Research Centre on
ZERO EMISSION
NEIGHBOURHOODS
IN SMART CITIES

NTNU SINTEF

ZERO EMISSION NEIGHBOURHOODS IN SMART CITIES

Definition, assessment criteria and key performance indicators: Version 4.0. English

ZEN REPORT No. 45 - 2022

SINTEF | NTNU

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ZEN Report No. 45

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Zero Emission Neighbourhoods in Smart Cities

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Preface

Acknowledgements

This report has been written within the Research Centre on Zero Emission Neighbourhoods in Smart Cities (ZEN Research Centre). 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, Tegn_3 , Asplan Viak, Multiconsult, Sweco, Civitas, FutureBuilt, Hunton, Moelven, Norcem, Skanska, GK, Caverion, Nord-Trøndelag Elektrisitetsverk (NTE), Smart Grid Services Cluster, Statkraft Varme, Energy Norway and Norsk Fjernvarme.

The Research Centre on Zero Emission Neighbourhoods 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 to plan, develop and run neighbourhoods with net 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 m^2 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.
- Catalyse the development of innovations for a broader public use, including 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, Kunnskapsaksen Sluppen and Kunnskapsaksen Campus NTNU in Trondheim, Mære landbruksskole in Steinkjer, Ydalir in Elverum, Campus Evenstad in Hedemark, NyBy Flyplass in Bodø, and Zero Village in 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.

https://fmezen.no
@ZENcentre
FME ZEN (page)

The editors would like to thank all practitioners and researchers for their contributions. The list below gives an overview of participants in the ZEN definition expert category groups that have contributed to the definition work:

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Urban form and land use: Tobias Nordström (NTNU), Lillian Sve Rokseth (SINTEF), Daniela Baer (SINTEF), Judith Thomsen (SINTEF), Lars Arne Bø (SINTEF), Bendik Manum (NTNU), Johannes Brozovsky (NTNU) and Peter Schön (NTNU).

Document history

Version	Date	Version description
Version 1.0	2018	The first version of this document outlined the central definition, key performance indicators (KPI) and assessment criteria used in the Research Centre on Zero Emission Neighbourhoods in Smart Cities (ZEN research centre). The seven ZEN categories (GHG emission, energy, power, mobility, spatial qualities, economy and innovation) and their related KPIs were described.
Version 2.0	2021	The second version (version 2.0) of the Zero Emission Neighbourhood (ZEN) definition builds upon v1.0 of the ZEN definition report. The ZEN categories GHG emission, energy and power have been updated after the KPIs have been tested in different pilot projects. There is also a new chapter (chapter 5) on the ZEN KPI tool and framework. The ZEN categories mobility, spatial qualities, economy and innovation are only partly updated in this version.
Version 3.0	2022	This third version (version 3.0) of the Zero Emission Neighbourhood (ZEN) definition builds upon the two previous versions of the ZEN definition report. The GHG emissions (GHG), energy (ENE) and power (POW) categories have been further developed and refined through empirical research and iterative testing in the ZEN pilot areas. Table 2: ZEN assessment criteria and Key Performance Indicators (KPIs) has been revised. Revision of mobility (MOB), economy (ECO), spatial qualities (QUA) and innovation (INN) categories has been performed. Innovation no longer contains ZEN assessment criteria or KPIs but is an important process that will be explored in subsequent versions of the ZEN definition report. The report is now split into an English version (EN) and a Norwegian version (NO).
Version 4.0	2022	This fourth version (version 4.0) of the Zero Emission Neighbourhood (ZEN) definition report builds upon the three previous versions of the ZEN definition report and the third version of the ZEN definition guideline report. This report gives details on the ZEN definition framework. A major change involves lifting the process KPIs out of spatial qualities and incorporating them into a process guideline for designing ZENs. Additional power KPIs have been added. The spatial qualities category has been renamed to urban form and land use, and additional KPIs have been added. This report has been shortened to give a synopsis of the ZEN definition and important definitions relating to the ZEN definition framework. Further details on ZEN KPIs can be found in the ZEN definition guideline report version 3.0.

Abstract

This document outlines the definition, key performance indicators (KPI) and assessment criteria for the Research Centre on Zero Emission Neighbourhoods in Smart Cities (ZEN research centre). This fourth version of the ZEN definition builds upon previous versions of the ZEN definition report and the third version of the ZEN definition guideline report. This report gives details on the ZEN definition framework. A major change involves lifting the process KPIs out of spatial qualities and incorporating them into a process guideline for designing ZENs. Additional power KPIs have been added. The spatial qualities category has been renamed to urban form and land use, and additional KPIs have been added. This report has been shortened to give a synopsis of the ZEN definition and important definitions relating to the ZEN definition framework. Further details on ZEN KPIs can be found in the ZEN definition guideline report version 3.0. Over 100 people involved in the ZEN research centre have contributed to this document.

Contents

1 Introduction

The goal of the Research Centre on Zero Emission Neighbourhoods in Smart Cities (FME ZEN Research Centre) is to enable the transition to a low carbon society by developing sustainable neighbourhoods with zero greenhouse gas (GHG) emissions. To reach this goal, there is a need for the following:

1. A clear ZEN definition
2. Assessment criteria and key performance indicators (KPIs), which will help to plan and implement the neighbourhood and to monitor its actual performance,
3. A ZEN KPI assessment tool to monitor the performance of a new and/or existing neighbourhoods with different ambition levels,
4. A guideline for how the definition of ZEN and its KPIs can be assessed and implemented into the planning, implementation, and operational phases of new and/or existing neighbourhoods
5. ZEN pilot projects to validate the ZEN definition through testing and implementation

The ZEN research centre is organised into six work packages (WP), see Figure 1. The ZEN definition, categories, assessment criteria and KPIs are developed in WP1 and are published in this series of reports (1–3). The definition work is an ongoing process throughout the programme period (2017-2024). The aim of the ZEN definition guideline developed under WP6 is to describe how the KPIs can be implemented in the various ZEN pilot projects. This is an iterative process whereby the KPIs will be continually tested and further developed through the ZEN pilot projects and the results of which will be fed back into the development of the ZEN definition, assessment criteria and KPIs in WP1.

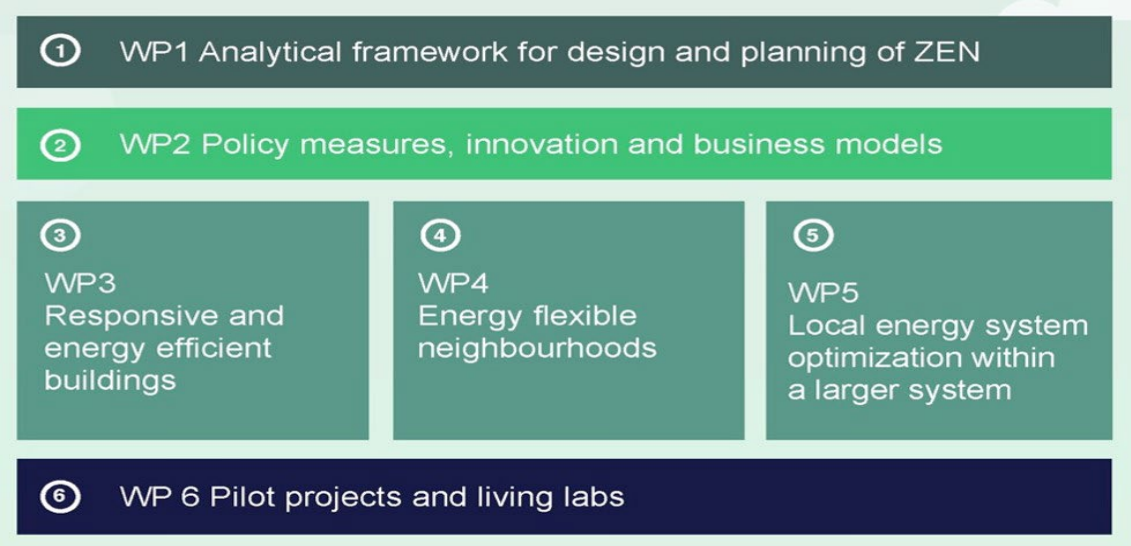

Figure 1. Work packages within the FME ZEN research centre.

