Research Centre on
ZERO EMISSION
NEIGHBOURHOODS
IN SMART CITIES

ZERO EMISSION NEIGHBOURHOODS IN SMART CITIES

Definition, assessment criteria and key performance indicators: Version 3.0. English

ZEN REPORT No. 39 – 2022

SINTEF | NTNU

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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 life cycle 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, Ny By – Ny 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.

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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:

GHG Emissions: Marianne Kjendseth Wiik (SINTEF), Selamawit Mamo Fufa (SINTEF), Kristin Fjellheim (SINTEF), Christofer Skaar (SINTEF), Carine Lausselet (SINTEF), Håvard Bergsdal (SINTEF), Eirik Resch (NTNU) and Camille Vandervaeren (SINTEF).

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Mobility: Solveig Meland (SINTEF), Unn Karin Thorenfeldt (SINTEF), Bendik Manum (NTNU), Peter Schön (NTNU), Eva Heinen (NTNU), Hampus Karlsson (SINTEF) and Astrid Bjørgen (SINTEF).

Economic: Caroline Cheng (SINTEF), Kristin Tolstad Uggen (SINTEF) and Stian Backe (NTNU).

Spatial qualities: Tobias Nordström (NTNU), Daniela Baer (SINTEF), Judith Thomsen (SINTEF), Lars Arne Bø (SINTEF), Bendik Manum (NTNU), Johannes Brozovsky (NTNU) and Lillian Sve Rokseth (NTNU).

Innovation: Shannon Truloff (NTNU), Ann Kristin Kvelheim (SINTEF), Terje Jacobsen (SINTEF), Raymond Andreas Stokke (NTNU), Eli Sandberg (SINTEF), Luitzen de Boer (NTNU), Kjell Olav Skjølsvik (NTNU), Poul Houman Andersen (NTNU), Asgeir Tomasgård (NTNU) and Elsebeth Holmen (NTNU).

In addition, the ZEN definition report was sent for external hearing to all ZEN partners. The editors would like to thank all ZEN partners for their contributions. The following ZEN partners have sent in suggestions, comments and contributions to this version of the ZEN definition report:

Bodø kommune, Energi Norge, Elverum Vekst, FutureBuilt, Norsk Fjernvarme, Statsbygg og Trondheim kommune.

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).

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 third version of the ZEN definition builds upon previous versions of the ZEN definition. 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 available as an English version (EN) and a Norwegian version (NO). Over 100 people involved in the ZEN research centre have contributed to this document.

Contents

1 Introduction

1.1 Research Centre on Zero Emission Neighbourhoods in Smart Cities

The Research Centre on Zero Emission Neighbourhoods in Smart Cities (3) aims to answer the following research question:

How should the sustainable neighbourhoods of the future be designed, built, transformed, and managed to reduce their greenhouse gas (GHG) emissions towards net zero?

In the proposal for the ZEN research centre, a preliminary description of a zero emission neighbourhood was provided:

> "a group of interconnected buildings with distributed energy resources such as solar energy systems, electric vehicles, charging stations and heating systems, located within a confined geographical area and with a well-defined physical boundary to the electric and thermal grids. The neighbourhood is not seen as a self-contained entity but is connected to the surrounding mobility and energy infrastructure and will be optimized in relation to larger city and community structures".

Whilst this preliminary description of the boundary conditions is primarily focused on energy aspects, the concept of the zero emission neighbourhood has aspects relating, but not limited to, greenhouse gas emissions (GHG), energy (ENG), power (POW), mobility (MOB), economy (ECO), spatial qualities (QUA) and innovation and process (INN) aspects.

When defining the concept of a zero emission neighbourhood, we have taken inspiration from a range of sources; including the work of other similar definitions and concepts across Europe, and more specifically Norway. Some of these sources are:

- FME ZEB - The Research Centre on Zero Emission Buildings (4)
- Research project PI-SEC - Planning Instruments for Smart Energy Communities (5)
- Horizon 2020 – Smart Cities and Communities (SCC) (6,7)
- The definition of PEB – Positive Energy Blocks in Horizon 2020 (8)
- The methodology of BREEAM Communities (9)
- CITYKeys (10)
- Relevant national and international standards

These sources of information are discussed in Chapter 2 Background. In addition, the KPIs have been tested in ZEN pilot areas. For some pilot areas the category topic is evaluated and the specific KPIs described in this report have not been tested (indicated by (x) in Table 1). In the long run, all KPIs will be tested out in a selection of the ZEN pilot areas. Background and more information can be found in the *ZEN guideline for the ZEN pilot areas, Version 1.0* report (11) and the version 2.0 report (12).

Table 1. Overview of testing of KPIs in ZEN pilot areas.

