Research Centre on
ZERO EMISSION
NEIGHBOURHOODS
IN SMART CITIES

GHG EMISSIONS ACCOUNTING

Recommendations for the methodology to follow in the zero emission neighbourhood definition

ZEN MEMO No. 57 – 2024

Camille Vandervaeren, Marianne Kjendseth Wiik, Kristin Fjellheim, Lilo Henke | SINTEF

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__A ZEN Memo__ is a summary of research done at the ZEN-center. The memo is not subjected to the same quality control as ZEN Reports | ***Et ZEN memo*** *er en oppsummering av forskning gjort ved ZEN-senteret. Memoet tilsvarer et notat og er ikke underlagt samme kvalitetskontroll som ZEN rapporter.*

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Preface

Acknowledgements

This memo has been written within the Research Centre on Zero Emission Neighbourhoods in Smart Cities (FME ZEN). The authors gratefully acknowledge the support from the Research Council of Norway, the Norwegian University of Science and Technology (NTNU), SINTEF, the municipalities of Oslo, Bergen, Trondheim, Bodø, Bærum, Elverum and Steinkjer, Trøndelag county, Norwegian Directorate for Public Construction and Property Management, Norwegian Water Resources and Energy Directorate, Norwegian Building Authority, ByBo, Elverum Tomteselskap, TOBB, Snøhetta, AFRY, Asplan Viak, Multiconsult, Civitas, FutureBuilt, Heidelberg Materials, Skanska, GK, NTE, Smart Grid Services Cluster, Statkraft Varme, Renewables Norway and Norsk Fjernvarme.

The Research Centre on Zero Emission Neighbourhoods (ZEN) in Smart Cities

The ZEN Research Centre develops solutions for future buildings and neighbourhoods with no greenhouse gas emissions and thereby contributes to a low carbon society.

Researchers, municipalities, industry and governmental organizations work together in the ZEN Research Centre in order to plan, develop and run neighbourhoods with zero greenhouse gas emissions. The ZEN Centre has nine pilot projects spread over all of Norway that encompass an area of more than 1 million m2 and more than 30 000 inhabitants in total.

In order to achieve its high ambitions, the Centre will, together with its partners:

- Develop neighbourhood design and planning instruments while integrating science-based knowledge on greenhouse gas emissions;
- Create new business models, roles, and services that address the lack of flexibility towards markets and catalyze the development of innovations for a broader public use; This includes studies of political instruments and market design;
- Create cost effective and resource and energy efficient buildings by developing low carbon technologies and construction systems based on lifecycle design strategies;
- Develop technologies and solutions for the design and operation of energy flexible neighbourhoods;
- Develop a decision-support tool for optimizing local energy systems and their interaction with the larger system;
- Create and manage a series of neighbourhood-scale living labs, which will act as innovation hubs and a testing ground for the solutions developed in the ZEN Research Centre. The pilot projects are Furuset in Oslo, Fornebu in Bærum, Sluppen and Campus NTNU in Trondheim, Mære Campus, Ydalir in Elverum, Campus Evenstad, Ny by-ny flyplass Bodø, and Zero Village Bergen.

The ZEN Research Centre will last eight years (2017-2024), and the budget is approximately NOK 380 million, funded by the Research Council of Norway, the research partners NTNU and SINTEF, and the user partners from the private and public sector. The Norwegian University of Science and Technology (NTNU) is the host and leads the Centre together with SINTEF.

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Abstract

The method for calculating greenhouse gas (GHG) emissions in zero emission neighbourhoods (ZEN) requires clarification on a set of methodological aspects. This is due to differing approaches in established methods, such as EN 15978, NS 3720, and FutureBuilt ZERO, as well as methodological considerations when changing the focus from building to neighbourhood level. The methodological aspects covered in this ZEN Memo relate to time-weighting, technological development, primary (neighbourhood site) land use and land use change (LULUC), and mobility. This Memo presents the advantages and drawbacks of some existing methods found in the literature for the four methodological aspects. One method is recommended for each aspect: NS 3720 with temporal presentation of the results (for time-weighting), NS 3720 (for technology-weighting), *Miljødirektoratet*'s Excel tool (for LULUC), and a combination of ZEN MOB KPI and NS 3720 (for mobility). Methodological aspects on how to estimate emissions from the use, generation and/or import/export of energy are covered in two other ZEN Memos and are summarised in Appendix of this Memo. GHG emission methodologies are under rapid development, which indicates that the comparisons and recommendations presented in this Memo might require a future revision.

Contents

Introduction

The method for calculating greenhouse gas (GHG) emissions in the zero emission neighbourhood (ZEN) definition requires clarification on a set of methodological aspects. This is due to differing approaches in established methods, such as the European standard for Life Cycle Assessment of buildings EN 15978 [1], the Norwegian standard for GHG emission calculation method for buildings NS 3720 [2], and FutureBuilt ZERO - a dynamic, Norwegian GHG emission calculation method for buildings [3], as well as methodological considerations when changing the focus from building to neighbourhood level. The methodological aspects covered in this memo are:

- time-weighting
- technology-weighting
- (primary) land use and land use change (LULUC)
- mobility

Methodological aspects on how to estimate emissions from the use, generation and/or import/export of energy are covered in ZEN Memo 52 and ZEN report 60 and summarised at the end of this memo.

There is also ongoing debate about the GHG emission calculation method for biogenic carbon and carbon uptake in cement-based products, and GHG emissions from secondary LULUC. For these aspects, we recommend the use of Environmental Product Declarations (EPDs) whenever available, or alternatively, the method outlined in EN 15804+A2 and in Product Category Rules (PCRs). We do not present alternative calculation methods in this Memo.

When different methodological solutions are possible for calculating GHG emissions, solutions are evaluated for the following criteria: physical reality (the solution that gives results that are closest to the materials and substances flows that physically occur) and simplicity (the calculation method provided by the solution is manageable and does not introduce excessive complexity for the assessor). If more than one solution meets these two criteria, then the recommended solution is the one that gives the largest incentive to reduce GHG emissions the quickest.

This memo presents the background and main issues for each methodological aspect and presents the advantages and disadvantages of each possible methodological solution. The recommended solution is highlighted in green. Readers should be familiar with LCA methodology terminology as presented in EN 15978 and NS 3720, including the definition of life cycle modules A, B, C, and D.

