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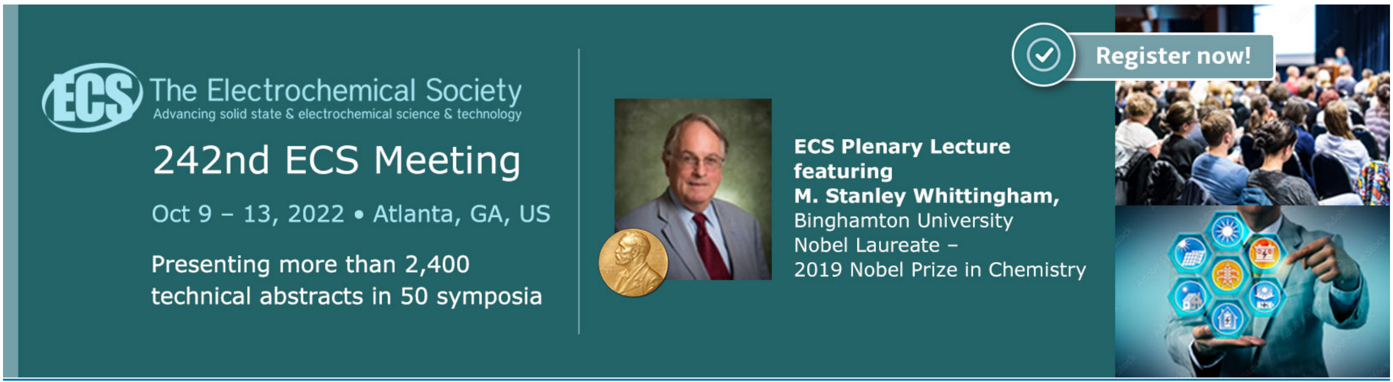

FutureBuilt Zero - A simplified dynamic LCA method with requirements for low carbon emissions from buildings

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Abstract. FutureBuilt is a voluntary program for ambitious low-carbon construction projects. To incentivize measures that lead to the lowest climate change impact from all aspects of buildings and according to national Paris agreement pledges, FutureBuilt Zero introduces an ambition level and a novel calculation methodology for net climate change impacts over the life of a building. The ambition level is tightened over time to help Norway achieve its climate goals. A comprehensive simplified calculation method is introduced, which considers how the timing of emissions during the building life affects the contribution to global warming. Both direct and indirect emissions throughout the lifetime are included; energy use in operation and at the construction site, material production and transport of materials to the construction site, and waste management (incineration). In addition, the climate-positive effects of biogenic carbon uptake, carbonation of cement, potential for future reusability, and exported energy are included. This paper presents the criteria, describes the method and the scientific basis as well as the principles and logic behind the choices made.

Keywords: building, LCA, low carbon, dynamic factors, emission intensities

1. Introduction

The construction industry must rapidly reduce direct and indirect embodied greenhouse gas (GHG) emissions if nations are to achieve the targets set in the Paris agreement (1). However, few current incentives facilitate such reduction targets, and they commonly ignore important emission sources and future scenarios. Because of large variations in methodologies used, both in calculation methods and in the scope of included emissions, it is challenging to compare results among different studies (2). This means that it is difficult to define meaningful benchmarks with accompanying clearly defined reduction targets. Attempts have been made to achieve carbon emission benchmarks and reduction targets at the national level. (3–8).