	GHG	ENE	POW	MOB	QUA	ECO
Ny By – Ny Flyplass, Bodø		x			(x)	
Kunnskapsaksen, Campus, Trondheim	(x)					
Kunnskapsaksen, Sluppen, Trondheim	x	x	x		(x)	
Mære landbruksskole, Steinkjer	x	x				
Fornebu, Bærum		x	x		(x)	
Ydalir, Elverum	x	x	x	(x)	(x)	
Campus Evenstad, Hedmark		x	x			(x)
Furuset, Oslo		x	x			
Zero Village, Bergen		x	x	(x)		

In the following chapters, the background for the ZEN definition report is presented in Chapter 2, the ZEN definition is presented in Chapter 3, a breakdown of the KPIs and assessment criteria included in the ZEN definition is included in Chapter 4, the innovation aspect is described in Chapter 5, the ZEN KPI Tool and framework is presented in Chapter 6, and an overview of the limitations of the ZEN definition report and scope for further work on the ZEN definition is presented in Chapter 7.

2 Background

2.1 The Research Centre on Zero Emission Buildings (ZEB research centre)

The ZEB research centre was a research centre for environmentally friendly energy (FME) from 2008-2016 (4). During the ZEB research centre, a methodology was developed for measuring and reporting greenhouse gas (GHG) emissions, in terms of CO_2 equivalents ($kgCO_2e/m^2/yr$), from operational energy use (O), materials (M), construction (C), end-of-life (E) and the use phase (PLET) of buildings (13–15). These GHG emissions should in a ZEB be compensated for through local renewable energy generation. For each ZEB pilot project, a ZEB ambition level was selected based on the scope of GHG emission calculations. For example, a ZEB-COM ambition level required the building to generate enough local renewable energy to compensate for all GHG emissions relating to the construction phase (C), operational energy use (O), and the production and replacement of materials (M). A more detailed description of the ZEB definition and methodology can be found in ZEB report no.17, ZEB report no. 29 and SINTEF design guideline 473.010 on zero emission buildings (13–15). A simplified illustration of the ZEB emission balance is shown in Figure 1.

The ZEB methodology was used in seven pilot building projects developed in the ZEB Research Centre, as well as in two concept studies, namely: A single-family house concept building (16,17), the Multikomfort house in Larvik (18), the Living Laboratory in Trondheim (19–21), an office concept building (22,23), Powerhouse Kjørbo in Sandvika (24–26), the administration and educational building at Campus Evenstad (27,28), the Visund office building at Haakonsvern, Bergen, five dwellings at Skarpnes, Arendal, and Heimdal high school in Trondheim (29). These buildings cover a range of typologies (residential, office, and school buildings). An overview of the ZEB emission balance for some of ZEB buildings is shown in Figure 2.

Figure 3 shows the time horizon of GHG emissions in ZEB Campus Evenstad's education and administration building over a building lifetime of 60 years. These results show that a high amount of GHG emissions occur during the production and construction phases, contra a low amount of GHG emissions for annual operational energy use because of energy effective solutions and low emission energy resources. The compensation of GHG emissions with renewable, local energy sources also occurs annually, during the 60-year operational phase. There is an increase in GHG emissions at 20, 30 and 40 years because of the replacement of building components during the building's lifetime. Campus Evenstad is also a pilot area in the ZEN research centre.

The method and experiences from the Norwegian ZEB Research Centre are important for the development of GHG emission calculations of buildings in Norway (11). Lessons learnt from the Norwegian ZEB Research Centre on methodological choices have been incorporated into *NS 3720 'Method for GHG calculations for buildings'* (30). Lessons learnt on GHG emission reduction measures (such as design and material choices) will be transferred to the ZEN Research Centre.