2 Definitions

2.1 ZEN definition

The following ZEN definition serves as an overarching guiding principle for the whole ZEN project and its pilot areas (4). The definition is based on previous projects and existing assessment frameworks (such as the ZEB research centre, PI-SEC, SCC, PEB, BREEAM communities and CITYkeys) as well as input from ZEN researchers and partners through numerous discussions and workshops.

In the ZEN research centre, a neighbourhood is defined as a group of interconnected buildings with associated infrastructure [1)], located within a confined geographical area [2)]. A net **zero emission neighbourhood** aims to reduce and compensate its direct and indirect **greenhouse gas (GHG) emissions** towards zero over the analysis period, in line with a **chosen ambition level**. The neighbourhood should focus the following:

a. Plan, design and operate buildings and associated infrastructure towards minimized life cycle **GHG emissions** and compensating remaining GHG emissions to obtain a net zero emission neighbourhood.
b. Become highly **energy efficient** and powered by a high share of new **renewable energy**.
c. Manage energy flows (within and between buildings) and exchanges with the surrounding energy system in a **flexible** way.
d. Promote **sustainable transport** patterns and smart mobility systems.
e. Plan, design and operate with respect to **economic sustainability**, by minimising total life cycle costs to achieve affordable zero emission neighbourhoods and choose cost optimal GHG emission reduction strategies.
f. Plan and locate amenities in the neighbourhood to provide good **urban form and land use** and stimulate **sustainable behaviour**.

The ZEN definition is intrinsically scalable, but should always be adapted to its local spatial, economic, technical, environmental, governance, and social contexts. A more detailed discussion of important terminology can be found in Chapter 2.2.

There must be a clearly defined set of assessment criteria and key performance indicators (KPIs) that address all aspects of the ZEN definition, which are defined in such a way as to enable the development of quantitative and qualitative methods and tools for assessing the status and progress of ZEN pilot areas in terms of achieving emission reduction goals. To operationalise the ZEN definition, more detailed guideline documents are and will be made available (4–6). Furthermore, they will inform how data is measured and collected for the ZEN KPI tool.

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1) Buildings can be of different types, e.g. new, existing, retrofitted or a combination. Infrastructure includes grids and technologies for supply, generation, storage and export of electricity and heat, as well as infrastructure for mobility.

2) The area has a defined physical boundary to external grids (electricity, heat, and mobility). The system boundary for analysis of energy facilities serving the neighbourhood may not be the same as the geographical area.

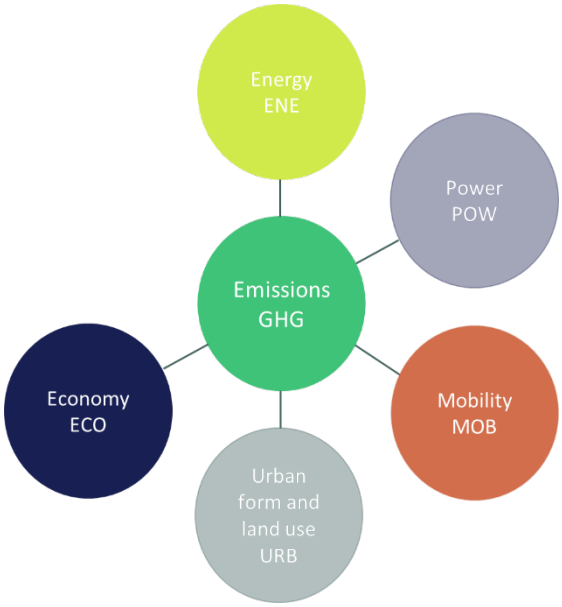

Figure 2. Six categories in ZEN definition

As a result, the scope of the ZEN definition includes the following categories (as shown in Figure 2) Greenhouse gas emissions (GHG), Energy (ENE), Power (POW), Urban form and land use (URB), Mobility (MOB) and Economy (ECO).

The above categories were identified through a series of definition workshops with stakeholders, as being important in the realisation of ZEN goal, and for the provision of an adaptable framework for the development of future ZENs. Technically, the ZEN definition should be scalable. The categories have a set of assessment criteria, and a corresponding set of key performance indicators (KPIs).

2.2 Other terms and definitions

The ZEN research centre utilises interdisciplinary knowledge and experiences from a vast range of fields, and from people with different professional backgrounds. It is therefore important to ensure that we have a common understanding of some of the main terms and definitions used in this ZEN definition report.

Firstly, there are varying definitions of *nearly/net zero emission/energy building/neighbourhood* (nZEB/nZEN) (7–11). In 2010, the energy performance of buildings directive (EPBD) (12) was recast to define a *nearly zero energy building* as a building that has a very high energy performance, while the nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby. This definition is used in the EU taxonomy (13), whereby one of the criteria for sustainable new buildings is that the energy need must be <10% lower than national nearly zero energy building definition. In 2022, the EPBD (14) was reproposed to define a *zero emission building* as a building with a very high energy performance in line with the energy efficiency first principle, and where the very low amount of energy still required is fully covered by energy from renewable sources at the building or district or community level where technically feasible (notably those generated on-site, from a renewable energy community or from renewable energy or waste heat from a district heating and cooling

system). More recently, ISO published *IWA 42: 2022 Net Zero Guidelines* (15) that defines net zero GHG emissions as the 'condition in which human-caused residual GHG emissions are balanced by human-led removals over a specified period and within specified boundaries…Residual GHG emissions are emissions that remain after taking all possible actions to implement emission reductions…Human-led removals include ecosystem restoration, direct air carbon capture and storage, reforestation and afforestation, enhanced weathering, biochar and other effective methods.' The guidelines go further to state that avoided emissions should not be used to counterbalance residual emissions.

In Norway, the research centre for zero emission buildings (FME ZEB) developed a definition for a *zero emission building* by developing a range of ambition levels ranging from the lowest ambition level of ZEB-O whereby GHG emissions from operational energy use (O) are compensated for with renewable energy generation, to the highest ambition level of ZEB-COMPLETE whereby all GHG emissions from the whole life cycle of the building from the construction phase (C), operational energy use (O), material production and replacement (M), use, repair and maintenance (PLE), operational transport use (T) and the end of life phase (E) are compensated for with renewable energy generation (9–11). The EPBDs definition of zero emission building corresponds to the lowest Norwegian ZEB ambition level (ZEB-O). The term *nearly* implies close to zero, whilst *net* implies a balance whereby remaining energy/emissions are balanced through either capture, storage, or compensation. In the ZEN definition, nZEB and nZEN refer to *net zero emission building* and *net zero emission neighbourhood* respectively.

