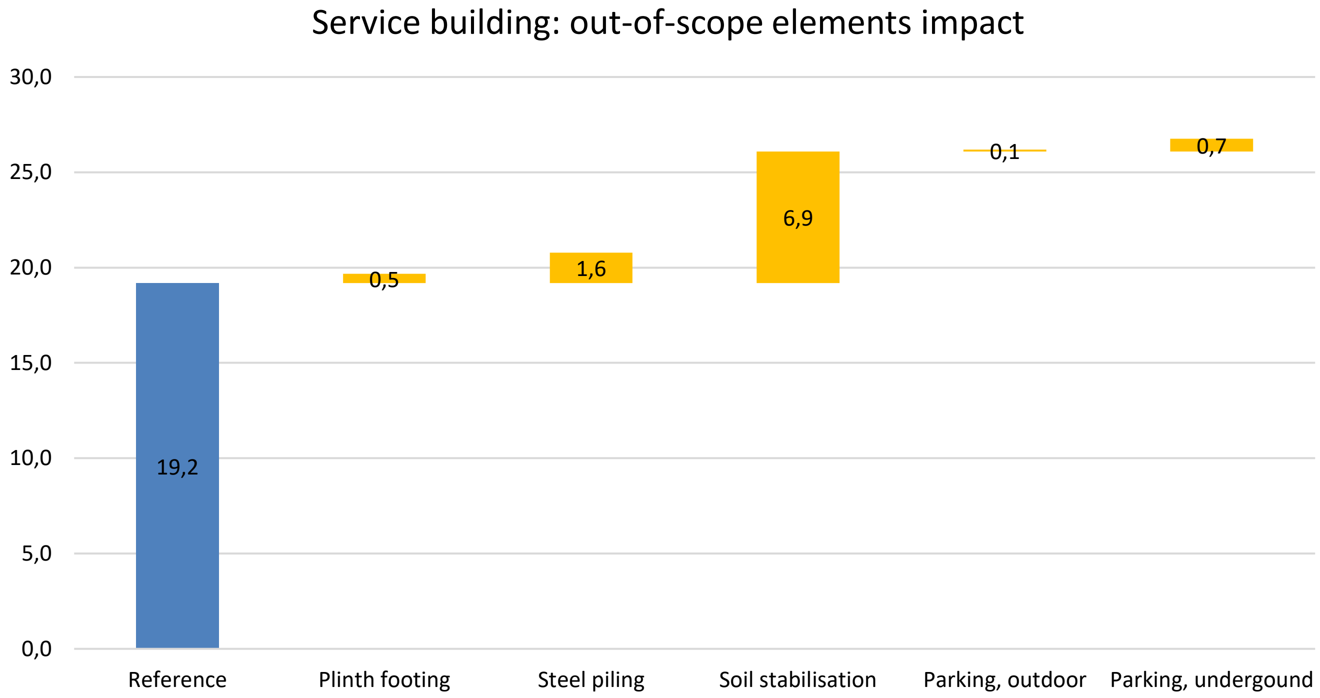
9.3 Out-of-scope elements – office buildings

The cumulative impact of unfavourable foundation and parking scenarios is a 19 % increase in the building carbon footprint. The impact of soil stabilisation could be an increase to the carbon footprint of up to 37 %.



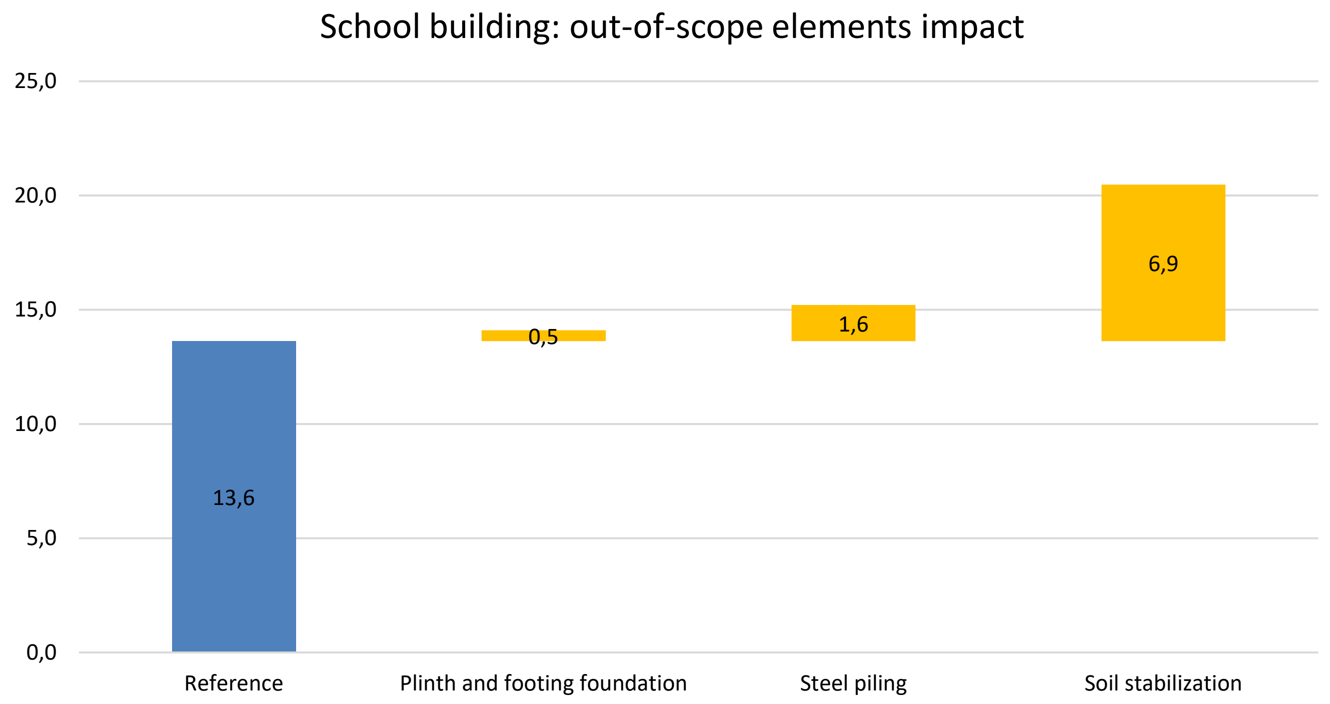
9.4 Out-of-scope elements – service buildings

The cumulative impact of foundation and parking scenarios is a 12 % increase of the building carbon footprint. The impact of soil stabilisation could be an increase to the carbon footprint of up to 36 %.