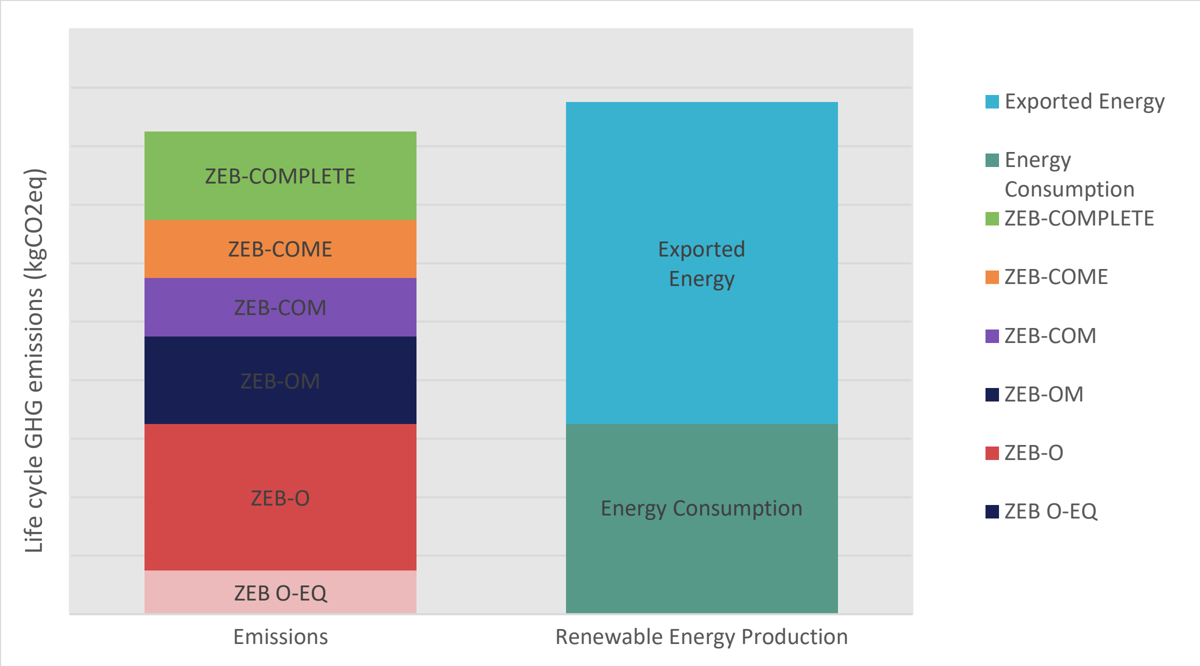

Figure 1. Compensation of emissions from operational energy use (O), materials (M), construction (C), end-of-life (E), and the use phase (PLET) in zero emission buildings (ZEB) from local, renewable energy generation (11).

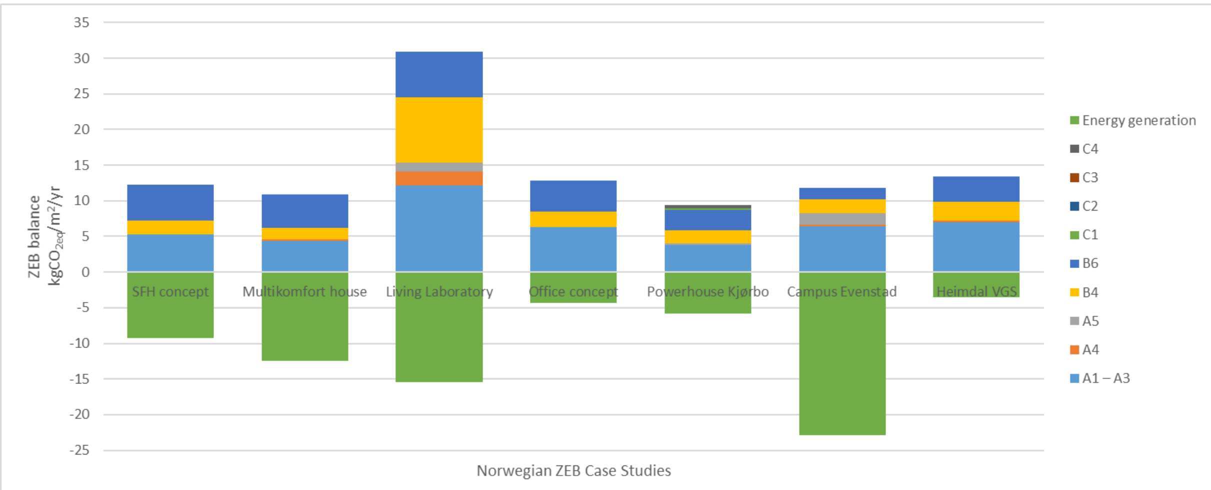

Figure 2. ZEB balance for each ZEB building per life cycle module (11).