Calculation methods developed by FutureBuilt are mentioned several times throughout this memo. FutureBuilt is an innovation program supported by the municipalities of Oslo, Bærum, Asker, Drammen, Nordre Follo and Lillestrøm supporting and showcasing exemplary built solutions for sustainable and attractive zero-emission cities [4]. FutureBuilt, which is a part of the FME ZEN research centre, has developed the following methods with the support of some of the ZEN researchers:

- "FutureBuilt ZERO" for buildings [3]
- "FutureBuilt ZERO-T" for mobility [5]
- "FutureBuilt ZERO-L" for outdoor infrastructure (under development)

Methodological aspects not considered include GHG emission accounting of land use change in upstream production, biogenic carbon, and the carbonation of cement-based products since ZEN uses GHG emission data from Environmental Product Declarations (EPDs), for which there already exists established methods [6–8]. More details on the method for calculating GHG emissions in ZEN can be found in the latest ZEN definition report [9] and ZEN guidelines [10].

Time-weighting

Common practice for calculating Global Warming Potential (GWP) is to sum up all GHG emissions generated during the life cycle of a product or system (in this case a neighbourhood) and apply GWP factors developed by the Intergovernmental Panel on Climate Change (IPCC) to obtain GWP in carbon dioxide equivalents (CO_2e) [11]. These GWP factors are defined according to the cumulative radiative forcing (CRF) of an emission evaluated over a predefined time horizon, usually 100 years. This approach does not take into account the moment at which GHG emissions are emitted – a CO_2 emission occurring in 2025 will lead to the same contribution in GWP [11] as a CO_2 emission emitted in 2050, which can lead to a misunderstanding of GWP contribution of the neighbourhood at a particular time in the future [11]. Another issue is the inconsistency between the time horizon chosen for the analysis in a given LCA study and the time period covered by the results (which depends on when the GHG is emitted) [12]. Three different methods for time-weighting are presented, namely: NS 3720, NS 3720 with a temporal presentation of the results, and FutureBuilt Zero.

NS 3720

NS 3720 does not include any time-weighing of GWP impacts [2].

Pros (+):

- \+ Future emissions are affected by today's decisions. For example, choosing durable materials with long service lives that can be easily demounted and reused.
- \+ It is important to reduce emissions across the whole life cycle to meet climate goals in 2030.
- \+ No time-weighting is simple for practitioners to calculate.
- \+ NS 3720 is a widely used and accepted standard for calculating GHG emissions of buildings in the Norwegian construction industry.

Cons (-):

- Does not provide additional incentives to reduce early phase emissions.
- CO_2 emissions occurring in year 1 or year 30 will lead to the same GWP contribution.

NS 3720 with a temporal presentation of the results

This approach builds upon NS 3720 but includes a temporal presentation of GWP results for each year of the neighbourhood's reference study period during the use and end of life phases, as presented in Figure 1.

Pros (+):

- \+ Future emissions are affected by today's decisions. For example, choosing durable materials with long service lives that can be easily demounted and reused.
- \+ It is important to reduce emissions across the whole life cycle to meet climate goals in 2030.
- \+ Gives a more realistic view of the timing of environmental flows contributing to GWP, which can incentivise the reduction of early phase emissions.

Cons (-):

- CO_2 emissions occurring in year 1 or year 30 will lead to the same GWP contribution.
- Will require some additional effort to present the emission results years by year.

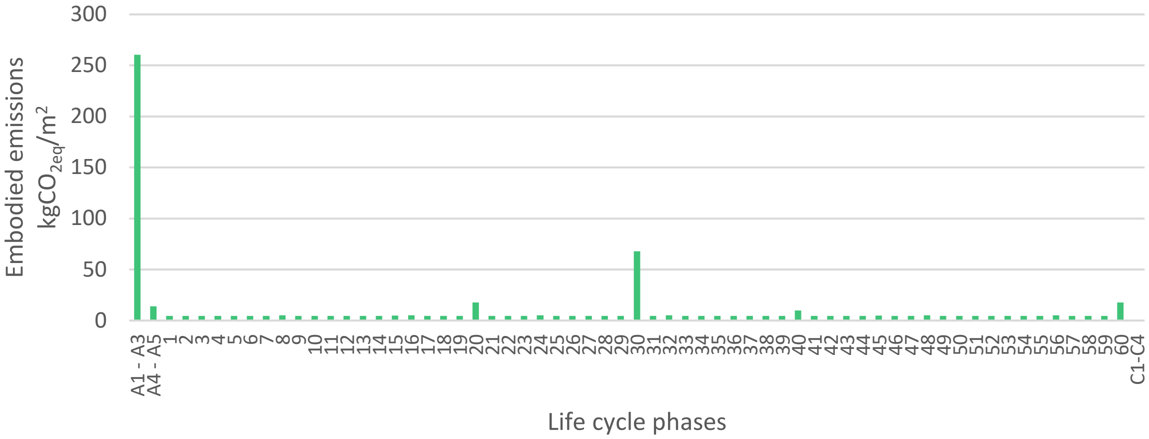

Figure 1. Embodied emissions of the Multikomfort house **[13]**, reported for modules A1-A3, A4-A5, B (per year of service life), and C1-C4.

FutureBuilt ZERO

FutureBuilt ZERO includes time-weighting of future emissions from life cycle modules B1, B4, B6, C, and D, and includes biogenic carbon of wood and wood-based products, and carbonation of cement and cement-based products in B1, see Figure 2 [3]. The justification for this time-weighting is that *"emissions that occur in the future will, from a 100-year perspective, have less time to heat the atmosphere than emissions that occur today"* [3]. In other words, today's emissions are considered to have a higher impact on climate change than future emissions.

$$\begin{aligned} E_{\text{tot}} &= E_{\text{A}_{1-3}} + E_{\text{A}_4} + E_{\text{A}_5} \\ &\quad + \underbrace{\underbrace{E_{\text{B}_{2-5}} + E_{\text{B}_6} + E_{\text{D}_{\text{energi}}} + E_{\text{B,C}_{\text{forbr.}}} + E_{\text{D}_{\text{ombruk}}}}_{\text{teknologivektes}} + E_{\text{B}_{\text{biog.}}} + E_{\text{B}_{\text{karb.}}}}_{\text{tidsvektes}} \end{aligned}$$

Figure 2. Formula to calculate total GHG emissions (E) in FutureBuilt ZERO, showing the emissions that are time-weighted and technology-weighted.