FutureBuilt is a voluntary program to demonstrate that climate-neutral urban areas, based on high-quality architecture, are possible. This has been established in the Oslo region in Norway through 69 pilot projects over the past 12 years. Pilot projects have focused on reducing GHG emissions from transport, energy, and materials for the built environment, and are required to perform carbon footprint calculations and document 50% emission reductions compared to a reference building. The reference building is based on 'business as usual' using current national building regulations and common practices. Since a set of FutureBuilt quality criteria have been developed, including a method for calculating GHG emissions from low emission buildings and areas in Norway, namely FutureBuilt Zero (9). The FutureBuilt Zero method takes into consideration changes in technology and policy and applies a range of adjustment factors such as biogenic carbon, time- and technology-dependent characterization factors, carbonization of concrete, and carbon uptake through regrowth of forests. The carbon content of materials determines the scale of biogenic and fossil carbon released back into the atmosphere at end-of-life incineration. Simplified and pragmatic circularity accounting is included, both for the benefits of reuse of products during construction and for the facilitation of future reusability. FutureBuilt Zero addresses these issues by employing complex methodological dynamic-LCA concepts in a simplified and practical method intended for industry practitioners. Thus, the method helps Norwegian building owners and contractors stay on track with their increasingly ambitious emission reduction goals.

2. Ambition levels and criteria

FutureBuilt Zero sets criteria for maximum emissions for a building's contribution to global warming potential over its lifetime and includes potential emission gains from carbon sequestration, reuse of materials, material recycling, and energy exports. The criteria emphasize emission reductions early in the building's lifetime and provide incentives to prevent future emissions and include potential gains after the end of the building's lifetime. The Norwegian government has announced national carbon emission goals that encompass 50-55% reduction by 2030 and a 90-95% reduction by 2050 (10). To ensure that reduction measures are used on both materials and energy, separate criteria are set with maximum emissions for both operational energy use and material use.

Figure 1 shows today's ‘current practice’ and ‘current best practice’, a projected reduction in emissions following the national climate targets as well as criterion levels for material and energy use. Buildings must adhere to the ‘best practice’ for the year of completion. The criterion is tightened every year so that it is 50-55% lower by 2030 and 90-95% lower by 2050 compared to the 2020 level for 'today's best practice'. For example, emissions from a building to be built in 2030 must be at least 50-55 % lower than current best practice to comply with national climate targets. The criterion applies to a functional unit of per m2 gross floor area (GFA) over a reference study period of 60 years. Numerical values for the criteria are given in the Appendix in Table A1.

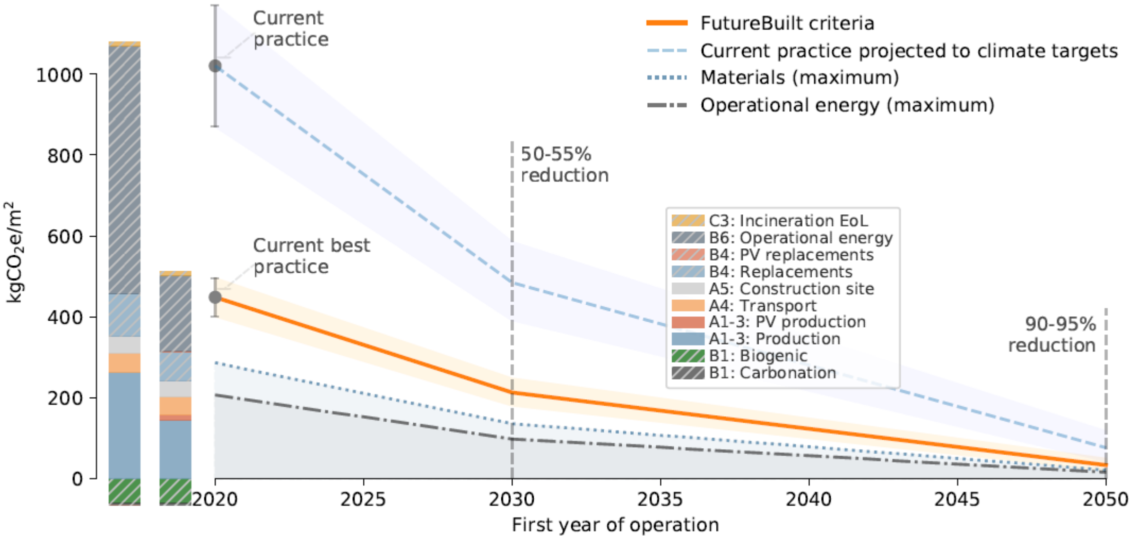

Figure 1. FutureBuilt Zero maximum emissions for a building's contribution to global warming over its lifetime (9). Numerical values for the criteria are given in the Appendix in Table A1.