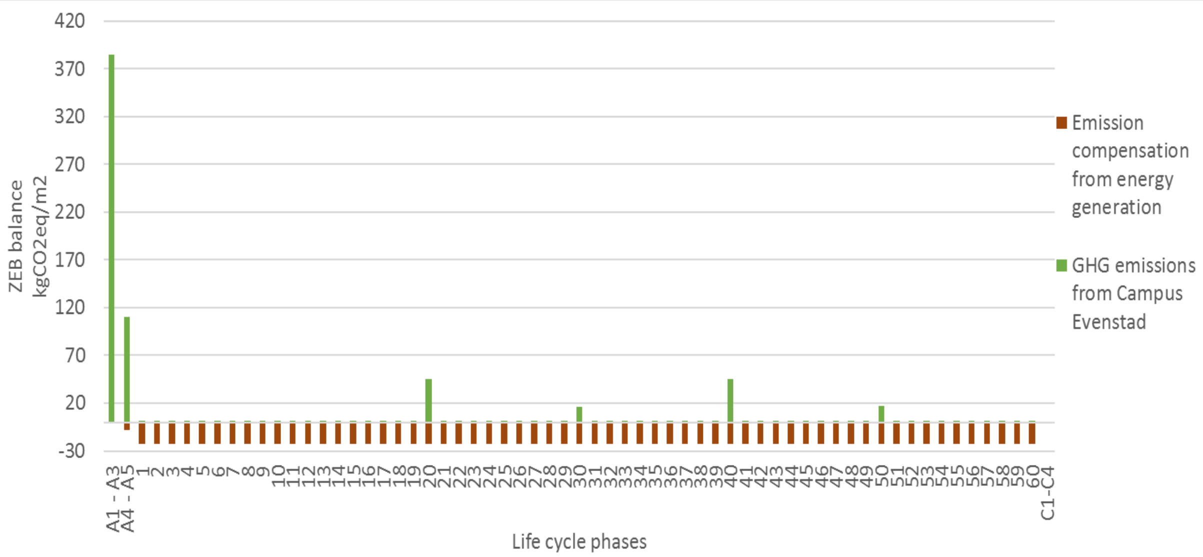

Figure 3. Time horizon of GHG emissions and emission compensation from energy generation in ZEB Campus Evenstad's education and administration building (31).

2.2 Planning Instruments for Smart Energy Communities (PI-SEC)

PI-SEC (Planning instruments for smart energy communities) is a Norwegian research project whereby the main deliverable was a toolkit that aims to resolve both municipal planning (top-down) and project planning and construction (bottom-up) needs (5). On the municipal planning level, it is important to understand the practice of urban planners and how energy consumption can become an integrated part of Norwegian planning practice, whilst on the project planning and construction level, the toolkit will increase knowledge about which parameters or key performance indicators (KPIs) are important for smart sustainable cities (5). Between these two levels, there is a challenge to connect key performance indicators for buildings with neighbourhood criteria. This requires a combination of quantitative and qualitative key performance indicators and assessment criteria. The municipal planning toolkit includes a 'planning wheel' approach, whilst the project planning and construction toolkit includes an indicator tool for setting targets. Based on this, PI-SEC specifically investigates CO_2 reduction, increased energy efficiency, increased use of renewable energy resources, increased use of local energy sources and green mobility. PI-SEC identifies 21 KPIs through a multi-disciplinary approach at all levels (building, neighbourhood, city, region, nation), and uses two ZEN pilot areas (Zero Village Bergen and Furuset) as test arenas (5).

2.3 Smart Cities and Communities (SCC)

The Horizon 2020 Smart Cities & Communities (H2020 SCC) programme is placed under the 'secure, clean and efficient energy' category of the Societal Challenges section of the Horizon 2020 work programme (8). The overall goal is to address the challenge of sustainable development in urban areas. It focuses on new, efficient and user-friendly technologies and services, within energy, transport and ICT. It also highlights the need for integrated approaches in the areas of research, development and deployment.

The SCC programme has a series of lighthouse projects (12 active projects since 2015). These lighthouse projects address city-driven challenges, and demonstrate solutions at scale, by building integrated, highly efficient commercial solutions with a high market potential. The widespread development of lighthouse projects in cities encourages the replication and uptake of new technologies (6,7). In parallel, efforts have been made to create a reporting platform and database for the Smart Cities Information System (SCIS), as well as key performance indicators in the H2020 project CITYkeys project (10).

Many aspects that are important for the ZEN research centre are also considered in SCC, making SCC a good comparison to the ZEN research centre on the European level. Some of these aspects include:

- development, testing and performance-monitoring
- sustainable energy transition
- increasing energy systems integration and energy performance levels
- integrating innovative solutions for positive energy blocks and districts
- analysing the interaction and integration between buildings, users and energy systems
- storage solutions and electro-mobility
- integration in planning and mixed-use urban districts
- replication of solutions, adapted to different local conditions
- reduction of greenhouse gas emissions and decarbonisation
- improving energy efficiency, storage, integration and self-consumption
- supporting climate mitigation and adaptation goals
- investigating urban, technical, financial, regulatory legal, gender, socio-economics, and social aspects
- developing new business models
- aligning indicators with overall city goals and scaling up to the city level
- including local communities and local governments
- air quality improvement
- big data, data management, digitalisation, data security and protection

2.4 Positive Energy Blocks (PEB)

The Horizon 2020 work programme states that, to achieve the necessary energy transition in cities, it is essential to increase energy systems integration and to push energy performance levels significantly beyond the levels of current EU building codes and to realise Europe-wide deployment of positive energy blocks and districts by 2050. The Horizon 2020 work programme provides a definition for positive energy blocks and districts (8):

> "Positive Energy Blocks [and] Districts consist of several buildings (new, retro-fitted or a combination of both) that actively manage their energy consumption and the energy flow between them and the wider energy system. Positive Energy Blocks [and] Districts have an annual positive energy balance. They make optimal use of elements such as advanced materials, local [renewable energy sources] RES, local storage, smart energy grids, demand-response, cutting edge energy management (e.g., electricity, heating, and cooling), user interaction [or] involvement and ICT. Positive Energy Blocks [and] Districts are designed to be an integral part of the district [or] city energy system and have a positive impact on it. Their design is intrinsically scalable, and they are well embedded in the spatial, economic, technical, environmental and social context of the project site."