Assessment Criteria: are requirements that need to be fulfilled for a neighbourhood to be considered environmentally, socially and economically sustainable and feasible (16). Assessment criteria can be either mandatory or voluntary. Criteria may be interconnected, meaning that the fulfilment of one criterion depends upon the fulfilment of another. The criteria use KPIs that are normally quantitative, but some could be qualitative. See Figure 3 for an overview of the system of categories, assessment criteria and KPIs within the ZEN definition.

Key Performance Indicator (KPI): a set of quantifiable performance measurements that define sets of values based on measured data from a project, making it easier to measure and track the neighbourhood's performance over time and against other similar projects (17).

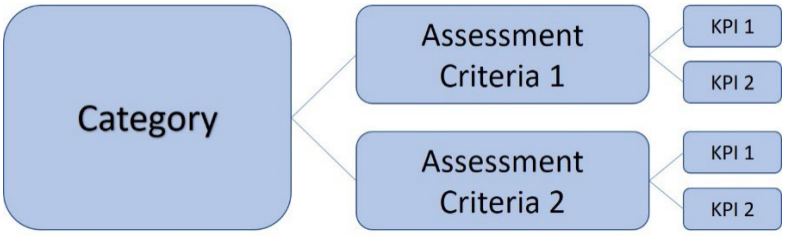

Figure 3. System of categories, assessment criteria, and KPIs within the ZEN definition.

ZEN metrics: This umbrella term covers the key values from both assessment criteria and key performance indicators used in the ZEN research centre.

System boundaries

The ZEN research centre utilises interdisciplinary knowledge and experiences from a vast range of fields, and from people with different professional backgrounds. It is therefore important to ensure that

we all have a common understanding of system boundaries. At first, an assessment was made to see whether the same system boundaries could be used across the ZEN pilot areas, regardless of whether a KPI or criteria being assessed concerned buildings, energy, or other infrastructure. However, it soon became clear that each ZEN definition category (GHG emissions, energy, power, urban form and land use, mobility and economy) already has established system boundaries and methodologies with various scopes. These different system boundaries have been designed with methodological consequences in mind for each professional field of research. For example, the system boundary for GHG emissions typically excludes the impact from existing buildings since the existing building belongs to the previous life cycle of that building. However, all new energy and material processes used for renovating the existing building are included in the system boundaries as the renovation works has initiated a new, longer life cycle for the building. Arguably, the new energy and material processes used in a renovation project will have lower GHG emission impacts compared to constructing a new building of equal performance since parts of the existing building envelope can be reused. The methodological implication of this GHG emission system boundary is that it promotes reduction, reuse, repair, refurbishment, and recycling in a circular economy. On the other hand, in the energy category, it would be disadvantageous to exclude energy needs for existing buildings from the energy system boundary, since existing buildings typically have higher energy demands than new buildings. Therefore, the ZEN definition acknowledges that system boundaries may vary across the ZEN categories, across the ZEN pilot areas and according to the scope of data resolution required to understand the assessment criteria and KPI being assessed. In this report, we define the following terminology as part of the ZEN system boundaries:

Neighbourhood: a group of interconnected buildings (which can be of different types, e.g., new, existing, retrofitted or a combination) with associated infrastructure (which includes grids and technologies for supply, generation, storage and export of electricity and heat, and mobility), located within a confined geographical area. The area has a defined physical boundary to external grids (electricity and heat, and mobility). However, the system boundary for analysis of energy facilities serving the neighbourhood is not necessarily the same as the geographical area. The system boundary for each ZEN pilot area is also dependent on the case and may vary accordingly.

Building assessment boundary: describes which elements of building(s) in the ZEN definition should be included in the system boundary. This may vary for each category (e.g., GHG emissions, energy, power, urban form and land use, mobility, or economy) identified in the ZEN definition.

Neighbourhood assessment boundary: describes which neighbourhood elements in the ZEN definition should be included in the system boundary. This may vary for each category (e.g., GHG emissions, energy, power, urban form and land use, mobility, or economy) identified in the ZEN definition. For example, the ‘energy-boundary’ for the electric or thermal grid is not necessarily the same as the geographical area of buildings and other infrastructure.

LCA system boundary: (relevant for the GHG emissions category) is more commonly referred to as just 'system boundaries' and is used in life cycle assessment (LCA) methodology. It defines what is included and excluded in the assessment, and also describes the scope of the assessment (adapted from the definition in *EN 15643* (18)). The system boundary for the life cycle phases can be defined in accordance with the life cycle modularity principle in *NS 3720: 2018* (19), whilst the physical system

boundary can be defined according to *NS 3451* (20). In the ZEN research centre, the whole life cycle shall be reported from extraction of raw materials, production, transport, installation, use, maintenance, repair, replacement, energy during operation, transport during operation, deconstruction, waste treatment, reuse, recovery, and end use of waste in a circular economy, as well as module D, benefits and loads.

2.3 ZEN Definition Categories

Greenhouse gas emissions (GHG): refer to greenhouse gas (GHG) emissions expressed in terms of kg of CO_2 equivalence calculated based on *NS 3720* in a life cycle perspective. Direct GHG emissions are those taking place directly from a source as consequence of an activity resulting in the GHG emissions, whilst indirect emissions are those occurring through indirect pathways (21). For example, the GHG emissions from driving a car includes not only the direct GHG emissions that come out of the exhaust pipe, but also the indirect GHG emissions that take place when oil is extracted, shipped, refined into fuel and transported to the petrol station, and also the indirect emissions caused by producing, using and disposing the car.

Energy (ENE): In physics, energy is the potential to perform work, or the amount of work performed over a period of time. Mathematically, energy is the integral of power/load over time. In relation to an energy system (e.g., electricity or heat), energy is the load on the grid over time and is measured in [kWh].

Power (POW): In physics, power is the instantaneous rate at which work is performed. Mathematically, power is the time derivative of energy. In relation to an energy system (e.g., electricity or heat), power is the instantaneous load on the grid and is measured in [kW]. It may also refer to the average value of energy in one hour and should then be measured in [kWh/h].

Urban form and land use (URB): In this context, urban form and land use refers to how spatial structure, land use patterns and the shape of buildings and public spaces can improve attractiveness of the neighbourhood and at the same time support carbon uptake from land use and low emissions from mobility, buildings, and infrastructure.

Mobility (MOB): In this context, mobility refers to inhabitants' and other users' daily transport patterns within, to and from the neighbourhood. Freight and utility transport to the neighbourhood is also included.

Economy (ECO): In the context of this report, economy refers to economic sustainability. Economic sustainability will be important in the mainstreaming of ZENs, where building owners and investors need to articulate a business case in developing a group of interconnected buildings into a Zero Emission Neighbourhood, which will likely entail higher upfront costs with investments in energy, heating, storage systems and innovative materials. Economic sustainability is considered using a life cycle costing (LCC) approach for buildings, energy, and other infrastructure within the neighbourhood. In other words, the initial costs, and future operational costs over the life cycle of the neighbourhood are considered.