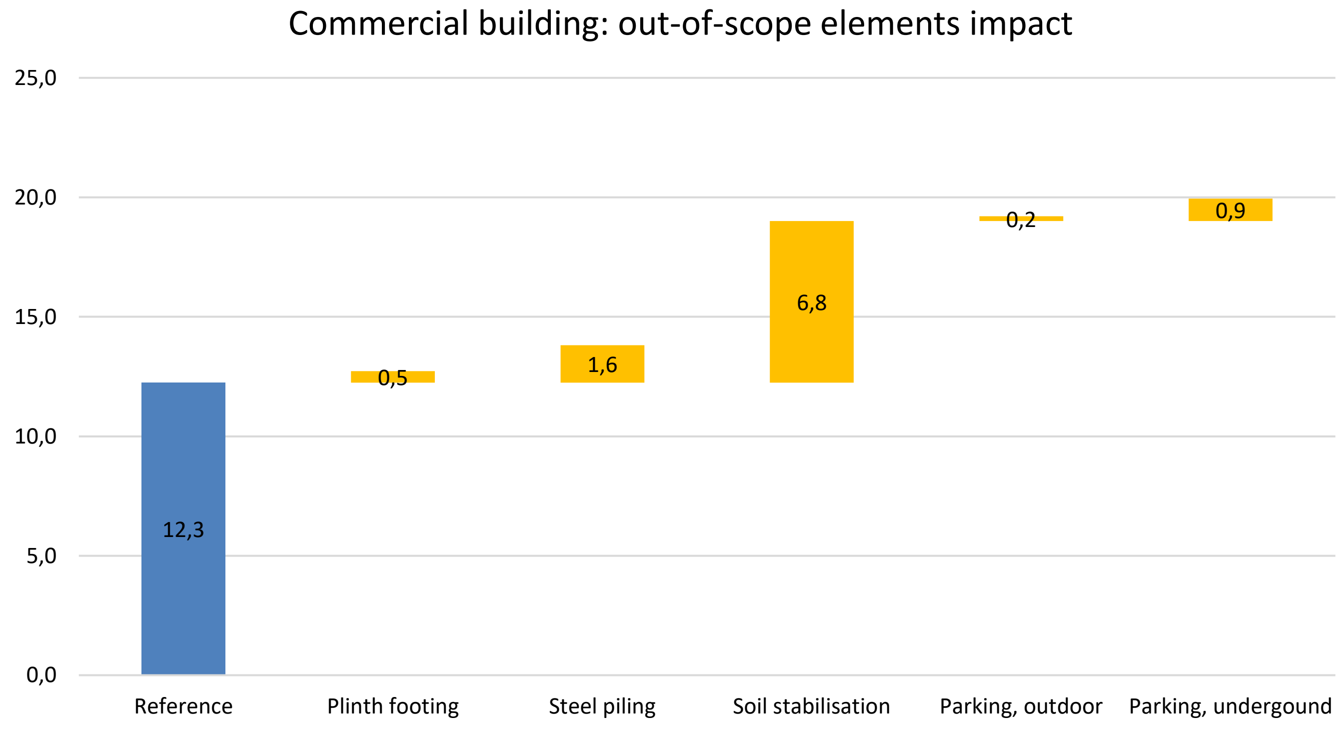
9.5 Out-of-scope elements – school buildings

The impact of an unfavourable foundation is a 12 % increase of the building carbon footprint. The impact of soil stabilisation could be an increase to the carbon footprint of up to 50 %.



9.6 Out-of-scope elements – commercial buildings

The cumulative impact of foundation and parking scenarios is a 20 % increase of the building carbon footprint. The impact of soil stabilisation could be an increase to the carbon footprint of up to 55 %.



10 Decarbonisation scenarios

10.1 Overview of the decarbonisation scenarios

The decarbonisation scenarios include one or two energy performance scenarios, and up to three construction materials change scenarios for each building type. The results should therefore not be read as a cumulation of all potential scenarios, but rather as the potential cumulation of one of the energy scenarios and one of the construction materials scenarios.

In the sample data that was used to establish the energy performance figures for buildings, some of the buildings have used ground heat pumps, and it is likely the share of ground heat pumps was higher in the energy class A buildings. This creates a statistical bias which potentially overstates the impact of ground heat pumps. In the view of the authors, however, it does not invalidate the overall potential improvement.

The energy performance of an energy class A service building could not be established from the sample. Therefore, it was descoped for this building type. Furthermore, for some building types the functional equivalence of a CLT frame structure could not be ensured, and these scenarios were descoped.

Furthermore, residential buildings have an additional regulated energy performance improvement – the §33 structural energy efficiency of the building energy performance decree (1010/2017). As this scenario is solely applicable for residential buildings, it was not included in the scenarios, but its impact can be considered broadly comparable to the energy class A scenario for residential buildings.

For each of the building types, the total potential impact of using low carbon concrete and the more efficient of the energy measures was considered the material-neutral decarbonisation potential. A summary of the results is provided below.

Parameter	Residential	Office	Service	School	Commercial
Maximum decarbonisation identified	36 %	30 %	43 %	34 %	28 %
Low-carbon concrete & ground heat pump	28 %	20 %	36 %	27 %	19 %
Low-carbon concrete & A energy class	18 %	18 %	-	13 %	22 %

The impact of low-carbon concrete is much higher than herein, if the foundations are included in the scope of the reference building and / or the limit values.