The methodology mainly follows Norwegian Standard NS 3720:2018. The scope of GHG emission sources includes energy use in operation (life cycle module B6); production of building materials used in construction (A1-3); transport of those materials to the construction site (A4); construction site energy use and construction waste (A5); replacements, construction waste, and replacement waste during the building's lifetime (B2–5); and deconstruction waste during the end-of-life (C3) for materials. Emissions from construction waste include production, transport to the site, and incineration.

Negative emissions include the uptake of carbon in forest regrowth during the building's lifetime and carbon sequestration in cement products during the life of the building (B1). Averted emissions may be deducted if the likeliness of future reusability of building materials is documented ($D_{\text{reusability}}$) because reusability will prevent combustion during demolition/dismantling and will substitute future production of similar new materials/building parts. Export of locally generated renewable energy that replaces the corresponding amount of energy in the grid (D_{energy}) may also result in a reduction of emissions, i.e., if exported energy averts emissions from other more polluting energy production. For reused products, the method introduces a simplified accounting which includes a percentage reduction in GHG emissions in module A1-3, based on the emissions from production of similar new materials.

The building assessment is classified according to NS 3451: 2009 Table of building elements (11). The building materials included are load-bearing structure, inner and outer walls, basement floors, foundation slab, floors, roof, stairs, balconies, and fixed inventory, as well as energy-producing systems such as photovoltaics. This corresponds to 'NS 3720 basic without location'(12).

The starting point of the criterion curve is based on the current best practice of a near-zero energy building with electricity production from solar cells on an area corresponding to 10% of HFA (13). GHG emissions from material use is based on the 25% best samples from a statistical analysis of 112 building life cycle assessments (LCAs) (14,15). The lifetime of the building is set to 60 years. The method considers an expected technology development, which will lead to lower emissions from future production, transport, and waste incineration of materials, as well as from future energy production and use in operation. The method includes a time weighting of all emissions and uptake. Future emissions are given a lower weight than emissions today. The reason for this is that the timing of emissions and uptake is essential to achieve the climate goals set for 2030 and 2050 through international, European, and Norwegian climate policy agreements. Emissions from remaining building parts (technical installations and infrastructure) are documented according to NS 3720 'advanced with location' but are not included in the criterion due to a lack of empirical statistics (12). As statistics become available, more building parts will be included, and the criterion adjusted. In addition, at least half of the energy use at the on-site (A5) should be 'emission-free' (without direct GHG emissions). This increases to 100% from 2025, and from then on, emission-free mass transport should also be included.

3. **Calculation method**

The method introduces some novel methodological concepts, based on (16). FutureBuilt Zero is built on the premise that substantial emission reductions must take place soon. This is implemented by introducing 'time factors' that assign less weight to emissions and uptake that occur in the far future, than to the ones that occur in the near future. This weighting is implemented in such a way that it is consistent with the actual contribution to climate change that happens during a 100-year period. The technological development that is reducing emissions from production, transport and waste handling of materials is considered by introducing 'technology improvement factors'. In addition, scenarios for emission factors are given for energy use in operation and are provided for all future years. Overall, the method provides incentives for measures that reduce emissions in the short term, while ensuring lasting and long-term GHG reductions. The following life cycle modules are included:

$$E = E_{\text{A1-3}} + E_{\text{A4}} + E_{\text{A5}} + \underbrace{\underbrace{E_{\text{B4}} + E_{\text{B6}} + E_{\text{C (incineration)}} + E_{\text{D}}}_{\text{TECHNOLOGY WEIGTHED}} + E_{\text{B1 (biogenic, carbonation)}}}_{\text{TIME WEIGTHED}} \qquad (1)$$