3 The ZEN KPI framework

The ZEN KPI conceptual framework is depicted in Figure 4 and demonstrates how the ZEN definition shall be operationalised within the ZEN pilot projects (22). The ZEN KPI framework demonstrates how different stakeholders, scope, and project phases (grey box) come together to select relevant tools (ZEN toolbox) to assess the assessment criteria and KPIs for each category within the ZEN definition (yellow box). The results from these assessments can be fed into the ZEN KPI tool (green box) and analysed to ascertain if the neighbourhood has achieved ZEN status. The results from the ZEN toolbox and ZEN KPI tool can then be used to create a various array of visualisations (blue box). This conceptual framework has been developed based on information and experiences from ongoing work with the ZEN definition, ZEN pilot areas, ZEN stakeholders and existing tools and builds upon the initial ZEN toolbox framework developed by Houlihan Wiberg and Baer in (23). The ZEN KPI framework will be applied in different contexts and will consider different project phases, scope, and stakeholders. The main components of the framework are:

- The ZEN toolbox
- The ZEN definition, assessment criteria and KPIs
- The ZEN KPI tool
- The ZEN visualisation toolbox
- The ZEN process guideline

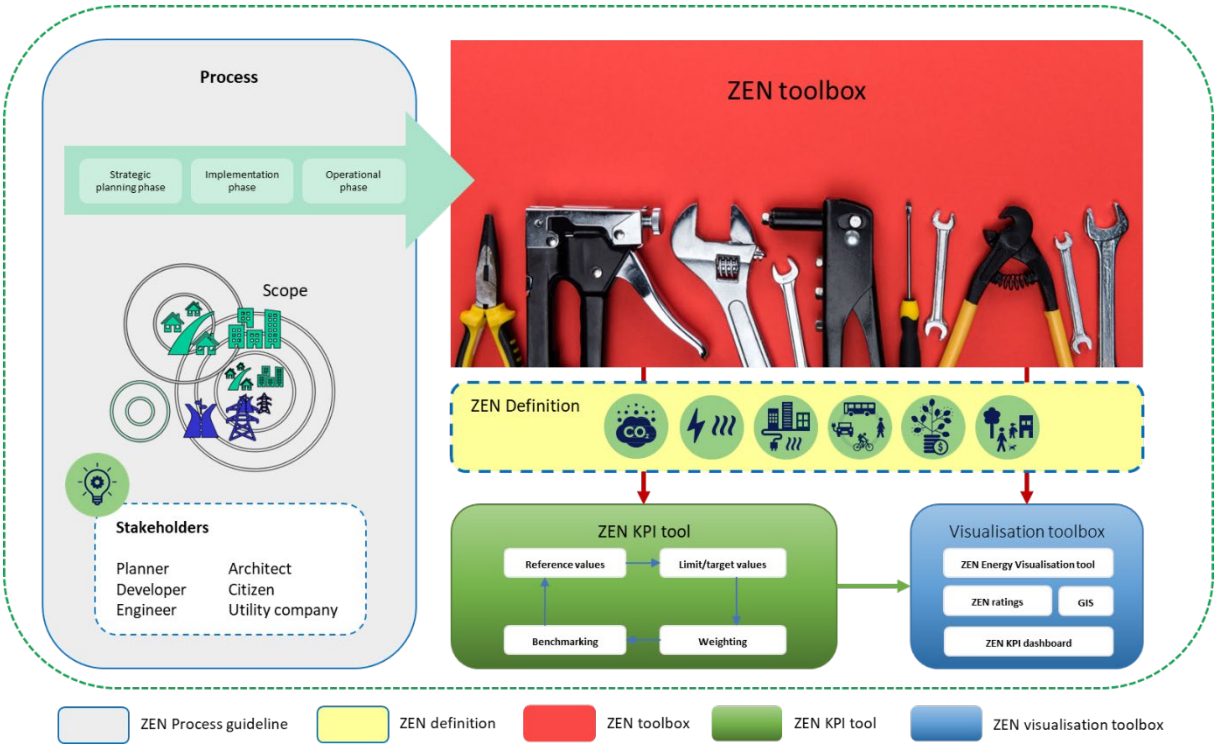

Figure 4. ZEN KPI conceptual framework developed from (52).

3.1 Scope

The scope of assessment varies from KPI to KPI, some KPIs are assessed at a building level, some at a neighbourhood level, and others consider both. The KPIs will be assessed by a range of stakeholders, ranging from but not limited to planners, architects, developers, citizens, engineers, consultants, and

utility companies. During its lifetime, a neighbourhood will go through many project phases. The three project phases, as depicted in Figure 5, and to be assessed in the ZEN definition are:

1. Strategic planning phase
2. Implementation phase
3. Operational phase

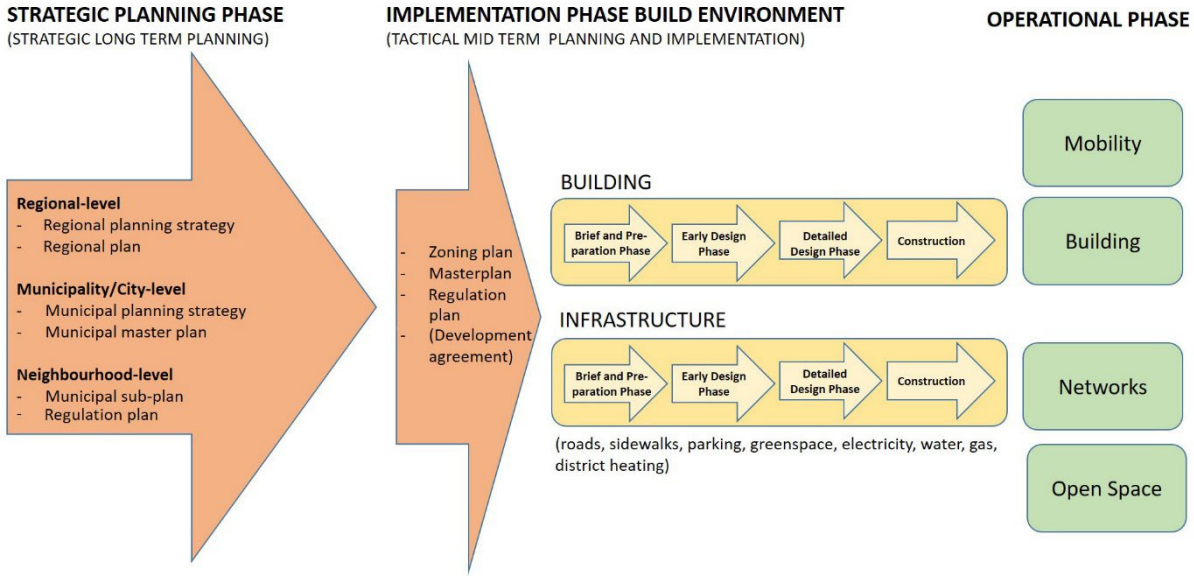

Figure 5. Diagram explaining the three project phases in ZEN.

It is possible, and even likely, for one neighbourhood to experience multiple project phases simultaneously. It is recommended that each ZEN pilot area is classified according to the various planned phases of development. Each development phase will go through the same project phases, but at different times. Therefore, it can ensure that each phase of the development is properly documented for each project phase, and that the project data for each phase of the development and project phase is compiled to represent the whole neighbourhood area.