2.5 BREEAM Communities

BREEAM Communities is a neighbourhood sustainability assessment (NSA) tool developed in the United Kingdom, and later adopted in Norway, that can be used to measure and improve various social, environmental and economic issues in a neighbourhood (9). BREEAM communities should not be confused with BREEAM-NOR – the Norwegian adoption of BREEAM (the British Research Establishment's Environmental Assessment Method) for buildings. BREEAM Communities can be used by planners, local politicians, communities, and other relevant statutory bodies. BREEAM Communities provides a holistic framework of assessment criteria that assesses issues concerning sustainability in an early stage of the design process. The tool has been specifically designed for developments which are likely to have significant impacts on future or existing communities and infrastructures. The BREEAM Communities methodology assesses neighbourhoods quantitively and qualitatively. As many partners are familiar with the BREEAM methodology, many partners expressed a wish to align ZEN KPIs with BREEAM Communities KPIs. The ZEN KPI set builds upon the BREEAM KPI set (e.g. BREAAM Government KPIs with the ZEN process indicators of spatial qualities), but these have been adopted and further developed to highlight the focus on GHG in ZEN and to give users of the ZEN KPI framework the ability to apply them.

2.6 CITYkeys

The goal of the CITYkeys project (10) is to support the development of smart city solutions and services, to have an impact upon the most urgent societal challenges relating to both continuous growth and densification of cities, together with EUs energy and climate targets. The overall aim of this two-year project is to develop and validate key performance indicators and different methods for collecting data for both transparent monitoring and comparability of smart city solutions in different European cities. The project has selected indicators that can be utilised when assessing smart city projects, and has key performance indicators at the city level (10).

2.7 Relevant national and international standards

A range of national and international standards have been identified as relevant to the ZEN definition and are thus implemented into the ZEN definition framework. To follow, is an overview of the core standards. For standards used specifically for each category see Table 2:

- *NS 3720: 2018*. Method for Greenhouse Gas Calculations for Buildings.
- *NS 3457-3: 2013*. Classification of Construction Works – Part 3 Building Types.
- *NS 3451: 2009*: Table of Building Elements.
- *ISO 52000: 2017*. Energy performance of buildings - Overarching EPB assessment - Part 1: General framework and procedures.
- *SN-NSPEK 3031:2021*. Calculation of energy performance of buildings - Method and data.
- *NS 3454: 2013*. Life cycle costs for construction works - Principles and classification.
- *NS-EN 16258: 2012*. Methodology for calculation and declaration of energy consumption and GHG emissions of transport services (freight and passengers).

3 Definitions

3.1 ZEN definition

The following ZEN definition serves as an overarching guiding principle for the whole ZEN project (3) and its pilot areas (11). 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 **zero emission neighbourhood** aims to reduce its direct and indirect **greenhouse gas (GHG) emissions** towards net zero over the analysis period [3)], in line with a **chosen ambition level**[4)]. The neighbourhood should focus the following aspects, where the first four have direct consequences for energy and emissions:

a. Plan, design, and operate buildings and associated infrastructure towards minimized life cycle **GHG emissions**.
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 [5)].
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.
f. Plan and locate amenities in the neighbourhood to provide good **spatial qualities** and stimulate **sustainable behaviour**.
g. Development of the area is characterised by innovative processes based on new forms of cooperation between the involved partners leading to **innovative solutions**.

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 3.2.

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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. Infrastructure may also include grids and technologies for water, sewage, waste, mobility, and ICT.

2) The area has a defined physical boundary to external grids (electricity and heat, and if included, water, sewage, waste, mobility, and ICT). However, the system boundary for analysis of energy facilities serving the neighbourhood is not necessarily the same as the geographical area.

3) The analysis period is normally 60 years into the future, assuming 60 years service life of buildings and 100 years service life of infrastructure, and relevant service lives for components that will be replaced.

4) Ambition level will be further developed in future versions of the definition and when reference values are established.

5) Flexibility should facilitate the transition to a decarbonised energy system and reduced power and heat capacity requirements.

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 (1,11,12,32). Furthermore, they will inform how data is measured and collected for the data management platform (33).