In summary, the method considers the following:

- Technology improvements (efficiency of old technology or improved new technology) will lead to lower emissions from the production and transport of materials that are replaced in the future, and lower emission intensities from other energy use.
- The use of wood products leads to the growth of new forest and thus carbon uptake through photosynthesis and will at the same time lead to temporary carbon storage in the building's wood products.
- Emissions from the combustion of wood and plastic products are postponed as long as they are in use in the building. In the future it will also be possible to prevent emissions from waste incineration into the atmosphere as carbon capture and storage technology is developed.
- Exposed concrete leads to carbon uptake and binding.
- Facilitating reusability can lead to materials in the building being able to substitute future production of similar products.

The FutureBuilt Zero method introduces several factors to adjust the calculation results by reducing the number of operations and making its application as simple as possible. The calculations are performed separately for each material and are then summarized to get the total result. The practical execution of the calculations is significantly simplified by multiplying either emissions (kgCO$_2$e) or mass (kg) by the factors given in Table 1. Production (A1-3) and transport (A4) emissions in the construction phase (A5) are unaffected by the FutureBuilt Zero method, but production and transport emissions for future replacements (B4) are weighted by factors. The benefits from circularity (reuse and reusability) are found by multiplying A1-3 results by the given factors. The remaining material emission sources (carbon uptake in forests and cement, and waste incineration) are calculated by multiplying the mass of the material by their wood, fossil, and cement content, and the given emission factors. Emissions from operational energy use are calculated from kWh energy use and the emission factors for each energy source. These simplified multiplication factors bring together several important effects in one number and include both technology improvements, time weighting, changes in emission factors, and uptake factors.

Table 1. FutureBuilt Zero total factors for use in calculations.

	A1-A5	B1-B6	C1-C4	D	Unit	Is multiplied with
Production and transport	1	0.57	-	-	-	Emissions [kgCO$_2$e]
Production, photovoltaics	1	0.25	-	-	-	Emissions [kgCO$_2$e]
Reuse	0.2	-	-	-	-	Emissions [kgCO$_2$e]
Reusability	-	-	-	0.1	-	Emissions [kgCO$_2$e]
Carbonation in cement	-	-0.06	-	-	kgCO2/kg	Mass [kg] · Cement [%]
Carbon sequestration in forest*	-	-1.27/-0.71**	-	-	kgCO2/kg	Mass [kg] · Wood [%]
Waste incineration, wood	0.92	0.52	0.24	-	kgCO2/kg	Mass [kg] · Wood [kg] · Incineration [%]
Waste incineration, fossil	1.47	0.84	0.39	-	kgCO2/kg	Mass [kg] · Fossil [kg] · Incineration [%]
Electricity	Table 3	Table 3	-	Table 3	kgCO2/kWh	Energy delivered or exported [kWh]
District heating, waste	Table 3	Table 3	-	-	kgCO2/kWh	Energy delivered [kWh]

* Limitation: Biogenic sequestration can as a maximum compensate for waste treatment and 75% of production, not transport or material loss.

**-1.27 corresponds to wood use in the construction phase and –0.71 corresponds to wood use during the replacement phase

3.1. Dynamic factors: Time of emissions and technology development

Emissions that occur today will by 2050 have spent a longer time in the atmosphere than emissions that occur further in the future. A longer time in the atmosphere increases the heating contribution. All emissions and uptake are therefore weighted according to when they occur. Also, postponing emissions may be beneficial, due to future technological improvements that will likely lead to lower emission intensities. Table 1 shows the emission sources with associated factors for technology and time weighting. Only the 'total factors' are to be used to adjust GHG calculations.