Pros (+)

+ More importance is placed on reducing today's emissions from the production and construction phase by scaling down future emissions, see ZEN Case FB Zero [14].

Cons (-)

- Gives an untrue picture of GHG emissions since the volume of future emissions is artificially reduced. Total emissions are 'less' than those estimated with conventional impact assessment methods [14]. The total emission balance could have been preserved if the downscaling of future emissions also included an upscaling of early phase emissions.

- The importance of long-term climate change mitigation goals (e.g., Paris Agreement) is reduced.
- Module D is time-weighted based on the argument that environmental flows in Module D occur only in the long-term, which is inaccurate. Module D accounts for benefits and loads outside of the system, including those which occur today, for instance through the export of own production of electricity or through reuse of overordered quantities during construction (A5).
- Carbon capture and storage (CCS) technologies are negatively impacted by time-weighting.

Recommendation

It is recommended to report ZEN GHG emissions according to **NS 3720 with a temporal presentation of the results**, since it does not artificially reduce the quantity of GHG emissions, is easy to understand and implement, and gives a more realistic view of the timing of environmental flows that contribute to GWP, which can incentivise the reduction of whole life cycle emissions. However, it is acknowledged that the temporal presentation of results at the neighbourhood level may be difficult to present year by year, especially when different contractors are responsible for different plot developments within an area over differing planning time horizons, in which case NS 3720 with no time-weighting should be considered.

Technology-weighting

Neighbourhoods have a relatively long service lifespan compared to other consumer goods. The GWP of future emissions may be lower than early phase emissions, due to technological development. Technological developments can include improved manufacturing processes, or the electrification of construction machinery, and will improve the future production of products and construction processes, which in turn consume less material and energy resources, and will have lower GHG emissions. The scope of technology-weighting is limited to the production, transport, and incineration of future material emissions. The evolution of energy is not considered in this memo, and the evolution of mobility in life cycle module B8 is presented in the section on "Mobility". Three different methods for technology-weighting are presented, namely: NS 3720, ZEB, and FutureBuilt Zero.

NS 3720

NS 3720 does not consider the effect of technological development on the production, transport, and incineration of materials [2].

Pros (+):

- \+ Simplifies the calculation of future GHG emissions.
- \+ Conservative approach since future emissions may not decrease for all types of products or for all countries or regions.

Cons (-):

- Future emissions relating to technological developments in material production and transport may be lower than current emissions, leading to an over-estimation of total emissions. This may in turn be considered as a positive since it will incentivise practitioners to also reduce future emissions.

ZEB

The Zero Emission Building (ZEB) GHG calculation method is a precursor to NS 3720 and does not consider any increase or decrease in future emissions from materials. The only exception is for PV modules, for which a 50% reduction in production impacts is assumed when the PV modules are replaced 30 years after installation [15].

Pros (+):

- + This is a common calculation approach for GHG emission calculations of ZEBs in Norway.

Cons (-):

- Incomplete method since it only considers the technological development of one material.
- Optimistic scenario, that could lead to underestimating future GHG emissions.

FutureBuilt ZERO

FutureBuilt ZERO considers technology-weighting and defines rules for the future emission intensity from material production: 1% annual reduction for all material types, of any origin (simplification based on historical development in Norwegian industry), except for photovoltaic (PV) solar cell systems, for which a 2/3 reduction after 30 years is assumed [3]. Similarly, the method assumes 1% annual reduction for the emissions related to transport of materials and waste incineration [3]. This assumption is based on a report from Enova [16] stating that the energy intensity (not the energy use or the GHG emissions) of the Norwegian territorial industry has reduced by 1% per year in average over the period 1990-2005. According to the report, energy use has been stable whilst production has increased. The average reduction of energy intensity in Norway is comparable to the European average.

Pros (+):

- + Considers the effect of technological development with a level of complexity lower than other methods such as prospective LCA.

Cons (-):

- The scenario for technological development considers that all production, transport, and incineration will be less impactful in the future based on average values for the Norwegian and European contexts that are over 15 years old. It could therefore lead to an underestimate of future GHG emissions, see Wiik et al. [17].
- For PV, it is an even more optimistic scenario than the recommended scenario in the ZEB calculation method, which has become a reference in the construction sector.
- The scenario does not distinguish between products of different origins.
- It considers the effects of technological development on the amount of GHG emitted for all types of emissions, not only for electricity generation.
- This is an optimistic approach since there is an assumption that technology will improve future GHG emissions.

Recommendation

It is recommended to report ZEN GHG emissions according to **NS 3720** since it does not overestimate GHG emission reduction from technological developments or add additional complexity to GHG emission calculations at the neighbourhood level, thus incentivising practitioners to reduce emissions today in a whole life cycle perspective.

Primary land use and land use change

Land use and land use change (LULUC) is an important aspect in the environmental assessment of neighbourhoods. Allacker et al. [18] distinguishes primary land use[1] "*for the land use surface transformed and occupied by the building itself*", and secondary land use as "*land transformation and occupation associated with the extraction of resources, production of building materials, heating and maintenance of buildings, and end-of-life (EOL) treatment of building products, including all necessary transport activities*" [18]. This section discusses primary land use since secondary land use is reported in EPDs following EN 15804+A2 under the "GWP-LULUC" indicator[2]. Seven different methods for LULUC are presented, namely: NS-EN 15978, prNS-EN 15978-1, ReCiPe, IMPACT 2002+, Eco-Indicator 99, ILCD handbook, the Norwegian Environment Agency's tool for considering the effects of land use change, Klimaeffektanalyseverktøy for kommuneplanens arealdel, and FutureBuilt ZERO-L. All listed methods have limitations in estimating GHG emissions from LULUC.

NS-EN 15978

According to NS-EN 15978, GHG emissions due to landscaping should be reported under life cycle module A5 [1]. However, there is no clear reference to land use or land use change. The standard is unclear whether the impact of primary land use should be accounted for in A5.

Pros (+):

+ Commonly accepted European standard.