3.2 ZEN toolbox

The ZEN toolbox depicted in Figure 6 contains suggestions of useful and existing tools that can calculate the results of various assessment criteria and KPIs in the ZEN definition. This list is not exhaustive and will be added to in the future. A first initial mapping of existing tools was carried out by ZEN stakeholders, and then more tools were added to the ZEN toolbox as various assessment criteria and KPIs have been tested out in the ZEN pilot areas. The tools are loosely grouped according to which category the different tools can be used in.

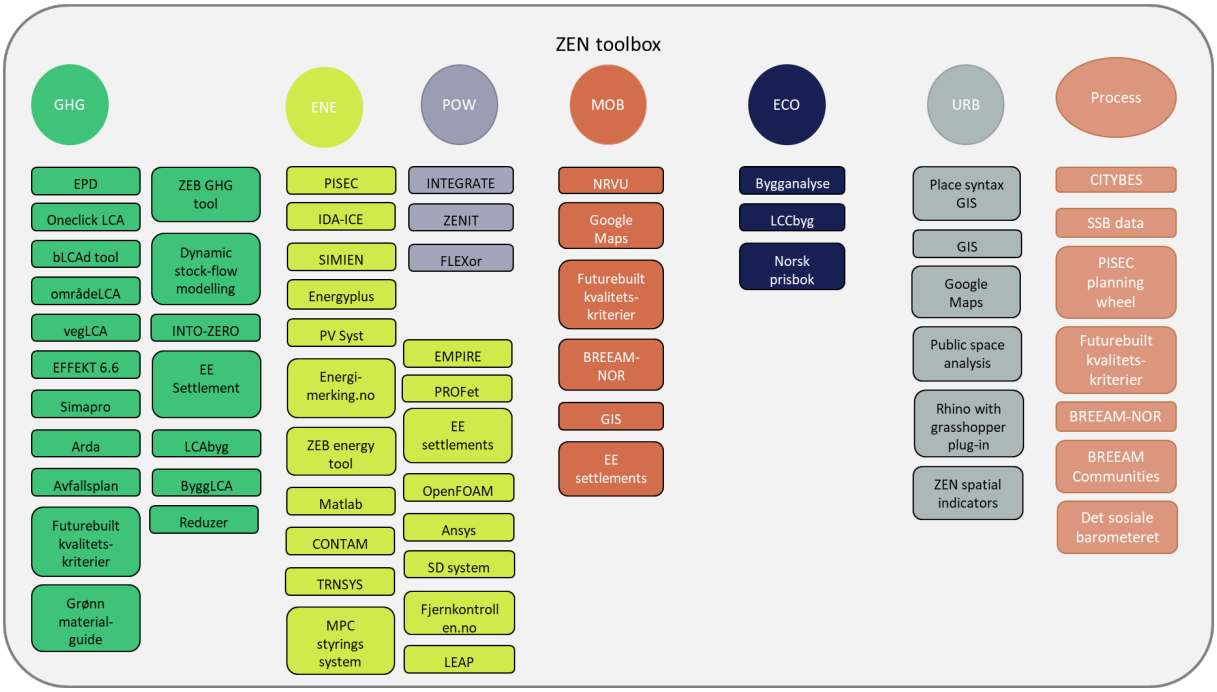

Figure 6. ZEN Toolbox overview (list of tools is not exhaustive)

The findings from the mapping of tools show a lack of harmonisation between these tools, which leads to difficulties in harmonising the inputs and outputs of the ZEN KPI tool. Some of the main issues include differences in system boundaries, methodology and background data (databases) used, as well as differences in data resolution used dependent on the phase of the project (i.e., typically a low data resolution is used in the early planning phases and a high data resolution in the latter project phases). The various tools identified in the mapping use a range of different computing formats(e.g., csv, xml, json, sql and html) (22,24).

3.3 ZEN KPI tool

The testing and development of the ZEN definition and ZEN KPI tool is a continuous, iterative process, which involves determining suitable reference project and reference values, limit and target values, weighting, and benchmarking for each KPI in the ZEN definition. The main purpose of the ZEN KPI tool is to operationalise the ZEN definition, and aid ZEN stakeholders through the planning, implementation, and operation of zero emission buildings, infrastructure, and neighbourhoods. The ZEN KPI tool has three main user groups; firstly researchers supply the background content and methodology for calculating KPIs, secondly, various consultants and contractors are responsible for calculating and entering KPI result data into the tool be that energy data or GHG emission result data, thirdly ZEN pilot owners such as the authorities, local councils, building owners or decision makers are responsible for assessing the output of the tool and tracking the progress of their ZEN pilot area across the project phases. The ZEN KPI tool should therefore be flexible, easy to use and understand and have a clear and concise output of the results. It should also be a tool that is transparent and that can be used to compare results between different projects and between different scenarios within a project. As the ZEN definition and the ZEN KPIs are still under development and will be tested and revised in the ZEN pilot areas, the tool will therefore have to be dynamic and easy to update as long as the FME ZEN project period lasts. For the KPI tool to be useful it has to have a clear user-perspective and it needs to have functionality so it can be used in various projects phases (i.e., strategic planning phase, implementation

phase and operational phase), for various scopes of assessment (i.e., material/component, building/infrastructure, neighbourhood and city) and for several different stakeholders (i.e., planners, developers, architects, engineers, utility companies and citizens etc.).

3.4 Reference projects and reference values

In some KPIs a reference project and/or reference values are used. A reference project is a project that represents the ZEN if it was designed and built according to today's standards (business as usual) instead of being designed, built, and managed to fulfil KPI goals or requirements. The purpose of the reference project is to act as a comparison with reference values to document how much a ZEN pilot area has managed to fulfil KPI goals or requirements. A reference project will use reference values based on today's technical standards. For example, a reference project may use building energy requirements from the current building code (TEK) to ascertain how much energy different buildings within the neighbourhood would use if they were not designed within the ZEN framework, or a reference project may use Norwegian travel survey (NRVU) to ascertain reference mobility patterns before measures have been implemented in the ZEN pilot area to encourage active and public transport over private transportation. A ZEN pilot area can then track how much it has been able to reduce energy or private travel demands compared to these reference values. The reference project will typically not include any zero emission strategies.

3.5 Limit and target values

Limit values are defined in regulations or national standards, see Figure 7. They relate to the minimum requirements for upper or lower values for different aspects of performance. Target values represent an objective that goes beyond the reference value.

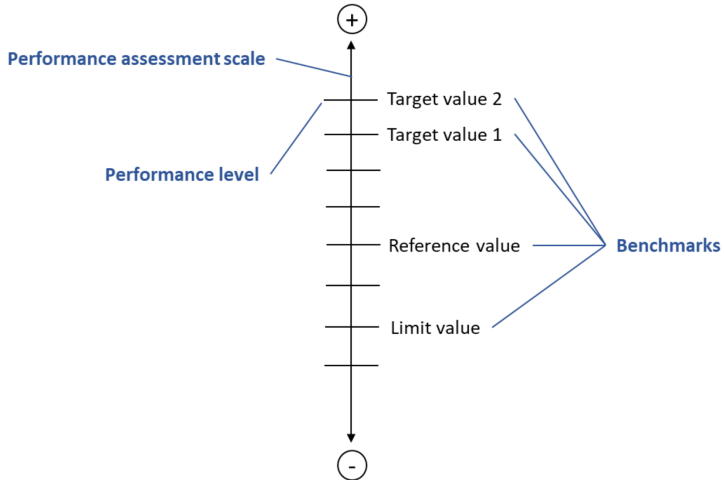

Figure 7. Performance assessment scale showing the benchmark reference, limit and target values (25).