In an infinite time-horizon, the effect of postponing emissions will be evened out, but in the limited time towards the Paris agreement targets, timing will be decisive. All future emissions are therefore weighed depending on the year in which the emissions occur. Emissions for each material in future life cycle modules (B, C) are multiplied by time-weighting factors. Future emissions will have a shorter time to warm up the atmosphere in a 60 or 100-year perspective than emissions that occur today. The decreasing significance of emissions is described by the function: $f(t) = 2-e.00693t$, which gradually gives future emissions less significance based on the heating potential in the period, and eventually ends up at zero after 100 years. For a building with a long service life where emissions are distributed throughout the reference study period, it is methodologically inconsistent not to take these time aspects into account, as the GWP100 indicator already has the time aspect embedded in the GHGs other than carbon dioxide. This is well described in (16,17), on which this method is based. GHGs will gradually break down in the atmosphere and therefore have a gradually decreasing GWP.

For emissions that occur in specific years, one can apply the factor for that year. In year zero, the construction year, the factor is 1, for replacements in year 30 it will be 0.77, and for end-of-life emissions in year 60 it will be 0.48. For simplification purposes, it is assumed that emissions uptake occurs evenly over the lifetime, from years 1-60, and use the average to weigh the total over this period. We then get a time factor f_{time}, for years 1-60. For higher precision, time weighting function can be used directly to weight emissions in each year where the emissions occur, or use an average factor weighted by the time and size of the individual emissions uptake (18).

A reduction in emissions related to the production of materials can be expected due to technological improvements in, among other things, materials technology, production technology, recycling rate, transport technology, and electrification together with a decarbonization of the energy network. The development in emission intensity from material production will depend on material types, but a simplification has been made based on historical development in the Norwegian industry, which has been approximately 1% annual improvement (19). This development is used for all building materials, except for energy-producing equipment (photovoltaic systems, etc.) where the reduction will likely be greater. For these, a 2/3 reduction is assumed before replacement takes place after 30 years (20) giving a technology factor of 0.33 for replacements in year 30. The assumption of a 1% annual technology development is also used for the transport of materials (decarbonization and efficiency) and waste incineration (efficiency and carbon capture and storage). In year zero, the construction year, the factor is 1, and for end-of-life emissions in year 60 it will be 0.55. For simplification purposes, it is assumed that the emissions occur evenly over the lifetime, with an average factor for years 1-60 of 0.75. For higher precision, one can choose to use the technology functions directly to weight emissions in each year where the emissions occur or use an average factor that is weighted by the time and size of the individual emissions uptake. The technology factors are the same for all future years.

3.2. *Emissions from energy use in operation*

The technology factor for electricity changes from year to year, and the factor therefore depends on the year the building is put into operation, see Table 3. The technology factor for electricity is:

$$F_{\text{technology, el}}(y) = \frac{\text{average emission intensity from year y to y+60}}{\text{emission intensity in year y}} \tag{2}$$

$$= \frac{1/60\sum_{t0=y}^{y+60} \begin{cases} 363-((363-24)/30)\cdot t & \text{when t is for year} < 2050 \\ 24 & \text{when t is for year} \geq 2050 \end{cases}}{\begin{cases} 363-((363-24)/30)\cdot y & \text{when y is for year} < 2050 \\ 24 & \text{when y is for year} \geq 2050 \end{cases}}$$

where y is the first year of operation after 2020. In calculations, it is possible to use the emission factor directly, which will be the average emission intensity factor for the coming 60-year period.

Table 2. Emission intensities for electricity and district heating.