Cons (-):

- Ambiguous on the inclusion of primary land use in A5.
- Does not provide a calculation method for the GHG emissions related to primary land use.

prNS-EN 15978-1

The proposed revision of the NS-EN 15978 outlined above (prNS-EN 15978-1) indicates that an optional environmental impact indicator "Land use related impacts/Soil quality" can be reported based on the *Potential soil quality index* (SQP - dimensionless) which may be included in the assessment where appropriate data is available. The preliminary standard provides guidance to assess land use and land use change *qualitatively*. Table 9 in the standard lists indicators that may be used to provide additional environmental information about the object assessment. The methodology is described in Annex E of the standard. For land use and land use change, the assessor can assess the degree of land consumption through a qualitative allocation to different scenarios following area zoning and land use plans. They can assess sealing and direct drainage into ground in terms of area (per m² or %). Effect on habitat can be reported per length (m), area (m²), or part of area (%) affected. Effect on biodiversity can be assess through the number of species and the percentage (%) of change. Local emissions to soil, outdoor air, and water can be measured according to the assessment methods of standards developed by CEN TC 351.

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[1] Primary land use encompasses land transformation (also called land use change) and land occupation in [18].

[2] In EN 15804+A2, GWP-LULUC "shall follow the latest PEF guidance document" and not include any "biomass-based net increase in carbon stocks, including carbon uptake". PEF guidance [19] does not provide a calculation method for LULUC but instead refers to the British standard PAS 2050 [20]. PAS 2050 refers to the method outlined in IPCC Guidelines for National Greenhouse Gas Inventories from 2006.

Pros (+):

- \+ Covers many different indicators under three areas: local land use and land use change, effect on local biodiversity, and local emissions to air, soil, and water.

Cons (-):

- \- The preliminary revision of the EN 15978 is not published yet and may be subject to change.
- \- No data is provided for emissions relating to land use change.
- \- Qualitative assessment.

ReCiPe

ReCiPe is an impact assessment method that considers the effects of both land use from the building footprint (referred to as primary land use) and land use in upstream production (referred to as secondary land use) [21, 22]. ReCiPe expresses total land use as the sum of "transformation from", "transformation to" and "occupation" impacts. Each impact assessment method has its own characterisation factors[3] for these three aspects. ReCiPe provides one method at a midpoint level and one at an endpoint level. At the midpoint level, three indicators are considered: Agricultural land occupation (ALO) in m^2/yr, Urban land occupation (ULO) in m^2/yr, and Natural land transformation (NLT) in m^2 [18]. At the endpoint level, ReCiPe considers Damage to ecosystem diversity (ED), given in species.yr or $PDF.m^2.yr$, Potential disappeared fraction (PDF) of species, and PDF.yr whereby yr equals the restoration time [18]. ReCipe does not consider the impact of land transformation from a non-natural to a non-natural land use and is based on global data.

Pros (+):

- \+ Commonly used impact assessment method.
- \+ Considers both land use (occupation) and land use change (transformation).

Cons (-):

- \- ReCiPe *"does not differentiate between land use conversions from a natural to a natural land use type such as transformation from forest to shrubland, nor from a non-natural to a non-natural land use type such as from agriculture to urban."* [18].
- \- Not based on country- or region-specific data.
- \- Separate environmental impact category not linked to GHG emissions.

IMPACT 2002+

IMPACT 2002+ [23] is an impact assessment method that only considers LULUC indicators at the endpoint level for Species diversity loss through Potentially disappeared fraction (PDF) per year per m^2.

Pros (+):

- \+ Commonly used impact assessment method.
- \+ Considers land use (occupation) [18].

Cons (-):

- \- Does not consider land transformation, which may influence the number of species in a given area, hence does not account for the consequences of building on a specific location [18].

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[3] Characterisation Factors are used to convert inventory data (e.g., 1 m^2 land use, urban) to impact (e.g., land use change). They are "a quantitative representation of the (relative) importance of a specific intervention" (https://lc-impact.eu/doc/deliverables/General_Structure_of_Life_Cycle_Impact_Assessment.pdf)

- Separate environmental impact category not linked to GHG emissions.

Eco-Indicator 99

Eco-Indicator 99 [24] is an impact assessment method that considers land use change, including from non-natural to non-natural uses.

Pros (+):

+ Commonly used impact assessment method.
+ More comprehensive than ReCiPe and IMPACT 2002+.
+ Considers land use (occupation).
+ Considers land use change (transformation).

Cons (-):

- Not based on local (specific) data.
- Separate environmental impact category not linked to GHG emissions.

ILCD handbook

The ILCD handbook states that "*direct land use and land transformation shall be inventoried along the needs of the applied LCIA method (if included in the impact assessment)*" [25]. It is ambiguous if the sentence includes the use of land by buildings and infrastructure or is only referring to the land use to produce the building materials. Yet, the handbook gives requirements to calculate emissions from land use and transformation. For soil organic carbon changes from land use and land use change, it refers to "*the use of the most recent IPCC CO_2 emission factors unless more accurate, specific data is available*" (similarly to the PAS 2050 method). "*For virgin forests and for soil, peat, etc. of all land uses shall be inventoried as "Carbon dioxide (fossil)". Emissions from biomass and litter of secondary forests shall be inventoried as "Carbon dioxide (biogenic)" ... Other emissions in result of land transformation (e.g. emissions from biomass burning, soil erosion etc.) should be measured or modelled for the given case or using authoritative sources*" [25]. Besides these rules, Annex B of the handbook presents a calculation method for CO_2 emissions from land transformation, by calculating the difference of the steady-state soil carbon content between the land use before and after transformation. This method considers four factors derived from the IPCC reports: native soil carbon stock, land use factor, management factor, and input level factor. The value of each factor can be read in tables given in the handbook, although the value for built areas is not explicitly given.

Pros (+):

+ Provides a GHG emission calculation method for land transformation, based on the IPCC reports.

Cons (-):

- The method is not explicitly for land use transformation towards built areas, but rather towards cropland, grassland, fallow, or natural forest.
- The ILCD handbook is from 2010.

Norwegian Environment Agency (Miljødirektoratet) Excel tool for considering the effects of land use change

The Norwegian Environment Agency provides an Excel calculation sheet for GHG fluctuations (CO_2, CH_4, N_2O) due to change in land use [26]. Users can choose between four land use types that are changed to a new land use type. There are six different land use types available. Land use change effect is calculated for a 20-year period, in line with UN guidelines, with the assumption that the soil carbon has stabilised after this period. There is an emission factor for the first year which is generally higher, and another factor for the next 19 years. Emission factors are based on municipal-level GHG accounts.

Pros (+):

- \+ Simple Excel sheet, no need to fill in a lot of data.
- \+ Clear description included in the Excel sheet.
- \+ Provides a link to a web-based map tool (*Kilden*) for calculating surface areas per area type if this information is not known.
- \+ Covers the whole country, not a specific municipality.