3.6 Weighting

Points will be awarded to each KPI in each category of the ZEN definition. Category scores will not be tallied to a single point score for the ZEN neighbourhood but instead be assessed on a category-by-category basis. KPIs within the same category may be weighted, and this is achieved through the allocation of whole points within that category. For example, more points are allocated to GHG1.5 Operational transport (B8) because this is the life cycle phase of a neighbourhood that typically contributes the most to GHG emissions, and is therefore beneficial to reduce these emissions, whilst

fewer points are allocated to GHG1.6 End-of-life (C1-C4) since these are GHG emissions that will occur over 50 years from now, and it is quintessential that we reduce GHG emissions from now and towards 2050 to reach national and international targets.

3.7 Benchmarking

The ZEN KPI tool will enable users to compile results from the ZEN toolbox to assess individual KPIs and receive a ZEN GHG rating and ZEN category rating. For the ZEN GHG rating 50 points are available and for the ZEN category ratings 20 points are available per category (ENE, POW, MOB, URB and ECO). Results for the ZEN GHG rating and each category rating will *not* be summed up to a single point score. The ZEN GHG rating is *mandatory* and must achieve a minimum of 20 GHG KPI points to achieve a bronze rating, see Table 1 and Figure 8. The ZEN category ratings (ENE, POW, MOB, URB and ECO) are optional. It will be possible for users of the tool to set ambition levels and track the progress of a ZEN pilot area through the different project phases according to how many points they have achieved for each category, see Figure 9. The legend shows what percentage (%) of KPI points are fulfilled for each project phase for each ZEN category.

Table 1. ZEN GHG rating and ZEN category ratings

ZEN GHG rating	**ZEN category rating (ENE, POW, MOB, URB and ECO)**	**Limit and target values**
Gold	Dark green	80-100%
Silver	Green	60-80%
Bronze	Light green	40-60%
None	Grey	< 40%

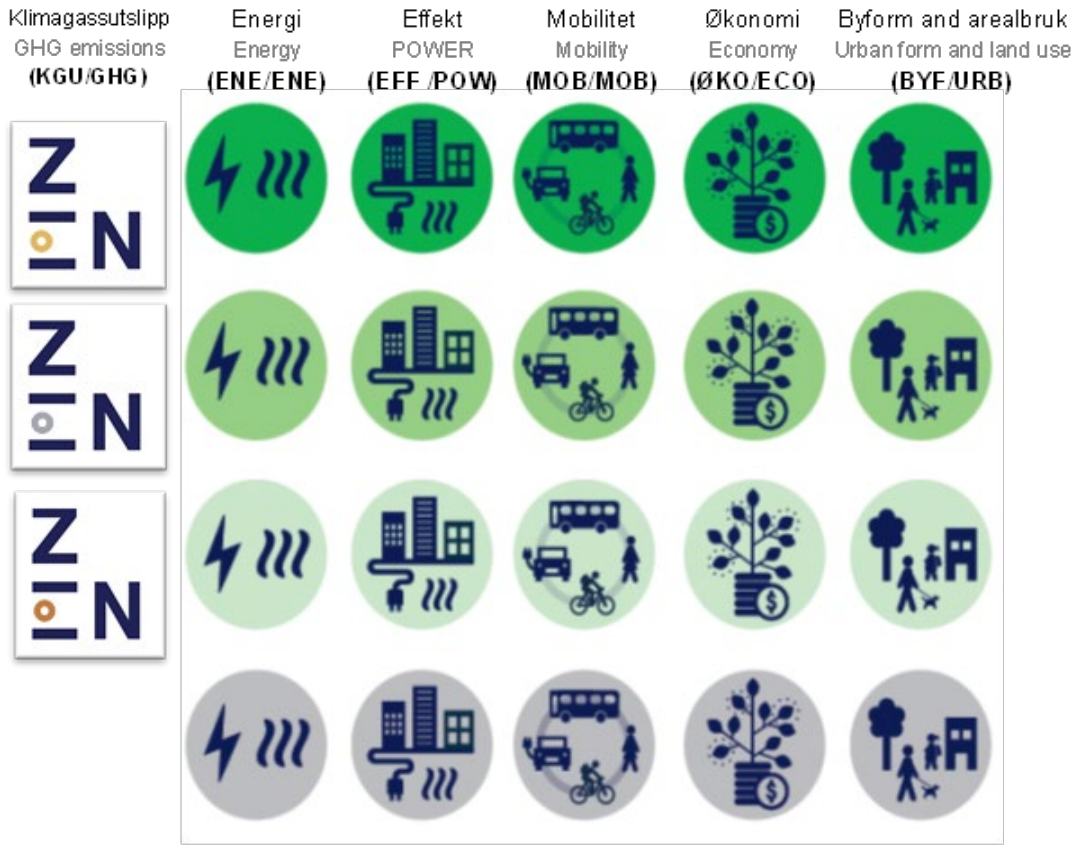

Figure 8. ZEN GHG emission rating and ZEN category ratings

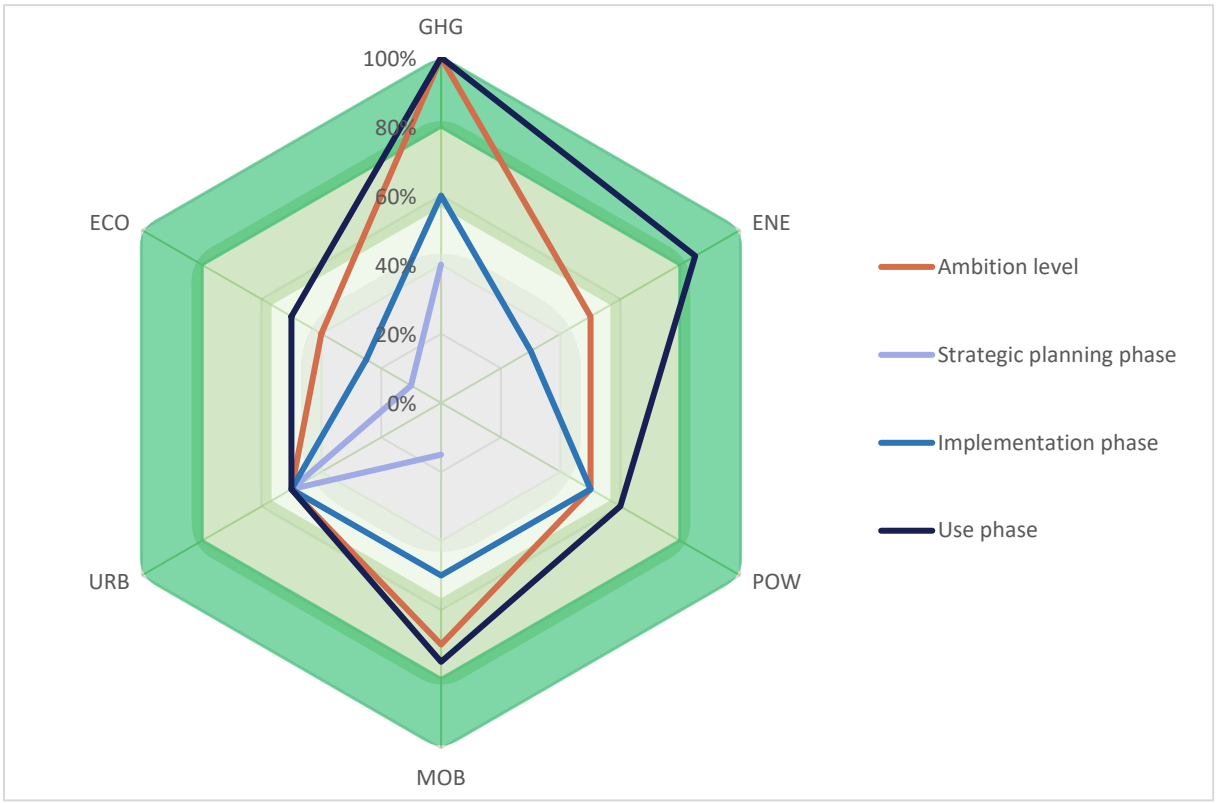

Figure 9. Spider diagram showing the development of a ZEN pilot area's performance through the different project phases. The legend shows what percentage (%) of KPI points are fulfilled for each project phase for each ZEN category.