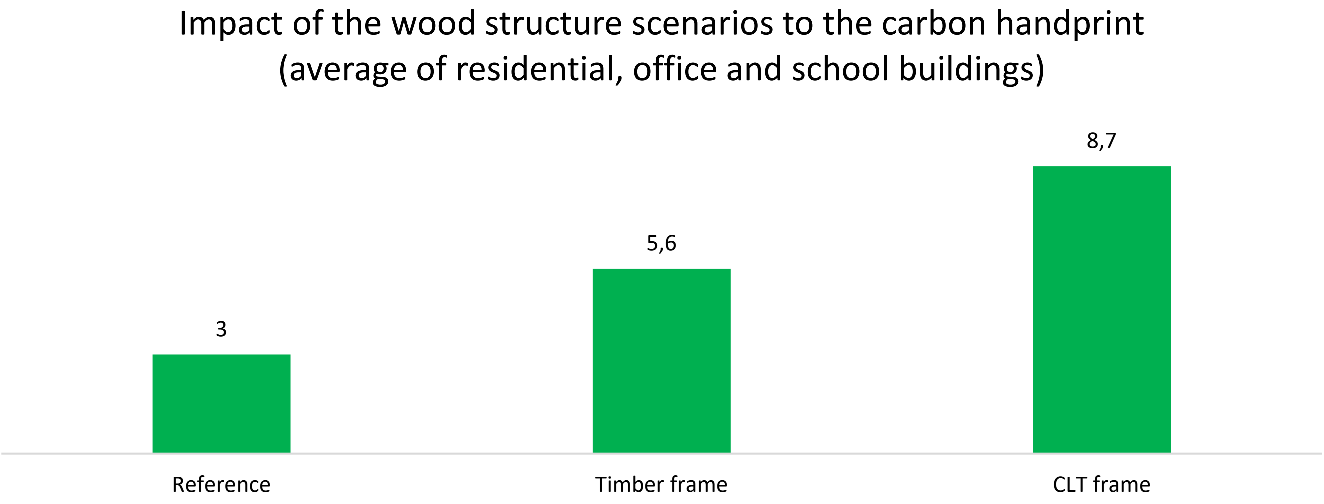
The reader is advised that comparison scenarios here exclude the impact of fixed government default values for phases A4-A5, B3 and C1-C4, which are always immutable and which add a total of 1,5 kg CO2e/m2/a to the results in all scenarios.

10.2 Decarbonisation scenarios – carbon handprint

It’s worth noting that the current carbon handprint calculation method used in decarbonisation scenarios may not be aligned with the methodology or default values the government is expected to issue in 2021, and the level of inherent uncertainty in the results may be higher than for carbon footprints.

Wood-based structures provide an increase in biogenic carbon storage, as well as potential energy recovery after the building life-cycle when wood-based materials are incinerated. Together both of these increase the carbon handprint significantly. The share of energy recovery after the building life-cycle is subject to the government methodology; here the assumptions used are detailed in chapter 5.1. and the energy mix that is substituted is the average *District heat Finland 2020-2070 (50 years)*.

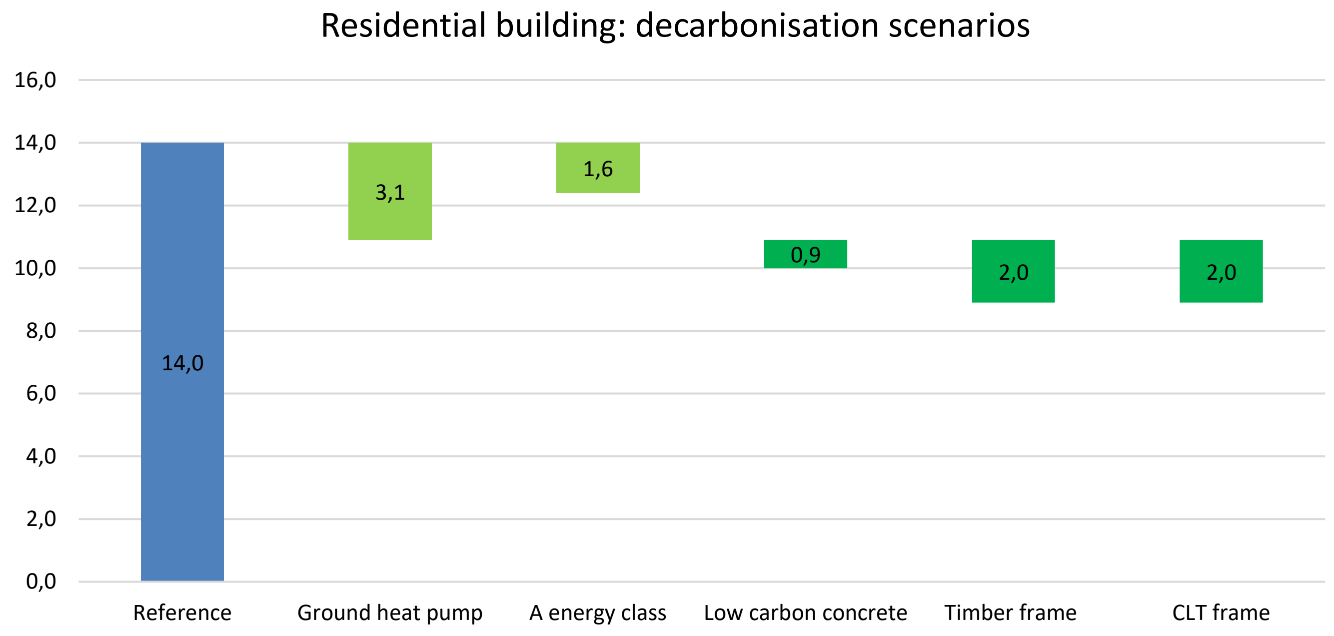
As uncertainty relating to the methodological changes in these scenarios may be higher, the figures are provided as an average of residential, office and school buildings in the graph below.