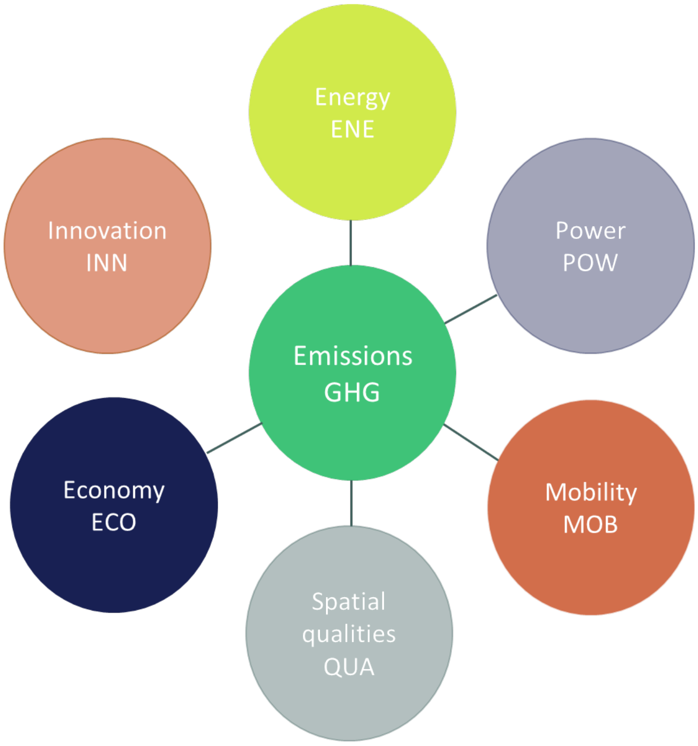

Figure 4. Seven categories in ZEN definition

As a result, the scope of the ZEN definition includes the following seven categories: (as shown in Figure 4) Greenhouse gas emissions (GHG), Energy (ENE), Power/load (POW), Mobility (MOB), Economy (ECO), Spatial Qualities (QUA), Innovation (INN).

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, however, adaption of the definition to its local contexts may require continued focus on innovation work at least for several years before it becomes the norm/mainstream. It is for this reason that the less tangible category of innovation remains investigated in terms of methodology. Six of the seven categories have a set of one or more assessment criteria, and a corresponding set of key performance indicators (KPIs). Innovation does not have associated KPI's.

3.2 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.

Assessment Criteria: requirements that need to be fulfilled for a neighbourhood to be considered environmentally, socially and economically sustainable and feasible (34). 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 5 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 (5).

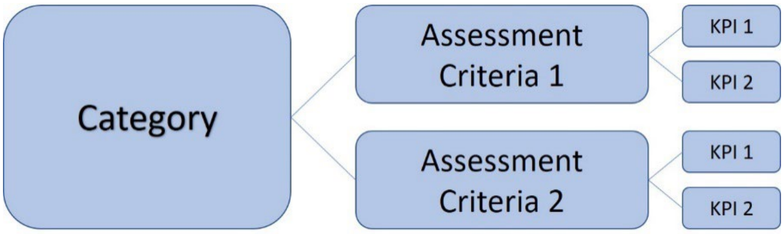

Figure 5. System of categories, assessment criteria, and KPIs within the ZEN definition.

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

ZEN KPI tool: The KPI tool will help partners to operationalise the ZEN definition and show the results for all the ZEN categories and KPIs. It will compile information on all the KPIs and present it in a comprehensible way.

ZEN toolbox: The ZEN toolbox is a compilation of existing tools used by ZEN stakeholders to calculate results for each individual KPI. The results from these various tools will be input into the ZEN KPI tool.

Project phases: The project phases to be assessed in the ZEN definition include strategic planning phase, implementation phase and operational phase, see Figure 6. A more detailed description of these phases is included in the 'ZEN guideline for the ZEN pilot areas. Version 1.0' report (11) and the Version 2.0 report (12).

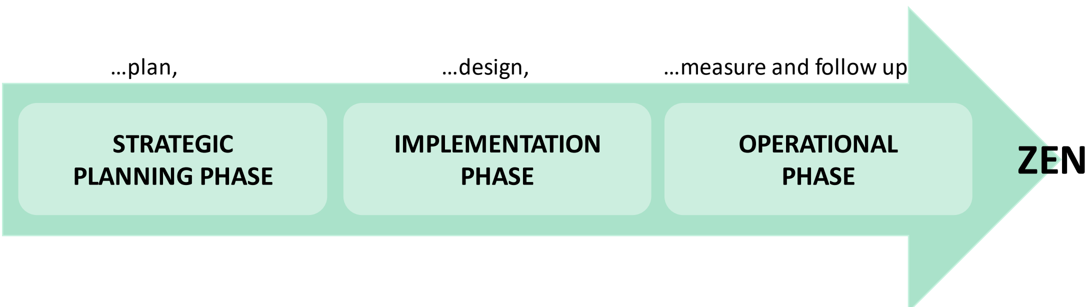

Figure 6. Project phases to be assessed in the ZEN definition.