3.8 ZEN Visualisation Toolbox

The ZEN visualisation toolbox is a collection of existing tools used by ZEN partners and tools developed by FME ZEN to visualise results from the ZEN toolbox and ZEN KPI tool. Such tools can include the ZEN energy visualisation tool, ZEN KPI dashboard (26), ZEN category ratings and GIS. The ZEN visualisation toolbox will be further mapped and developed in subsequent versions of the ZEN definition and guideline reports.

3.9 ZEN Pilot Projects

The ZEN Research Centre has nine ZEN pilot areas in Norway, where new solutions for the planning, implementation and operation of buildings and infrastructure are tested to cut total GHG emissions towards zero on a neighbourhood scale. The ZEN pilot areas function as role models, inspiring others to build ZENs and offering explanations about how the best possible results can be achieved. It is acknowledged that various stakeholders will have different influences on the ZEN pilot areas at varying times during the development of an area. In all, nine ZEN pilot areas are included in the ZEN Research Centre, namely: Ydalir in Elverum, Furuset in Oslo, Ny by – ny flyplass in Bodø, Knowledge Axis in Sluppen in Trondheim, Knowledge Axis at NTNU Campus, Mære landbruksskole in Steinkjer, Zero Village Bergen, Campus Evenstad and Fornebu in Bærum, see Figure 10.

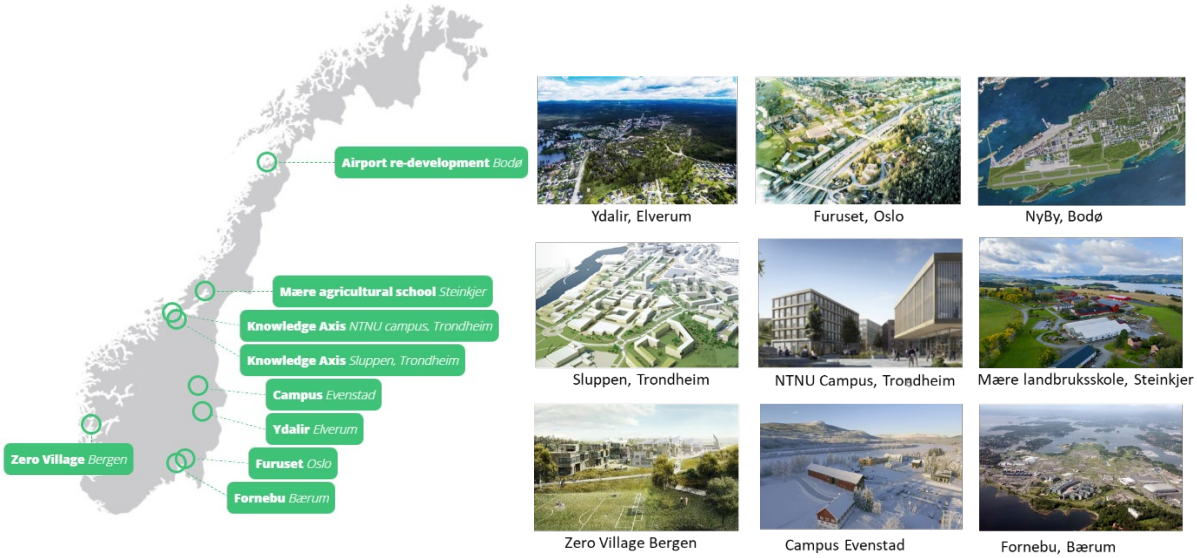

Figure 10. Location (left) and illustration (right) of the ZEN pilot projects. (Credits for illustration and pictures from left to right are as follows: tegn3, a-lab, Bodø Municipality, Kjeldsberg Eiendom, Koht Arkitekter, Zeiner Media, Snøhetta/Mir, Statsbygg, Wilhelm Joys Andersen).

Work has begun on testing out the various KPIs in the ZEN pilot areas. Table 2 provides an overview of which KPI categories have been tested out in the different ZEN pilot areas. X indicates KPIs under investigation. So far, nearly all ZEN pilot areas have tested out the GHG emission, energy and power categories, and a few ZEN pilot areas have tested out the remaining categories.

Table 2. Overview of testing of KPIs in ZEN pilot areas, x indicates KPIs currently under investigation.

	GHG	ENE	POW	MOB	URB	ECO
Bodø		x			ZEN memo no. 19 (27) ZEN report no. (28)	
Campus Gløshaugen	x					
Sluppen	Master thesis (29) Rambøll report (30)	x	x		ZEN memo no. 20 (31)	
Flytårnet (Fornebu)	ZEN memo no. 38 (32)	x	x	Kommune delplan (33)	ZEN memo no. 21 (34) ZEN report no. (28)	
Mære	ZEN memo no. 44 (35)	ZEN report no. 36 (36)				
Oksenøya (Fornebu)			ZEN report no. 36 (36)	Kommune delplan (33)	ZEN memo no. 21 (34) ZEN report no. (28)	
Ydalir	ZEN report no. 43 (37) Lund et al. (38)			x	x	ZEN report no. 43 (37)
Evenstad	ZEB report no. 36 (39)					x
ZVB / Dolvik				ZEN memo no. 37 (40)		
Furuset	FutureBuilt rapport (41)	x	x			

4 ZEN assessment criteria and key performance indicators

The set of assessment criteria and key performance indicators (KPIs) shown in Table 2, have been developed based on previous projects and existing assessment frameworks (such as the ZEB research centre, PI-SEC, SCC, PEB, BREEAM communities and CITYkeys) as well as input from ZEN researchers and partners through numerous discussions and workshops. The criteria and KPIs were identified and defined by experts for each category. The criteria and KPIs utilise existing policies, frameworks, standards and references professionals within each of those fields are already familiar with. The criteria and KPIs will be used to track, understand and validate the progress and performance of the ZEN pilot areas, and may also be used outside of the ZEN research centre to quantify and qualify the performance of other neighbourhoods. The criteria and KPIs are grouped into six categories, namely GHG emissions (GHG), energy (ENE), power (POW), mobility (MOB), economy (ECO), and spatial qualities (QUA). Each category has 1-3 assessment criteria and for each of those a set of KPIs. Not all KPIs can be measured during all project phases (strategic planning phase, implementation phase and operational phase (annually)), therefore Table 2 includes an overview of which project phases the criteria and KPIs are valid for.