Cons (-):

- \- Based on generic values, does not account for local conditions (e.g., peatland/swamp depth).
- \- Not all area type conversions have emission values since they are based on measured emissions, and not all combinations have occurred or been measured in all municipalities (e.g., conversion from cropland to built up area is not available for Bergen municipality).

Klimaeffektanalyseverktøy for kommuneplanens arealdel

SINTEF and CICERO have developed a climate assessment tool for Oslo plan, bygg og eiendom (PBE), with the goal of assessing the potential emissions from changes to local regional plans [27]. The tool estimates and assesses emissions from several aspects of changes to development plans, including buildings and infrastructure, land use change, and mobility. The tool models land use change for predefined development areas within Oslo, with pre-assessed land use categorisation at the level of the AR5 map, a national map developed by NIBIO and that describes land resources based on the production base for agriculture and forestry. Land use change (from one category to another) for user-defined areas (m^2) within each predefined development area is modelled using an automated approach to land use change from the Norwegian Environment Agency, noted above.

Pros (+):

- \+ Consistency: uses the Miljødirektoratet's land use change values.
- \+ Automated and simplified: land areas and emissions from land use change are calculated in the background.

Cons (-):

- \- Requires a set of predefined areas and pre-assessed land use categories.
- \- Based on generic values, does not account for local conditions (e.g., peatland/swamp depth).
- \- Not all area type conversions have emission values since they are based on measured emissions, and not all combinations have occurred or been measured in all municipalities (e.g., conversion from cropland to built up area is not available for Bergen municipality).
- \- Specific to the Oslo region.

FutureBuilt ZERO-L

FutureBuilt has recently published a preliminary method for calculating GHG emissions from outdoor infrastructure [28]. This includes parks, squares, sports facilities, roof gardens, walkways, cycle paths, and access roads within the specified area, but not municipal roads or buildings and corresponds to building parts 71-79 in NS 3451. Some aspects are excluded from the list due to lack of emission data availability. Rooftop gardens are only considered if they are constructed on existing rooftops. If the rooftop garden is part of a new building, then it should be included in the building's GHG emission calculations according to FutureBuilt ZERO method. Biogenic carbon from land use change is considered in modules A5 (removal of existing biomass) and B1. For the latter, the theoretical GHG uptake/emissions of the original landscape must be considered for the full 60 years, as well as emissions/uptake of the new landscape due to the change, which is calculated over years 1 - 19 in line with Miljødirektoratet's guidelines. The GHG impact of new plants and crops are included for production, construction and use phases (including replacements)[4]. The method still under development at the time of preparing this Memo.

Pros (+):

+ Considers emissions from land use change in life cycle module A5 as demolition of existing landscape.

Cons (-):

- Lack of data especially for vegetation, and many life cycle stages may be excluded.
- High dependence on generalised reference values which may differ substantially from actual emissions.
- Not in line with EN 15804+A2 since ZERO-L includes emissions/uptake from biomass and soil (in EN 15804+A2, biomass-based net increase in carbon stocks, including carbon uptake, should not be considered in GWP-LULUC and is set to zero).
- Requires additional documentation and data collection.

Recommendation

It is recommended to report direct LULUC emissions according to **the Norwegian Environment Agency (Miljødirektoratet) Excel tool for considering the effects of land use change** in life cycle module A5 under groundworks and landscaping as presented in NS 3720, although the authors acknowledge the limitations of this tool (i.e., generic values, limited land use change scenarios). GWP-LULUC and GWP-biogenic should be reported separately to total GHG emissions in the ZEN definition.

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[4] Asplan Viak, 'FutureBuilt ZERO-L – kriterier for klimagassberegninger for landskap V01', last updated 30 April 2022

Mobility

This section presents five methods to calculate the mobility of people, goods, and services within, to and from a zero-emission neighbourhood. Mobility habits of users are likely to change over the whole life cycle of a neighbourhood. This section includes both present and future impacts of mobility and considers the change in transport need, transport mode, and technological developments of vehicles.

NS 3720

NS 3720 includes operational transport use in life cycle module B8. The calculation method is based on NS-EN 16258 and is calculated for one year of operation. It includes the sum of whole life cycle GHG emissions from private cars, public transport, goods transport, and waste transport. Active forms of transport (cycling and walking) are excluded. Data on trip production can be gathered from the national travel habit survey (NRVU), transport models (RTM), or specific data gathered from the neighbourhood users. Calculations shall include a scenario that reflects technological evolution of the vehicle fleet. Appendix B and C in the standard includes estimates of average journeys according to different building typologies, and emission factors for different private vehicles, respectively.

Pros (+):

- \+ Widely used and accepted standard in the Norwegian construction industry for GHG emission calculations of buildings, see Lausselet et al. [29].
- \+ Based on the standard NS-EN 16258.

Cons (-):

- \- Does not specify emission factors for public transport, goods transport, or waste transport.
- \- Does not specify how scenarios are to be calculated for technological evolution of the vehicle fleet.
- \- The system boundary for trip production is unclear e.g., one-way trips, round trips, and/or trips within the neighbourhood.

FutureBuilt ZERO-T

FutureBuilt ZERO-T [5] only covers daily trip production shorter than 100 km, because of lack of data for estimating long journeys. Transport need data is based on the PROSAM report 242, which covers travel habits in Oslo and Viken based on the NRVU 2018/2019. Emission factors for passenger cars (fossil and electricity), buses (fossil and electricity), and rail (subway and train, only electricity) -for years close to 2022-are taken from various sources and are used as a starting point for projecting emissions throughout the building's lifetime. Other transport modelling tools can be used if they follow the requirements described on page 10 of the FutureBuilt Zero-T report. The method includes technological evolution of the vehicle fleet based on projections from TØI [30] and Ruter [31]. It assumes an annual emission reduction of 0.5% for fossil vehicles, and a 2.5% annual emission reduction for electric vehicles, including emissions from production of vehicle and infrastructure, and operation (emissions for electricity production are considered close to zero in 2050). The time-weighting of emissions described in FutureBuilt ZERO applies. The number of passengers per vehicle is considered constant.

Pros (+):

- \+ Provides an estimation of the evolution of mobility-related emissions for short trip production.
- \+ Includes the evolution of emissions due to electricity production.