Increased use of cementious materials – for example in cast-in-place concrete building, or reduced use of cement clinker – for example when using low carbon concrete, also have an impact, as does the higher reuse of construction products at the end of life. However, these impacts are smaller.

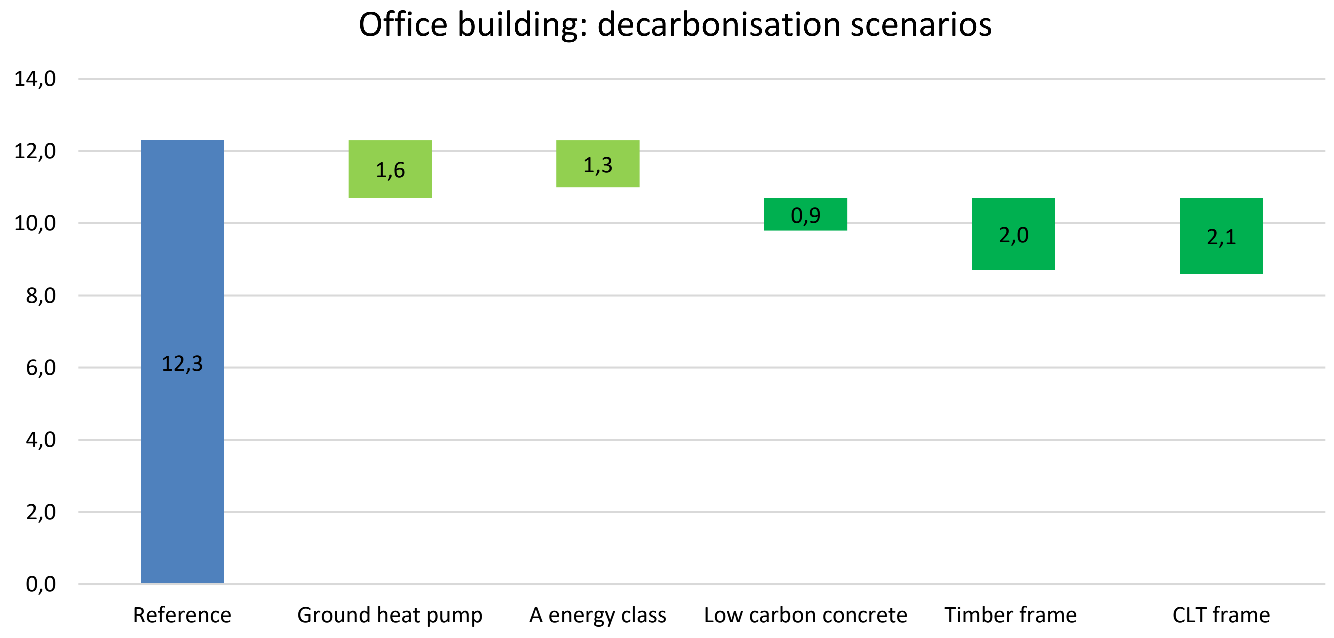
10.3 Decarbonisation scenarios – residential buildings

In the residential building scenarios, the maximum reduction that analysed scenarios can achieve is 36 %. The combination of low carbon concrete and energy class A achieves an 18 % reduction, and the low carbon concrete and a ground heat pump achieve a 28 % reduction. An additional decarbonisation scenario is defined in the §33 of the building energy performance decree, but it was not quantified here.



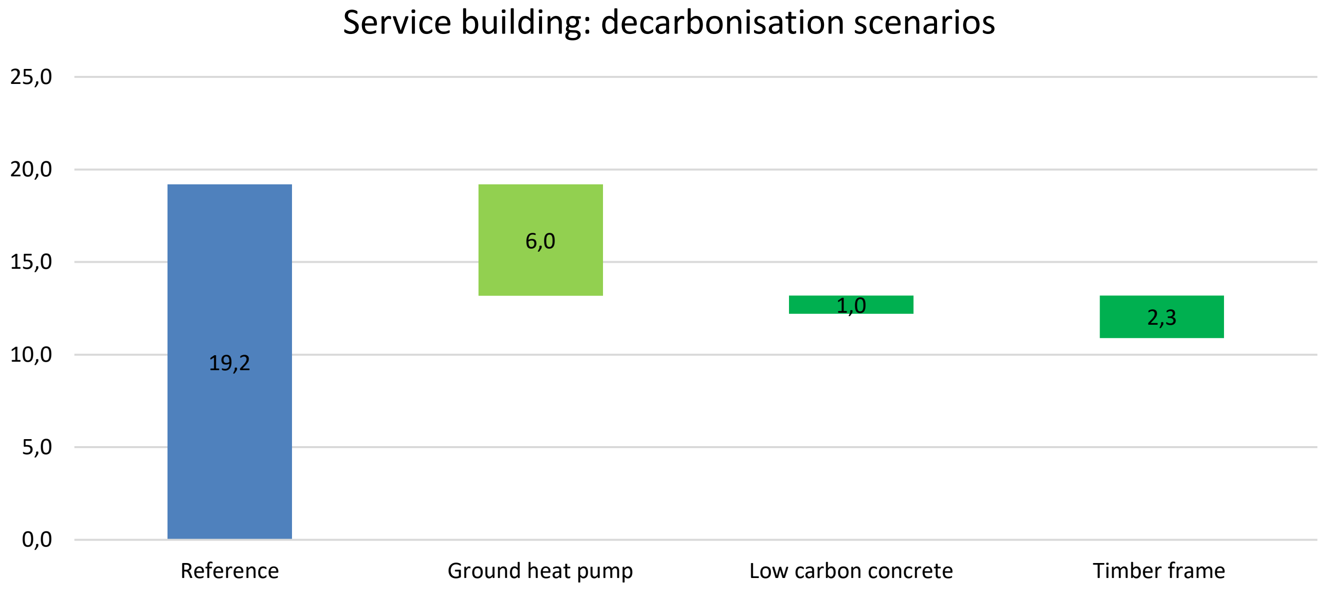
10.4 Decarbonisation scenarios – office buildings

In the office building scenarios, the maximum reduction that analysed scenarios can achieve is 30 %. The combination of low carbon concrete and energy class A achieves an 18 % reduction, and a combination of low carbon concrete and a ground heat pump achieves a 20 % reduction.