Through the various ZEN workshops, the ZEN partners have highlighted the importance of clearly defining system boundaries and have identified a need for a 'building assessment boundary' and a 'neighbourhood assessment boundary'. These boundaries can be used across the various ZEN definition categories that assess criteria and KPIs and may vary according to the needs and requirements of each category. As a result, the scope for each criterion and KPI information is given as to whether the criteria and KPI is valid at the building assessment boundary level (B), neighbourhood assessment boundary level (N) or both (BN). In this ZEN definition report, the criteria and KPIs are shown in Table 3. When describing KPI requirements, efforts have been made to use methodological and organisational maturity by setting either (in order of preference):

1. Performance targets e.g., kgCO2eq/m2/yr
2. Reduction targets e.g., %
3. Information targets e.g., use of EPDs
4. Prescriptive targets e.g., must use a timber-based support system or photovoltaics

When assessing criteria and KPIs, a multi-criteria analysis approach will be used, due to the multiple dimensions involved in the ZEN definition. This allows for different dimensions to be evaluated alongside each other simultaneously. As with any set of assessment criteria and KPIs, users should evaluate the proposed indicators against data availability and reliability, alignment with existing monitoring and evaluation methods (both in Norway and in Europe), relevance to existing city-wide strategic goals, and applicability to project scale (i.e., building, block, district, or city scale). Such adaptations for pilot areas shall be harmonised with the ZEN definition, metrics, data management and monitoring working group in WP1, and the ZEN pilot area partners in WP6. More details on how to use the criteria and KPIs can be found in (4,5), whilst further details on the monitoring and tracking of the KPIs and criteria can be found in (42).

Table 3. ZEN assessment criteria and Key Performance Indicators (KPIs)

Category	Assessment criteria	KPI	Scope	KPI Points	Strategic planning phase	Implementation phase	Operational phase
GHG	Emission reduction	*GHG1.1 Materials (A1-A3, B4)**	BN	11	X	X	X
		*GHG1.2 Construction (A4-A5)**	BN	2	X	X	X
		*GHG1.3 Use (B1-B3, B5)**	BN	1	X	X	X
		*GHG1.4 Operational energy use (B6)**	BN	12	X	X	X
		*GHG1.5 Operational transport (B8)**	N	19	X	X	X
		*GHG1.6 End-of-life (C1-C4)**	BN	1	X	X	X
	Compensation	*GHG1.7 Benefits and loads (D)**	BN	4	X	X	X
ENE	Energy efficiency in buildings	*ENE2.1 Energy need in buildings*	B	8	X	X	
	Energy carrier	*ENE2.2 Delivered energy**	N	8	X	X	X
		ENE2.3 Self-consumption	N	2	X	X	X
		ENE2.4 Net load profiles	N	1	X	X	X
		ENE2.5 Colour-coded carpet plots	N	1	X	X	X
POW	Power performance	*POW3.1 Peak load*	N	6	X	X	X
		POW3.2 Peak export	N	2	X	X	X
		POW3.3 Energy stress	N	6	X	X	X
		POW3.4 Representative days	N	2	X	X	X
	Load flexibility	*POW3.5 Delivered energy difference*	N	1	X	X	X
		POW3.6 Operational cost difference	N	1	X	X	X
		POW3.7 Energy stress difference	N	1	X	X	X
		POW3.8 Peak load difference	N	1	X	X	X
URB	Density and land use mix	*URB4.1 Population density*	N	2	X		
		URB4.2 Block density	N	1	X		

Category	Assessment criteria	KPI	Scope	KPI Points	Strategic planning phase	Implementation phase	Operational phase
		URB4.3 Land use mix	N	2	X		
		URB4.4 Access to a diversity of amenities	N	2	X		
	Building layout	*URB4.5 Dwelling type*	B	1	X		
		URB4.6 Building envelope	B	1	X		
		URB4.7 Active frontages	B	2	X		
	Street network	*URB4.8 Street connectivity*	N	2	X		
		URB4.9 Street intersection density	N	1	X		
		URB4.10 Walkable and bikeable streets	N	1	X		
	Green open space	*URB4.11 Share of green open space*	N	2	X		
		URB4.12 Share of green permeable area	N	2	X		
		URB4.13 Number of trees	N	1	X		
MOB	Access	*MOB5.1 Access to public transport*	N	3	X	X	X
		MOB5.2 Travel time ratio	N	3	X	X	X
		MOB5.3 Parking facilities	BN	3	X	X	X
		MOB5.4 Vehicle ownership	BN	3	X	X	X
	Travel behaviour	*MOB5.5 Mobility pattern**	N	3	X	X	X
		*MOB5.6 Passenger and vehicle mileage**	N	3	X	X	X
	Logistics	*MOB5.7 Freight and utility transport*	N	2	X	X	X
ECO	Life Cycle Costs (LCC)	*ECO 6.1 Capital costs*	BN	6	X	X	
		ECO6.2 Operating costs	BN	6	X	X	X
	Cost benefit	*ECO6.3 Overall performance*	BN	8	X	X	X

* Indicates mandatory KPI

5 Limitations and further work

There are some limitations to the ZEN definition report series. It should be noted that the following is not considered:

- *Other environmental indicators than GHG emissions:* Other environmental indicators than GHG emissions have more uncertainty. It is also easier to communicate environmental impacts to stakeholders in terms of GHG emissions since these are most frequently used and understood by the industry. It would be extremely time consuming to complete a detailed life cycle assessment at the neighbourhood level for all environmental indicators, and there may not be enough life cycle inventory data available for all environmental indicators. After all, the other environmental indicators tend to be proportional to GHG emissions.
- *Building quality:* Building quality should be considered in all building projects as a minimum standard (e.g., law on planning and building regulations (*Plan- og bygningsloven (PBL)*) and Norwegian building requirements (*Byggteknisk forskrift (TEK17)*) but is not a prerequisite for zero emission neighbourhoods. By not limiting the ZEN definition to Norwegian planning and building codes, then the ZEN definition can also be applied internationally.
- *Universal design and climate change adaptation:* Universal design and climate change adaptation strategies should be considered for all neighbourhood development projects as a minimum standard (e.g., law on planning and building regulations (*Plan- og bygningsloven (PBL)*) and Norwegian building requirements (*Byggteknisk forskrift (TEK17)*) but are not prerequisites for zero emission neighbourhoods.
-

The fourth version of the ZEN definition report has highlighted scope for further work. Therefore, the following aspects will be resolved in the next version of the ZEN definition report:

- **Testing and evaluation of assessment criteria and KPIs in all ZEN pilot projects**: All ZEN pilot areas shall select ZEN assessment criteria and KPIs to be tested and evaluated. Knowledge gained from this testing shall be used to evaluate reference values and establish limit and target values.
- **Validate reference projects and reference values**: In this ZEN definition guideline report, basic background information used for developing reference projects and reference values are incorporated. Reference projects and reference values shall evaluate and document how much a ZEN pilot area has managed to fulfil KPI criteria.
- **Establish limit and target values, weighting, and benchmarking**: Next steps in the development of the ZEN definition include the further development of setting limit and target values after testing and evaluating assessment criteria and KPIs in pilot project against reference projects and reference values.
- **ZEN KPI tool**
    - **Data collection and documentation**: Develop a transparent ZEN KPI tool for data collection, monitoring, evaluation, and documentation.

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