Sustainability: the state of the global system, including environmental, social and economic aspects, in which the needs of the present are met without compromising the ability of the future generations to meet their own needs (adapted from the definition in *ISO 37100* (35) as specified by the United Nation's (UN) 17 sustainable development goals (SDG) with 169 associated targets (36). UN SDGs addressed by the ZEN research centre include:

- SDG 3: Ensure healthy lives and promote well-being for all at all ages
- SDG 7: Ensure access to affordable, reliable, sustainable and modern energy for all
- SDG 8: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
- SDG 9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
- SDG 11: Make cities and human settlements inclusive, safe, resilient and sustainable
- SDG 12: Ensure sustainable consumption and production patterns
- SDG 13: Take urgent action to combat climate change and its impacts
- SDG 15: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
- SDG 17: Revitalize the global partnership for sustainable development

Figure 7. UN SDG goals relevant to the ZEN research centre (36).

<u>**ZEN Definition Categories**</u>

Greenhouse gas emissions (GHG): refer to greenhouse gas (GHG) emissions expressed in terms of kg of CO_2 equivalence calculated based on *NS 3720* (30) 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 (37). 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/load (POW): In physics, power/load is the instantaneous rate at which work is performed. Mathematically, power/load 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].

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 taken into account.

Spatial Qualities (QUA): In this context, spatial qualities refer to how spatial structure, land use patterns and the shape of buildings and public spaces can improve attractiveness of the neighbourhood. It also refers to the process, the stakeholder dialogue, and the use of local knowledge in planning and design.

Innovation (INN): Innovation in ZEN is defined as new or improved products, services, processes, organisational forms, and business models that are utilised to gain value creation or be useful to society. ZEN innovation strategy identifies 3 pillars:

1. Open innovation
2. Testing and demonstration for faster commercialisation
3. Highlighting milestones and success stories (communication)

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, mobility, economy, spatial qualities, and innovation) 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 may also include grids and technologies for water, sewage, waste, mobility and ICT), located within a confined geographical area. The area has a defined physical boundary to external grids (electricity and heat, and if included, water, sewage, waste, mobility and ICT). 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 pilot areas should be included in the system boundary. This may vary for each category (e.g. GHG emissions, energy, power, mobility, economy, spatial qualities and innovation) identified in the ZEN definition. More details on the scope of the building assessment boundary can be found in (11,12), under the GHG emissions, energy, power, economy, mobility and spatial qualities chapters.

Neighbourhood assessment boundary: describes which neighbourhood elements in the ZEN pilot areas should be included in the system boundary. This may vary for each category (e.g. GHG emissions, energy, power, mobility, economy, spatial qualities and innovation) 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. More details on the scope of the neighbourhood assessment boundary can be found in (11,12), under the GHG emissions, energy, power, mobility, economy and spatial qualities chapters.

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* (38)). The system boundary for the life cycle phases can be defined in accordance with the life cycle modularity principle in *NS 3720: 2018* (30), whilst the physical system boundary can be defined according to *NS 3451* (39). 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.

More details on these terms are discussed in the 'ZEN guideline for the ZEN pilot areas. Version 1.0' report (11) and Version 2.0 (12).

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, for each criterion and KPI information is given as to whether the criteria and KPI is valid at the building assessment boundary level (B), neighborhood assessment boundary level (N) or both (BN).

In this ZEN definition report, the criteria and KPIs are shown in Table 2. 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. $kgCO_{2eq}/m^2/yr$
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

More details on how to measure the criteria and KPIs in terms of the ZEN pilot areas are presented in the 'ZEN guideline for the ZEN pilot areas. Version 1.0' report (11) and the Version 2.0 (12).

Table 2. ZEN assessment criteria and Key Performance Indicators (KPIs)

Category	Assessment criteria	Key Performance Indicator (KPI)	Unit	Building (B), neighbourhood (N) or both (BN)	Standards & References	Strategic planning phase	Implementation phase	Operational phase
GHG	Emission reduction	GHG1.1 Materials (A1-A3, B4)	tCO_2e $kgCO_{2e}/m^2$ gross floor area (GFA)/yr $kgCO_{2e}/m^2$ plot area (PA)/yr	BN	*NS 3720: 2018* (30), *NS 3457-3* (40), *NS 3451* (39) *NS-EN 15804* (41) *NS-EN 15978* (42) *NS-EN 16258* (43) *NS-EN 16449* (44)	x	x	x
		GHG1.2 Construction (A4-A5)		BN		x	x	x
		GHG1.3 Use (B1-B3, B5)		BN		x	x	x
		GHG1.4 Operational energy use (B6)		BN		x	x	x
		GHG1.5 Operational transport (B8)	tCO_2e $kgCO_{2e}$/user/yr	N		x	x	x
		GHG1.6 End-of-life (C1-C4)	tCO_2e $kgCO_{2e}/m^2$ gross floor area (GFA)/yr $kgCO_{2e}/m^2$ plot area (PA)/yr	BN		x	x	x
	Compensation	GHG1.7 Benefit and loads (D)		BN		x	x	x
ENE	Energy efficiency in buildings	ENE2.1 Energy need in buildings	kWh/m^2 heated floor area (HFA)/yr	B	*SN-NSPEK 3031:2021* (45), *ISO 52000* (46)	x	x	
	Energy carrier	ENE2.2 Delivered energy	$kWh//m^2/yr$	N	*SN-NSPEK 3031:2021*(45), *ISO 52000* (46), IEA EBC Annex 52 Task 40 (47), IEA EBC Annex 67 (48,49)	x	x	x
		ENE2.3 Self-consumption	%	N		x	x	x
POW	Power performance	POW3.1 Peak load	kWh/h	N		x	x	x