Cons (-):

- Excludes long trip production over 100 km.
- Is linked to the FutureBuilt ZERO method of time-weighting emissions, which diminishes the relevance of long-term emission reduction. If the time-weighting method in FutureBuilt ZERO is not selected for ZEN GHG emission calculation, selecting FutureBuilt ZERO-T could lead to methodological inconsistency.

EE Settlement

The EE Settlement tool assesses the energy and emission implications of developing new settlements. The tool includes changes to mobility patterns resulting from new developments by using a mobility simulation tool (MST). EE Settlement is not a tool dedicated to mobility but includes some specific aspects of mobility (i.e., GHG emissions occurring within the city boundaries). The MST estimates transport mode probabilities and generated vehicle kilometres (vkm) using multivariate and logistic regression methods and calculates associated energy consumption and GHG emissions from those estimates [32]. Technological development is expressed as changes in both the vehicle fleet composition as well as vehicle age, weight, and drivetrains [30]. Generated travel estimates are based on survey data from NRVU in 2013 [33].

Pros (+):

+ Specific to Norway.
+ The method calculates generated travel and associated emissions from the new settlement based on population.
+ Transparent method, calculations are explained in the report [32].
+ Ability for the user to adjust some specific assumptions and values.

Cons (-):

- Altering values from technological change must be calculated (averaged over the study period) and changed by the user of the tool. Some changes require administrator rights.
- Electric vehicle emissions are assumed to be zero, and not calculated according to NS 3720.
- NRVU data is from 2013/14.
- The travel model has a high level of variance (R^2) ($R^2 = 0.1$ for predicted travel distance and R^2 between 0.10 to 0.27 for different mode probabilities).
- Shared e-scooters are not included in mode choice predictions, as the tool focuses on GHG emissions within the city boundaries.
- Not adaptable for a specific municipality.

Klimaeffektanalyseverktøy for kommuneplanens arealdel

Mobility demand is modelled using a custom run Regional Transport Model (RTM23+) commissioned by the user and then input by the user into the model. The results are converted to GHG emissions using detailed (unpublished) background data used to create a reference path for Oslo [34]. The reference path for vehicles includes technological development expressed as vehicle choice, fuel type, and resulting emissions to 2030, specifically for Oslo, as Oslo has different ambitions and expectations than the national average [34]. If the user chooses a longer assessment period, the reference path values are extrapolated beyond 2030 to fit the model (up to 2050). *Klimaeffektanalyseverktøy* is not a tool dedicated to mobility but includes some specific aspects of mobility as defined by the project (i.e., GHG emissions occurring within the city boundaries). Therefore, electric vehicles have zero emissions.

Pros (+):

+ RTM can be run for other municipalities[5], but this will require additional work.

Cons (-):

- Specific to Oslo.
- Only covers direct emissions from mobility.
- Requires a set of predefined areas.
- Requires access to the Regional Transport Model, which can be expensive.
- Detailed reference path data is not publicly available.
- RTM does not include micro-mobility, such as e-scooters or e-bikes.

CICERO's estimation for GHG emission of transport in Oslo until 2030

CICERO's report shows the estimated evolution of GHG emissions of different means of transport in Oslo until 2030 [34]. It is not a GHG accounting method but could be used as background data.

Pros (+):

+ Considers 220 different categories of vehicles.

Cons (-):

- Figure 7 in CICERO's report only shows the total GHG emission evolution in Oslo. The background data is not published.
- Specific to Oslo.

Recommendation

It is recommended to use **NS 3720** method to calculate the GHG emissions from mobility in ZEN GHG KPI 1.5 and life cycle module B8 at the whole neighbourhood level (both for mobility needs and for emission factors), because it is simple to use and based on the European standard, and it does not have the drawbacks of the other methods. In the ZEN definition, the scope of trip production is limited to residents, and is not calculated according to building function. Trip production is allocated 100% to the residents.

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[5] The RTM has been run for Trondheim, see https://s3.eu-west-1.amazonaws.com/rr-urbanet/Filer-Dokumenter/UA-rapport-108_2020_RTM_AIMSUN.pdf

Conclusion

The methodological choices suggested for the ZEN GHG emission calculation method are summarised in Table 1. GHG emission methodology is under rapid development. Updates and changes to these methodological choices may need to be revised in the future. Further work will include harmonising methodological choices and emission factors for energy use in the operational phase and consider technological evolution of energy-related emission factors.

Table 1. Summary of recommended methodological choices.

Methodological aspect	**Recommendation**
Time-weighting	NS 3720 with a temporal presentation of the results.
Technology-weighting	NS 3720.
Primary land use and land use change	*Miljødirektoratet*'s Excel tool for considering the effects of land use change. GWP-LULUC and GWP-biogenic should be reported separately to total GHG emissions in the ZEN definition.
Mobility	NS 3720.

A Emission factors for electricity

A separate ZEN memo, ZEN memo 52, presents the recommended method to allocate the GHG emissions from the consumption, production and exchange of electricity in connection with the ZEN areas: "*Regneregler for utslipp knyttet til strøm - Prinsipper og regler for allokering av klimagassutslipp til strømforbruk og kompensasjon fra strømproduksjon i ZEN*". These principles and rules are summarised[6] below.

The authors have compared the five following methods:

1. Method 1 - Emission savings allocated to the operational electricity use (in line with ISO Net Zero Guidelines)
    a. Variant 1.a) "Consistent"
    b. Variant 1.b) "Pragmatic"
2. Method 2.a) Emission savings based on improvement from a reference case
    a. Variant 2.a) "Consistent"
    b. Variant 2.b) "Pragmatic"
3. ZEN-a) Allocation of emissions from net imports: Fixed reference year for average mix
4. ZEN-b) Allocation of emissions from net imports: Running average mix
5. ZEN-c) Allocation of emissions from net imports: Running average mix adjusted for other ZEN

The aspects they have analysed in the different methods are:

- Does the method lead to double counting of emission savings?
- Are there any barriers to the practical use of the method?
- Is it possible to combine the method with emission accounting and compensation for other parts of the ZEN than electricity use (district heating, materials etc)?
- Is it in line with the principles laid out in ISO IWA 42:2022 Net Zero Guidelines?
- Does it give an incentive to reduce electricity consumption?
- Does it give an incentive to utilize local renewable energy?

For the FME ZEN definition, they recommend the use of the fifth method, ZEN-c), a method that they developed and tested in the work underlying the report.