	Electricity					District heating				
	Emissions [kgCO2e/kWh]	Technology factor	Time factor	Total factor	Weighted emissions [kgCO2e/kWh]	Emissions [kgCO2e/kWh]	Technology factor	Time factor	Total factor	Weighted emissions [kgCO2e/kWh]
2020	0.36	0.3	0.76	0.23	0.084	0.12	0.75	0.76	0.57	0.069
2021	0.35	0.3	0.76	0.23	0.08	0.12	0.75	0.76	0.57	0.068
2022	0.34	0.29	0.76	0.22	0.075	0.12	0.75	0.76	0.57	0.068
2023	0.33	0.29	0.76	0.22	0.071	0.12	0.75	0.76	0.57	0.067
2024	0.32	0.28	0.76	0.21	0.068	0.12	0.75	0.76	0.57	0.066
2025	0.31	0.28	0.76	0.21	0.064	0.12	0.75	0.76	0.57	0.066
2026	0.29	0.27	0.76	0.21	0.061	0.11	0.75	0.76	0.57	0.065
2027	0.28	0.27	0.76	0.2	0.057	0.11	0.75	0.76	0.57	0.065
2028	0.27	0.26	0.76	0.2	0.054	0.11	0.75	0.76	0.57	0.064
2029	0.26	0.26	0.76	0.19	0.051	0.11	0.75	0.76	0.57	0.063
2030	0.25	0.25	0.76	0.19	0.048	0.11	0.75	0.76	0.57	0.063

For district heating (DH), the emission factor must be calculated based on the specific DH system the building is connected to. This means that the distribution of energy products used in heat production, the distribution loss up to the building, and the system efficiency internally in the building, must be included. When waste is included as an energy product in the DH system, an emission intensity of 0.121 $kgCO_2e/kWh$ per imported waste is used for the year 2020. The 2020 intensity is based on (21), which assumes that approx. 20% plastic in the residual waste goes to energy recovery until 2035, with an energy content in the waste of 11.5 GJ/ton. Furthermore, a 50/50 allocation of emissions between energy recovery and waste disposal has been used, according to The European Commission's PEF guide (22). The time of uptake of biogenic carbon is considered in the factor. Technology development for waste incineration is assumed through reduction of process emissions and system losses, changes in recycling, and carbon capture, which gives a 1% annual reduction. This leads to annual emission intensities for incineration of waste as an energy product in the district heating system. Then the yearly value is weighted by the technology factor and gives an average value.
The emissions must also be time-weighted, and this gives the total emission intensities, see Table 3.

The use of bioenergy releases GHG emissions during combustion, and carbon sequestration during new growth of biomass. The method for emissions accounting related to the use of bioenergy is like the methodology described for wood products in the building. The time for biogenic uptake through the growth of new forest is determined by the rotation period, i.e., the time between harvesting points. The emission factor for bioenergy from residual products from forestry (wood, wood chips, pellets, etc.) has the same rotation period as material use, i.e., 100 years.

3.3. Emissions from replacements and construction activity

Construction site emissions (A5) include production, transport, and waste incineration of cut and waste masses during the construction phase, and all direct energy use on the construction site. Since these activities happen in the construction year(s), there is no technology development and to time effects.

Replacements of materials happen in the future, and therefore the emissions occurring due to the production, transport to the construction site, and waste incineration are adjusted by technology and time factors. In the operation phase, construction waste masses are included in the replacement mass.

Carbon emissions from waste incineration of combustible, organic materials, are calculated for all phases, except for products with documented reusability. The following equation applies:

$$E_{\text{incineration}} = m_{\text{waste}} \cdot f_{\text{wood/fossilcontent}} \cdot f_{\text{energy recovery}} \cdot f_{\text{wasteincineration}} \qquad (3)$$