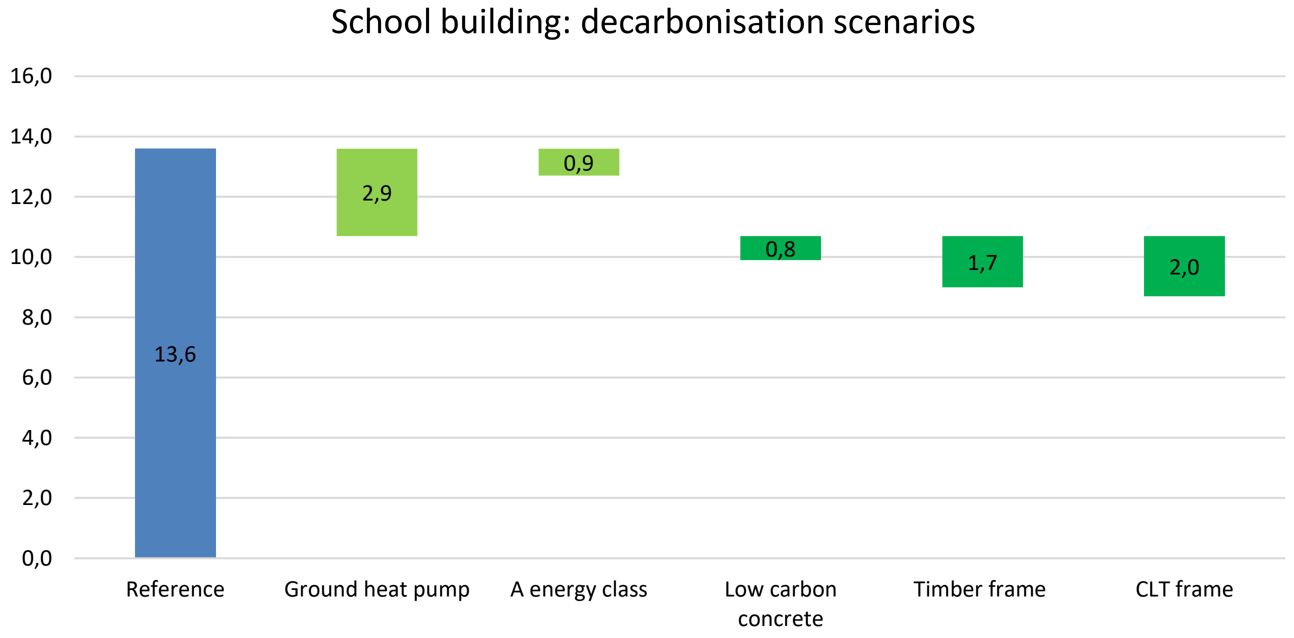
10.5 Decarbonisation scenarios – service buildings

In the service building scenarios, the maximum reduction that analysed scenarios can achieve is 43 %. The combination of low carbon concrete and ground heat pump use achieves a 36 % reduction. This building type did not have data for calculating impact of average A energy class performance. The main reason for the high saving potential for the building type is the poor average energy efficiency.



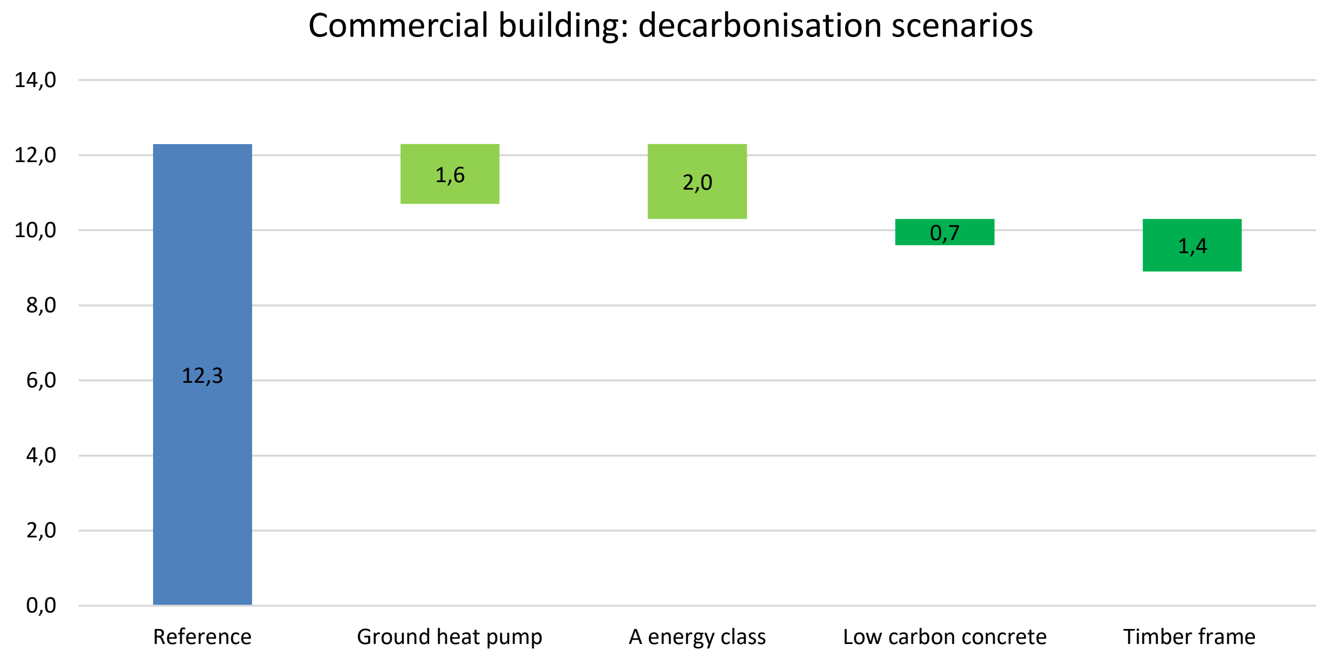
10.6 Decarbonisation scenarios – school buildings

In the school building scenarios, the maximum reduction that analysed scenarios can achieve is 34 %. The combination of low carbon concrete and energy class A achieves a 13 % reduction, and the combination of low carbon concrete and ground heat pump use achieves a 27 % reduction.