The ZEN-a) method corresponds to using emission factors from a historical reference year for the import and export of electricity in the future and is found not practical, nor consistent. The ZEN-b) method is in line with the practice of the former research centre FME ZEB and the current standard for greenhouse gas calculations from building NS3720, but they find that the ZEN-b) method could lead to double counting the emission savings from the local production of electricity from PVs in ZEN area. The new ZEN-c) method avoids possible double counting of emissions savings, which is particularly relevant when new ZEN areas are developed and excess PV electricity for the ZEN is added to the grid. In the new ZEN-c) method, the emission factors for electricity are calculated as a running average of the electricity mix for remaining electricity from fossil energy sources in the power grid, which is the part of electricity production that is going to be phased out. Nevertheless, the authors point out some questions to be answered before this method can be used in practice:

- Which energy sources should be extracted from the electricity mix, in order to find a representative fossil residual mix, and how should one quantify this mix?

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[6] The text in this section is heavily based on the translation from Norwegian to English of the Executive summary of the ZEN memo (under preparation) *Regneregler for utslipp knyttet til strøm* written by Magnus Korpås (NTNU), Ove Wolfgang (SINTEF Energi), and Helge Brattebø (NTNU).

- Should the electricity mix be adjusted with regard to so-called Power Purchase Agreement (PPA) and other contracted electricity delivery?
- Can the emission factors from the residual mix be calculated in a simplified way, based on marginal emissions (e.g., natural gas)?

Nevertheless, they recommend that Method 1.b), which aligns with ISO IWA 42:2022 Net Zero Guidelines, is tested and developed further, preferably in one of the ZEN pilots. This way, ZEN areas can be better prepared to a future revision of NS 3720, in case the revised standard aligns with the approach followed in ISO 2022 Net Zero Guidelines, which state that a state of net zero emissions cannot be achieved through compensation of avoided emissions, only by directly reducing GHG emissions inside the system or organization within its boundaries and by counterbalancing residual emissions through investments in high-quality removals.

Similarly, they recommend that Method 2 is further tested and developed in an R&D context, but not considered for the ZEN definition. This method does not follow the ISO IWA 42 Guidelines. The emissions savings are calculated by comparing the situation to a defined reference case. This method can in practice lead to the same result as the variants ZEN-a), -b), and -c), but the calculation is set up in a different way. The method is based on a logical and academically well-founded principle that is used in many contexts, and especially in economics. In a practical ZEN context, however, it will require many changes, as you then must calculate climate measures from a reference point in time instead of calculating energy exchange with the overlying system. The method may also risk being replaced if the intentions of the ISO Net Zero Guidelines are introduced in new standards in the future.

Table A.1 summarizes what they believe to be the basic characteristics of each of the 5 methods for emission calculations for ZEN areas, in regard to how they perform on the comparison principles (first column). Further explanations on this comparison can be found in the ZEN memo.

Table A.1. Comparison of the five methods for GHG emissions calculation for electricity use, import and export.

	Method 1 Emission savings allocated to the operational electricity use		**Method 2** Emission savings based on improvement from reference		**ZEN-a** Allocation of emissions from net imports	**ZEN-b** Allocation of emissions from net imports	**ZEN-c** Allocation of emissions from net imports
	a) Consistent	b) Pragmatic	a) Consistent	b) Pragmatic	a) Fixed reference year for average mix	b) «Extended ZEB» - Running average mix	c) Running average mix adjusted for other ZEN
Double counting	No	Avoided with a fixed reference year	No	No	No	Ja	No
Practical challenges	Current CO_2e-intensity in the system must be adjusted continuously	Must determine reference year for CO_2e-intensity in the system to avoid double counting	Reference emissions must be calculated	Reference emissions must be calculated	Must determine reference year for CO_2e-intensity in the system	None	Current CO_2e-intensity in the system must be adjusted continuously
Possible to compensate other emissions	No	No	Yes	Yes	Yes	Yes	Yes
In line with the ISO IWA 42:2022	Yes	Yes	No	No	No	No	No
Incentive to save energy	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Incentive to produce renewable energy	Yes, until net zero energy	Yes, until net zero energy	Yes	Yes	Yes	Yes	Yes
Emission factors	Import: Running average based on residual mix Export: 0	Import: Average from reference year Export: 0	Based on emissions from non-renewable sources in reference year	Average emission factors from reference year	Average emission factors from reference year	Current average	Running average adjusted for other ZEN areas (Residual mix)

B Emission factors for waste to energy processes

When waste is incinerated with energy recovery, the environmental burdens and savings must be allocated among the different processes, waste treatment and energy production. TheZEN report 60, presents recommendations to allocate the GHG emissions from the incineration of waste with energy recovery: "*Allokering av klimagassutslipp fra avfallsforbrenning med energigjenvinning i livsløpsanalyser*". These recommendations are summarised[7] below.

The authors have analysed the current allocation methodology used for zero emission areas and compared it to other allocations methods found in the scientific literature (Table B.1). The allocation methods are typically characterized by two factors depending in the fate of materials at end-of-life (recycling or energy recovery): factors A and B, which represent the part of environmental impacts that are respectively allocated to the life cycles that use recycled materials and that use recovered energy. In previous versions of the ZEN-methodology, the historical default values were A=0 and B=0, i.e., all environmental impacts were allocated to the life cycle producing waste. The report primarily focuses on allocation for waste-to-energy, offering recommendations for choosing factor B, but not for factor A.

Table B. 2 Allocation methods for waste incineration with energy recovery compared in the ZEN report, with chosen abbreviation and references.