Waste is generated in three different ways: construction waste both during construction and operation, the replaced products in the operation phase, and during end-of-life decommissioning. The factors f_{wood} f_{fossil} is the proportion of the product that consists of combustible material, i.e., the proportion of the product that can be attributed to biogenic or fossil materials. For example, a plastic moisture barrier will have 100% fossil content, while a window with plastic frames will have a lower fossil content. The factor $f_{\text{energy recovery}}$ is the proportion of waste that is not recycled. In time, more focus on circular economy is likely to increase recycling rates and reduce the number of materials that are incinerated. It is assumed that there will be a linear reduction from 100% in 2020 to 20% in 2080, which will remain constant thereafter. In the design and construction phases, the project team can minimize the proportion of construction waste that is recycled, which then can be documented and thus replace the default value. In the use and final phases, the project has no opportunity to influence this share. For the use phase, the average of all operating years is used. For the final phase, 80% material recycling is used regardless of the year of construction, since there will always be some waste that cannot be recycled. The product of these three parameters ($m_{\text{waste}} \cdot f_{\text{wood/fossil}} \cdot f_{\text{energy recovery}}$) gives the mass of the wood/fossil content in the waste that goes to incineration. This mass is multiplied by the $f_{\text{waste incineration}}$ factor to obtain the emissions per combustible mass. This results in one factor each for the construction, use, and end-of-life phases. These factors do not change and can be used directly from Table 3.

Table 3. Fraction of waste recovered (i.e. not incinerated) for the first year the building is in operation.

	Construction phase (A5)	Use phase (B2-B5)	End-of-life phase (C3)
2020	1.0	0.6	0.2
2021	0.99	0.59	0.2
2022	0.97	0.57	0.2
2023	0.96	0.56	0.2
2024	0.95	0.55	0.2
2025	0.93	0.54	0.2
2026	0.92	0.52	0.2
2027	0.91	0.51	0.2
2028	0.89	0.50	0.2
2029	0.88	0.49	0.2
2030	0.87	0.48	0.2

3.4. Carbon sequestration related to wood-based products

The effect of temporary storage of biogenic carbon when using wood-based materials is twofold. First, the growth of new forests leads to carbon uptake when new trees grow up in the area where the forest is cut down to supply the production of wood-based products. This carbon uptake takes place during the operational phase of the building. Secondly, the wood products in the building will be disposed of at the end of their service life, and some of the carbon stored in the products will then be oxidized due to incineration or decay and returned to the atmosphere. Carbon uptake in forests takes place during the life of the building and carbon uptake is therefore reported in module B1. Waste incineration takes place in all modules (A5, B4, C3) and is reported in the respective modules. In literature, it is argued to use a dynamic LCA to take this effect into account (23). A variation of this method is used.

A simplified growth function equal to $1 - \exp(-.03t)$ is assumed, where t is the number of years after harvest. This function is based on a rotation period of 100 years, which is assumed to be representative of Norwegian spruce. The carbon content varies between wood products but is around 50% per dry mass (24). When carbon is oxidized and becomes carbon dioxide, the mass increases by two oxygen atoms, and each kg of carbon becomes 3.67 kg of carbon dioxide. The total factor for biogenic carbon uptake during the growth of trees then becomes 1.27 time-weighted kilograms of carbon dioxide during the life of the building ($\text{kgCO}_2\text{kg}^{-1}$).

The effect of biogenic carbon content only applies to wood originating from sustainable forestry. There is a limited amount of wood available in the world's forests, so the scarcity of resources must be considered. During the development of the method, there has been a concern that an excessive deduction in the accounts for wood can lead to less focus on reducing material quantities, and thus increased material consumption. Since overconsumption is undesirable for a limited resource, it is in the FB-criterion only possible to obtain partial compensation from the climate effect of biogenic uptake. The biogenic uptake is reported in module B1 and limited so that it at most can be the same size as the sum of emissions from waste management of the wood product and 75% of emissions from material production (A1-A3). Transport emissions (A4) cannot be compensated for with biogenic uptake.