10.7 Decarbonisation scenarios – commercial buildings

In the commercial building scenarios, the maximum reduction that analysed scenarios can achieve is 28 %. The combination of low carbon concrete and A energy class achieves a 22 % reduction, and the combination of low carbon concrete and ground heat pump use achieves a 24 % reduction.



11 Conclusions and recommendations

All the conclusions and recommendations in this chapter are exclusively those of the authors, and do not represent the view of the Finnish government nor are they endorsed by the Finnish government.

11.1 Methodology considerations and validity of these results

The results presented herein are based on the Finnish government's calculation method from September 2019, and associated scenarios, assumptions and scope. The changes to the methodology and data planned for early 2021 will result in these results being outdated very soon after publication. While the authors recommend updating these results to align with the new methodology, in the view of the authors, it's more advisable to do so once a significant number of actual projects have been calculated using the new version of the methodology. This could be in late 2021 or early 2022. Reader should note that set values for phases A4-A5, B3 and C1-C4 (total of 1,5 kg CO2e/m2/a) are excluded from all scenarios.

11.2 Decarbonisation potential and the authors' recommendation

The decarbonisation potential of the building stock, using the measures defined in this study (chapter 9), allows every building type to achieve a reduction in the carbon footprint of up to 28 % compared to the reference building level. The level of carbon footprint reduction that is achievable in a materials-neutral manner is 20 % compared to the reference building level. The impact of low carbon concrete as a decarbonisation measure is much higher if the foundations are included in the scope of assessment.

Parameter	Residential	Office	Service	School	Commercial
Maximum decarbonisation identified	36 %	30 %	43 %	34 %	28 %
Low-carbon concrete & ground heat pump	28 %	20 %	36 %	27 %	19 %
Low-carbon concrete & A energy class	18 %	18 %	-	13 %	22 %

The decarbonisation measures available to market players are not limited to the ones analysed in this report. One effective measure would be sourcing low carbon products for all categories, not just concrete. This measure could not be quantified as part of this project. Additionally, materials-efficient design and materials use optimisation provide further potential for cost and carbon reductions.

Based on this project and applicable methodology and scope, the authors recommend targeting a decarbonisation target of 20-30 % from the reference carbon footprint. This would achieve meaningful decarbonisation yet allow every building type to pursue a materials and energy strategy most appropriate to their needs. The percentage is arrived at based on the methodology and scope of the study. The reduction level can be calibrated by building type. The report authors recommend revising the decarbonisation targets based on the new methodology, as well as considering a different sampling basis for the energy performance – for example, taking the average of the top half of energy using buildings.

11.3 Variance in the carbon footprint values of the buildings

Note: the term "variance" is used here with its general meaning, not by its statistical definition.

In this project, the variance has been analysed both statistically using real projects, as well as using scenarios. The variance in the real projects consists of differences in energy performance, as well as differences in the carbon footprint of construction materials. The variance in the real projects has been quantified as the difference of arithmetic average and the 80th percentile in the sample. Operating energy was calculated only as energy use; the carbon footprint is assumed to correlate. In other words, it shows the scale of difference between the average and the four fifths highest result. These statistical variance parameters are shown below. However, this also captures lot of variance that is within project control. Higher variance in embodied carbon for commercial buildings is for a large part due to the limited sample.

Statistical variance in real projects	**Residential**	**Office**	**Service**	**School**	**Commercial**
Embodied carbon – delta of average & 80th percentile in sample (chapter 1)	+17 %	+19 %	+17 %	+38 %	+41 %
Energy use – delta of average and 80th percentile in sample (chapter 2)	+10 %	+22 %	+19 %	+21 %	+14 %

The Finnish building stock has different site-specific conditions and zoning constraints for each of the building types. Understanding and quantifying the variance is necessary in order to set limit values and to avoid setting limit values that would lead to insurmountable difficulties for well-managed construction projects. The parameters the designers can't overcome are zoning-imposed and site-dependent parameters. These are factors outside a projects control, and must be accommodated. The different variance factors are summarized below with the authors' estimate of the variance-adjusted reference carbon footprints. It is unlikely that all adverse zoning parameters would apply on a single project at once.

Calculated zoning-related scenarios	**Residential**	**Office**	**Service**	**School**	**Commercial**
All zoning-related scenarios (chapter 7)	+13 %	+9 %	+ 7 %	+ 9 %	+6 %
Zoning scenarios ex cast in place frame	+8 %	+4 %	+3 %	+5 %	+2 %
Est. variance outside project control	**+10 %**	**+5%**	**+5%**	**+5%**	**+5%**

The authors recommend setting the decarbonisation targets that consider the variance of conditions outside project team control. This should take into account zoning-imposed constraints, site-specific factors and potentially other factors. Using the available data, the order of magnitude for the total variance is from 10 to 20 % of the reference building carbon footprint, but the authors hold unlikely that all adverse factors would apply at once on actual projects other than very rarely. The variance has to be updated when methodology is updated; however, the authors estimate that range of 2 - 8 % variance can be used as a cast in place frame would only be required on a very limited number of building sites.

11.4 The authors’ recommendation for carbon footprint limit values

The authors recommend setting the carbon footprint limit values using variance-adjusted reference carbon footprint values by building type. This would allow for buildings of different shapes and with different zoning constraints and other parameters to meet the thresholds. The authors further recommend applying a significant reduction target, so that the regulation leads to actual improvements in the carbon emissions from the built environment, as opposed to creating an administrative burden with little impact in practise.