Allocation method	Abbreviation	Reference
100 % to waste treatment	B=0	Product Category Rules – Electricity, Steam and Hot/Cold Water Generation and Distribution, NS 3720 – Metode for klimagassberegninger for bygninger, EN 15804 – Sustainability of construction works, Zero Emission Neighbourhoods, Ecoinvent (cut-off models), Klimapartnere, Norsk Energi, Sandberg et al. (2021), Sandberg et al. (2019), Lausselet et al. (2022), Næss et al. (2018), Resch et al. (2023)
50-50% allocation	B=0,5 (50-50)	FutureBuilt, Lausselet et al. (2022), Ekvall (2000), Resch et al. (2023)
Economic allocation (based on relative earnings of waste treatment and energy sales)	EA	Waste Sweden, Ekvall et al. (2021), Helseth (2022)
100 % to energy production	B=1	Intergovernmental Panel on Climate Change – Guidelines for National Greenhouse Gas Inventories, The Greenhouse Gas Protocol, Miljöbyggnad (Sverige), Värmemarknadskommittén (Sverige), Lausselet et al. (2022)
Economic price elasticity	PE	Ekvall (2000)
Allocation at Point of Substitution	APOS	Ecoinvent
Circular Footprint Formula (100% to waste treatment)	CFF	Product Environmental Footprints, Ekvall et al. (2021)
Economic price-based substitution	EPS	Schrijvers et al. (2016)

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[7] The text in this section is heavily based on the translation from Norwegian to English of selected parts of the 2024 ZEN report *Allokering av klimagassutslipp fra avfallsforbrenning med energigjenvinning i livsløpsanalyser* written by Jan Sandstad Næss (NTNU), Kim Rainer Mattson (NTNU), Bapitste Giroux (NTNU), Ida Rustad (NTNU), Helge Brattebø (NTNU) and Edgar Hertwich (NTNU).

The authors have used system expansion with substitution, according to LCA theory, to evaluate alternative waste treatments. The effects of different allocation methods are analysed through calculation examples from the perspective of both the producer of waste and the designer of energy systems for building energy consumption. The authors have analyzed how, on a scale from 1 (lowest performance) to 5 (best performance), the identified allocation methods (listed in Table B.1) perform on ten criteria from Ekvall [35] and Ekvall et al. [36]:

1. **Simplicity**: The method is simple to use.
2. **Data availability:** The data required for the use of the allocation method is available.
3. **Generalizability**: The results can be generalized for different cases.
4. **Environmental coherence**: The method gives incentives to design choices that are generally considered environmentally responsible. The method differentiates between primary and secondary material use, between recycling, energy recovery and disposal, between how recovered resources are utilized and between material types and quality.
5. **Life cycle scope**: The method covers the whole life cycle of the materials in a way that double counting is avoided.
6. **Explicitness**: The allocation method is clearly documented (for example, in a standard), justified and evaluated (by sensitivity analyses or scenario analyses).
7. **Clarity**: The method is documented in such a way that its mathematical basis can be easily understood by target users through clear structure and terminology.
8. **Relevant for decision-makers**: The method is adapted to the knowledge needs of decision makers, and they can use the method and change key parameters to calculate environmental impacts.
9. **Legitimacy**: The method is seen by users as well-founded and fair.
10. **Reproducibility**: The method's calculation process is inflexible enough to avoid misuse, hence ensuring reproducibility of the results.

In addition, the authors checked five additional criteria specific to methodology for zero emission areas (yes/no/not proven):

i) The allocation method ensures that a joint production that creates a smaller environmental impact than a separate production of the same products or services is not allocated greater environmental impacts than the separate production.
ii) The allocation method avoids the risk of waste heat not being recovered and used.
iii) The allocation method contributes to increased incentives for energy efficiency beyond incentives given from peak loads in the energy mix for district heating.
iv) The allocation method can be used in the methodology for zero emission areas in module B6 – energy use in operation.
v) The allocation method can be used in the methodology for zero emission neighbourhoods for waste produced across modules A-C and D.

The results of the comparative qualitative evaluation of the allocation methods are shown in Table B.2 and Table B.3. It offers an overview of potential benefits and drawbacks of different allocation methods. Scores should not be aggregated to mean values as different criteria should not be weighted equally.

Table B. 3 Performance of the compared allocation methods on the 10 criteria, from 1 (low compliance to the criteria) to 5 (high compliance to the criteria).

Criteria	B=0	B=0.5 (50-50)	EA	B=1	PE	APOS	CFF	EPS
Simplicity	5	5	4	5	1	1	3	1
Data availability	5	5	4	5	1	1	2	1
Generalizability	5	5	5	5	5	5	5	5
Environmental coherence	3	2	2	1	5	3	4	5
Life cycle scope	5	5	5	5	5	5	5	5
Explicitness	5	5	5	5	2	5	5	3
Clarity	5	5	5	5	1	1	3	1
Relevant for decision-makers	4	5	5	3	5	5	5	5
Legitimacy	3	4	4	2	4	3	4	5
Reproducibility	5	5	4	5	3	2	3	1

Table B. 4 Compliance of the compared allocation methods to the 5 additional criteria relevant for the use of the method in the ZEN context. "?*" means that it is not known how the method complies with the criteria.

Criteria	B=0	B=0.5 (50-50)	EA	B=1	PE	APOS	CFF	EPS
i) Allocates less emissions to beneficial co-production than to competing separate production	Yes	No	No	No	?*	?*	Yes	?*
ii) Avoids the risk of waste heat not being used	Yes	No	No	No	?*	?*	Yes	?*
iii) Contributes to increased incentives for energy efficiency beyond peak loads reduction incentives	No	Yes	Yes	Yes	?*	?*	No	Yes
iv) Can be used in Module B6	Yes	Yes	Yes	Yes	No	Yes	Yes	No
v) Can be used for waste produced across modules A-C and D	Yes	Yes	Yes	Yes	No	No	Yes	Yes

The authors recommend that the factor is set to B=0, thereby allocating all emissions from burning waste to the life cycle that produced the waste. The recommendation ensures the competitiveness of energy recovery as an environmentally beneficial joint production relative to separate production. Allocating all environmental impacts to the waste treatment will reduce the risk of a waste producer sending fossil plastics for incineration instead of recycling. B=0 will also lead to a low emission intensity in district heating grids that rely on waste incineration with energy recovery. However, this can also weaken the incentives for advanced energy efficiency investments in buildings. If B=0 is used, energy efficiency measures in buildings should be motivated through supplementary usage of other indicators. In the ZEN-framework, this is done through a set of key performance indicators that includes both greenhouse gases and energy use that should be used in parallel. If construction projects are evaluated through other LCA frameworks that lack indicators for energy use, the authors acknowledge that other values for B can be chosen that differs from their B=0 recommendation. In such cases, the choice must be justified based on the goal of the LCA and be thoroughly evaluated through both quantitative and qualitative analysis.

In the future, greenhouse gas emissions from waste incineration must be eliminated, likely both through increased circularity measures and carbon capture and storage deployment. It is vital to evaluate the environmental consequences of waste incineration with energy recovery from different viewpoints and across life cycles to enhance environmental performance.

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