3.5. Carbonation of cement

Cement products will over time bind carbon dioxide from the air; a process called carbonation. These negative emissions can compensate for some of the emissions from the production of materials. Here, an uptake of 94 kg CO_2 per ton of cement is assumed after a service life of 100 years (25). There will be most uptake in the first years, and the uptake will then decrease exponentially. The approximate function used here is $0.094[1 - \exp(-.03t)]$ per kg of cement. After 25 years, approximately half of the uptake that takes place over a 100-year period will have taken place. Only the uptake that takes place in the building's lifetime is attributed to the building. The uptake per kg cement during the building's lifetime is given by the factor

$$f_{cement} = f_{uptake\ per\ kg\ 100\ years} \cdot f_{\%-uptake\ 60\ years} \cdot f_{time}$$
$$= 0.094 \cdot 0.083 \cdot 0.083 = 0.06$$

where $f_{uptake\ per\ kg\ 100\ years}$ is the carbon uptake per kg cement in a 100-year use phase, and $f_{\%uptake\ 60\ years}$ is the percent taken up in the first 60 years. To get the carbon uptake per kg of concrete (or other cement product) used in the building, f_{cement} is multiplied by the proportion of cement in the product.

3.6. Prevented emissions

Products that in the construction phase are reused from previous use in another building or similar, will have avoided emissions from waste management and the production phase. When reusing materials in the construction phase, we have simply stated that 80% of the production emissions (A1-3) can be deducted from the production emissions from a similar product that would otherwise have been used in the building. If desired, one can make more accurate calculations for the products that are reused and use such figures instead of a general 80% reduction. The gain from reuse only applies to original material use, not replacements. It is difficult to predict what will happen to materials in today's buildings far into the future, but one can still arrange for reuse so that the probability of reuse increases. For materials with documented design for disassembly and reuse, we have assumed a future negative climate effect of 10% of the current production emissions for these materials (A1-A3). This value also includes technology development and time weighting.

Net exported on-site energy production substitutes a corresponding amount of energy from the grid and is deducted from D_{energy}. Emission factors for electricity and waste incineration in district heating, Table 2, are used in the calculation. Renewable electricity must be generated locally, i.e., be integrated into the building stock or on the site/property, but energy products used to generate renewable energy on-site can be produced elsewhere (e.g., biofuels). Renewable thermal energy can be generated on or off-site, but all losses should be considered. Renewable electricity generated on-site and delivered to the grid weighted equally to the imported energy, i.e., 1 kWh exported to the grid = 1 kWh imported from the grid. Exports of renewable heat can also be credited to the energy accounts but is limited so that exported renewable heat over the year cannot exceed annual imported heat.

4. **Conclusions**

This paper presents a method for calculating GHG emissions from buildings based on a simplified dynamic LCA method that considers several new aspects that have traditionally been excluded. It also presents new requirements for carbon emissions from buildings in Norway, that aim to help achieve national emission goals. The method introduces new concepts to the Norwegian building industry and LCA practice, such as technological weighting, the timing of emissions, biogenic carbon from wood products, carbon release from waste incineration of plastic and wood products, carbonation of cement products, and reusability in a circular economy. The framework is currently being tested in several construction projects in Norway. This will provide feedback from the construction industry upon the applicability of the method, regarding ease of use and the feasibility upon meeting emission targets.

Appendix

Table A1. FutureBuilt Zero criteria (shown in Figure 1), as well as maximum allowed emissions from materials and operational energy use. All criteria apply for the first year the building in operation, with unit [$kgCO_2e/m^2$].

	FutureBuilt Zero criteria	Maximum materials	Maximum energy
2020	449	287	207
2021	425	271	196
2022	401	256	185
2023	378	241	174
2024	354	226	163
2025	331	211	153
2026	307	196	142
2027	284	181	131
2028	260	166	120
2029	237	151	109
2030	213	136	98
2031	204	130	94
2032	195	125	90
2033	186	119	86
2034	177	113	82
2035	168	107	78
2036	159	102	73
2037	150	96	69
2038	141	90	65
2039	132	85	61
2040	123	79	57
2041	114	73	53
2042	105	67	49
2043	96	62	44
2044	87	56	40
2045	78	50	36
2046	70	44	32
2047	61	39	28
2048	52	33	24
2049	43	27	20
2050	34	21	16

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