The findings and recommendations in this study are based on the currently available methodology, scope and data, which are all soon to be superseded. The numerical recommendations as such will need to be adjusted to future methodology, scope and assessment data prior to application in the regulatory context. The authors believe, however, that using the findings as indicative or for pilot uses could be appropriate.

The upcoming methodology may include additional factors, for example uncertainty factors for generic materials datasets, which would basically bump up the carbon footprint impacts of materials that do not have valid Environmental Product Declarations. This kind of factors do not increase – or directly influence – the carbon footprints of buildings per se, however it is important to consider that not all building materials are likely to have Environmental Product Declarations by the time a regulation comes into force. Meeting the limit values should be possible also for projects that use generic data with uncertainty factors.

The authors find that applying the following reduction targets would be achievable: 25 % for residential and school buildings, 30 % for service buildings and 20 % for office and commercial buildings. This would partly comprise of measures identified and analysed in this study, as well as other approaches, including design and procurement measures. This does not consider construction cost impacts, however, as all measures retained are market-based and have existing adoption, they can be considered viable.

The following table summarizes the authors’ recommendation for the preliminary carbon footprint limits. The proposed limit values have been rounded to one half kg CO2e/m2/a precision. The fixed default values of the methodology (A4-A5, B3, C1-C4), currently 1,5 kg CO2e/m2/a, need to be added to the final limit values. Authors suggest setting them based on the fixed values of the new version of methodology.

Results	**Residential**	**Office**	**Service**	**School**	**Commercial**
Reference carbon footprint (see 5)	14,0	12,3	19,2	13,6	12,3
Variance outside projects’ control (see 11.3)	+8 %	+4 %	+3 %	+5 %	+2 %
Variance-adjusted reference carbon footprint	15,1	12,8	19,8	14,3	12,5
Proposed decarbonisation from variance-adjusted reference carbon footprint (see 11.2)	25 %	20 %	30 %	25 %	20 %
Variance-adj. carbon footprint less reduction	11,3	10,2	13,8	10,7	10,0
Proposed preliminary limit value	**11,5**	**10,0**	**14,0**	**11,0**	**10,0**

11.5 The authors' recommendations on methodology

In the view of the authors', not just the upcoming limit values but the methodology itself has a significant impact on the national construction sector carbon footprint. The following recommendations are made in consideration of potential improvements to the methodology itself.

1. Require reporting site carbon footprint (foundations, parking, external areas) as a separate item
The authors draw special attention to the impact of the foundations, soil conditions and parking structures to the building carbon footprint. Considering that these elements can be of very high importance in terms of carbon impacts of projects, not considering them would impair the carbon reducing impact of the planned regulation in a very significant manner. However, the zoning authority is in fact often the most important decision maker that determines the "site carbon footprint". Reporting and calculating these impacts separately of the building itself would make this a parameter for zoning authorities to consider in their planning processes, and make the impact of the site-specific factors more transparent.

2. Include site carbon footprints in the regulatory limits, if needed, initially with a default value
The authors recommend including these elements in the assessments in the regulatory limit values, owing to their very high impact. However, this might limit the possibility of any construction on certain sites with adverse conditions. The authors suggest that every project report an accurate site carbon footprint, but that projects are allowed to opt to use for example in the first five years of the regulation a fixed default value instead of the site-specific impacts towards the regulatory limit values. This would make it possible to protect private property while still driving the market to develop solutions that reduce the significant carbon impacts of site improvement on a larger commercial scale.

3. Require separating transparently the constituents of the carbon handprint
If EPD results are allowed for carbon handprints, calculations could start to vary between projects. Module D results are calculated using very different scenarios in different EPDs. This will lead to diverging results and confusion in the market, which risks discrediting the methodology and reduce the value of the carbon handprint on the market. The carbon handprint is an important element on the marketplace, as it contains information that can be used to make net zero carbon assessments.

On the other hand, if the government does not remove the need for ready-made carbon handprint scenarios for all product categories, using data from EPDs may be unavoidable. Therefore, the authors recommend requiring reporting every major part of the carbon handprint as a separate line item. In this context, it would be consistent to move the carbonisation during the life cycle of the building to the carbon footprint. The authors suggest the following groups:

1) Biogenic carbon storage,

2) Carbon handprint (module D) from EPDs,
3) Carbon handprint (module D) from generic data,
4) Exported energy, and
5) Carbonisation during the building life-cycle (if carbonisation is not moved to the carbon footprint).

In addition, the report authors would recommend considering adding the additional groups outlined to the following recommendation.

4. Include renovation benefits to the carbon handprint calculations to accelerate renovations

Renovation of existing buildings has significant potential to reduce energy consumption and to increase circular material flows. The government methodology may provide added incentives for parties to pursue such projects, as it boosts the sustainability credentials of such projects. To provide added incentives for energy renovations, the authors would recommend that every renovation project that increases an existing building's energy performance by more than 20 % (or another appropriate watermark value) can be taken into account as an additional carbon handprint group: 6) Energy renovation impacts the projected energy carbon footprint reductions.

To provide added incentive for recovery and commercialisation of construction materials, the authors recommend that every renovation project that recovers any products for reuse (not for recycling) would allow new product impacts to be taken into account in their carbon handprints, either in full or partial (e.g., 50 %). This could be reported in another suggested new carbon handprint group: 7) Existing materials recovery benefits.

5. Include refrigerant leakages in the carbon footprint with a simplified methodology

The Finnish government method is laudable for its consideration of building systems in the scope of assessment. However, in the current methodology, refrigerant leakage impact is not considered. Choosing a low-GWP refrigerant is far more important for climate change mitigation than optimizing building systems material efficiency. As the exact leakage is difficult to quantify, the authors suggest applying a simple calculation method, consisting of a fixed annualised leakage (e.g., 5 %) and a fixed system commissioning, replacement and decommissioning leakage (e.g., 30 %) to be calculated as part of the total initial charge of the refrigerant, all within the B1 Use life-cycle phase of the building. This will incentivise designers to prioritise passive systems and low-GWP refrigerants in their projects.

6. Include material losses in the assessment and define defaults in government methodology

Non pre-fabricated materials have a share of the materials lost on the construction site when they are cut to size. Considering these losses in the assessments is important to achieve materials efficiency, which underpins the carbon footprint of materials. The authors recommend that the government methodology provide the default loss factors by materials categories, to ensure such values are also applicable to products with EPDs. The authors further recommend that any party be allowed to use their own specific loss factors always for the as-built phase, and also in the construction permit phase when their construction technique allows lower losses, for example when building prefabricated elements that use the same materials. The authors further recommend that the methodology take into account the reuse of surplus materials. In such cases, unused products from project A are taken to use in project B via a surplus goods operator. This could be handled by simply allowing both projects to consider the material impacts with a 50 % weighting to benefit both sides of the circular materials market. Alternatively, to simplify calculations, such materials could be simply considered zero carbon for the project putting them to use, even if such materials would not have a waste status.

7. Enable investment in district level heat/cooling systems by allowing energy to use EPDs

In the current methodology, the construction products market can use EPDs when a specific supplier is known. This allows manufacturers to invest in improvements as they can reap benefits. However, heat and cooling supply must use average factors. This limits incentives to invest in developing district level systems that would achieve carbon reductions, and thus impairs a functioning market. This is undesirable, as it may limit exploiting potential energy system level synergies, such as the reuse of excess heat from data centres in heating buildings, or district cooling systems, or district level solar systems, for example, where they are not sufficiently profitable to be invested in without carbon considerations. In addition, it removes the potential for an existing district heating system to gain benefits by investing in decarbonizing their energy production. Energy EPDs are used for example by the RTS EPD program in line with the EN 15804 standard. Values from such EPDs could be used for example for the first 20-30 years of the assessment period, thereafter defaulting to the government issued decarbonisation scenario for the respective energy systems; or a separate set of rules for such EPDs could be drafted. As an added benefit, this would ensure that energy consumers are not driven away from existing low carbon district heat systems. This incentivises investments in low carbon energy systems to align with the government’s emissions roadmap.

8. Provide market visibility on the planned long-term carbon limit development path

Investments in production systems, design competence, factories and supply chains take several years to come to fruition. Therefore, in the view of the authors, the government should provide an indicative reduction path for the carbon footprint thresholds with projected, but not binding, reduction levels approximately every five years. Considering the low carbon construction sector will require very significant private investments, this would provide the market with the confidence to do so, instead of dragging their feet. Such a roadmap could be also used by cities and other players, who wish to push the market forward faster, and they could adopt planned, even if indicative, performance levels in advance. Enacting any changes to the thresholds would be obviously the prerogative of the government in office.

9. Consider establishing market-based thresholds for low carbon construction materials

While the government may be legally limited from setting regulatory carbon thresholds for construction material categories, this remains a very effective decarbonisation measure. In this study, the only product category for which this was considered was concrete. This type of measure has been shown to have significant impact, e.g., by Norwegian public construction organisations, Statsbygg, Vegvesen, Nye Veier, Bane NOR and some cities, which each set material category-specific carbon footprint limit values for key construction products in procurement. These requirements in essence required that a supplier provide an EPD demonstrating performance below the set limit value for products in the category. For the Finnish market, developing such specifications could be done by the marketplace, and they could be used by a range of public and private procurement and design organisations. This simplifies setting requirements, as each party is not required to develop their own limit values. This could be synchronized with regulations.

10. Define rule of replacement frequency of construction products mathematically

The current government methodology does not dictate the number of replacements of construction products in a normative, mathematical fashion. Instead, it provides examples. Such ambiguity is extremely undesirable, when this would have impact on the carbon footprint limit values. The authors recommend adopting a mathematically interpretable rule for the amount r of construction product replacements. This could require including the product impacts fractionally (that is, not requiring number of lifetimes to be an integer, as applied in the French regulation), or rounding the replacements to an integer (as is more common). Both methods have their benefits, however the view of the authors is that clarity is imperative. In a simplified form, this could be as follows: *“Construction products, whose service life is shorter than the assessment period, shall be required to be replaced during the assessment period as follows. Number of replacements for the products is calculated as follows: n = (assessment period / service life – 1), rounding the result to the nearest integer, rounding upwards from 0,5”.* Of course, the rounding rule can be defined differently, or fractional impacts adopted.

11. Define a strict rule for eligibility of construction product EPDs and the choice of data to use

The current construction product EPD marketplace is changing rapidly, and it has brought about new types of EPDs, which do not strictly meet the requirements of ISO 14025. These new types of EPDs are machine-verified EPDs and internally verified EPDs; neither of which fulfil the ISO 14025 requirement of independent verification of EPD by a competent person or a body. This matter is discussed at length in this article. Such documents typically are connected to a single economic operator or EPD program, and they can allow for human error or abuse more easily, in the absence of an independent verification. This issue coincides with existence of EPDs created with EN 15804+A1 as well as EN 15804+A2, which also differ. The authors recommend the government only allow the use of construction product EPDs with independent verification. The following language is provided to convey the suggestion: “*Environmental*

product declarations for construction products may be used instead of generic data, when the EPD meets all of the following requirements: 1) The specific product and the specific supplier used in the project are known and both are specifically named on the EPD, 2) The EPD is valid at the time of specification, 3) The EPD conforms to ISO 14025 and EN 15804 or ISO 21930 standards, 4) The EPD has been independently verified by a third party verifier, who is named as the independent verifier of the EPD on the EPD, and 5) The EPD has been approved by an EPD program operator, who is named on the EPD, 6) The EPD has the minimum mandatory scope required by the regulation (comprising either of cradle to gate scope or cradle to gate with module D, as applicable in the future government methodology).”
Further, the authors recommend requiring that the GWP-fossil values (as defined in the EN 15804+A2) is always used in priority for the assessment, when an EPD would provide both EN 15804+A2 and EN 15804+A1 compliant GWP values.