Category	Assessment criteria	Key Performance Indicator (KPI)	Unit	Building (B), neighbourhood (N) or both (BN)	Standards & References	Strategic planning phase	Implementation phase	Operational phase
		POW3.2 Peak export	kWh/h	N	IEA EBC Annex 52 Task 40 (47), IEA EBC Annex 67 (48,49)	x	x	x
	Load flexibility	POW3.3 Load flexibility	kWh/h	N		x	x	x
MOB*	Access	MOB4.1 Access to public transport	Meters, frequency, connections	N	NRVU (50), Input data in transport models (51), national and regional travel planners	x	x	x
		MOB4.2 Travel time ratio	Hours	N		x	x	x
		MOB4.3 Parking facilities	Number of places Parking cost	BN		x	x	x
		MOB4.4 Car ownership	Number of cars / households	BN		x	x	x
	Travel behaviour	MOB4.5 Mobility pattern	Amount of trips /person per mode of transport % share	N		x	x	x
		MOB4.6 Passenger and vehicle mileage	Personkm/year Drivingkm/year per energy carrier	N		x	x	x
	Logistics	MOB4.7 Freight and utility transport		N		x	x	x
QUA*	Process	QUA5.1 Demographic analysis	Quantitative/ Qualitative	BN	BREEAM Communities (9); City Keys (10), DGNB	x	x	
		QUA5.2 Stakeholder analysis	Quantitative/ Qualitative	N		x	x	
		QUA5.3 Needs assessment	Quantitative/ Qualitative	N		x	x	

Category	Assessment criteria	Key Performance Indicator (KPI)	Unit	Building (B), neighbourhood (N) or both (BN)	Standards & References	Strategic planning phase	Implementation phase	Operational phase
		QUA5.4 Consultation plan	Qualitative	N		x	x	
	Urban form	QUA5.5 Urban accessibility	No. of categories	N	IPCC (52), UN Habitat (53)	x		
		QUA5.6 Street connectivity	No. of well-connected streets			x		
		QUA5.7 Land use mix	Share of residents			x		
		QUA5.8 Green space	Share of land			x		
ECO*	Life Cycle Costs (LCC)	ECO6.1 Capital costs	NOK/m^2	BN	*NS 3454* (54), Norsk prisbok (55)	x	x	
		ECO6.2 Operational costs	NOK/m^2/yr	BN			x	x
	Cost benefit	ECO6.3 Overall performance	NOK/CO_2e	BN		x	x	x

***These categories will be further developed in 2022-2023.**

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. Visualisation of the results will be investigated in first versions of the data management (33) and data visualisation reports, developed further in subsequent versions of these reports, and tie back to subsequent versions of the ZEN definition report. More details on how to use the criteria and KPIs can be found in (11,12), whilst further details on the monitoring and tracking of the KPIs and criteria can be found in (33).

4.1 GHG emissions (GHG)

The primary goal of the ZEN research centre is for a zero emission neighbourhood to reduce its direct and indirect **GHG emissions towards net zero** over the analysis period. To achieve this, the neighbourhood must plan, design and operate buildings and their associated infrastructure components towards minimised life cycle GHG emissions from the whole life cycle; 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 (see Figure 8).

During the ZEN workshops, the top-down approach used in the Global Protocol for Community-Scale GHG Emission Inventories report (56) was suggested for use, but deemed unsuitable during the planning and design phases of a neighbourhood, as the top down approach does not follow the modular life cycle approach and has been developed for cities (not neighbourhoods) which are already operational. Additionally, it is difficult to separate out direct and indirect emissions from different emission factor sources (e.g. environmental product declarations) to follow the scope 1, 2 and 3 system boundaries suggested in (56).

Therefore, KPIs in the GHG emissions category build upon pre-existing standards and methodologies used in the building and construction industry, such as *NS 3720* A methodology for GHG emission calculations for buildings (30) and *NS 3451 Table of building elements* (39). Here it is important to note that the ZEN LCA methodology includes life cycle module B8 from NS3720 on operational transport use. These standards and methodologies will be adopted and expanded for use at both the building and neighbourhood level through future ZEN definition, ZEN guideline (11,12) and ZEN LCA reports (57).

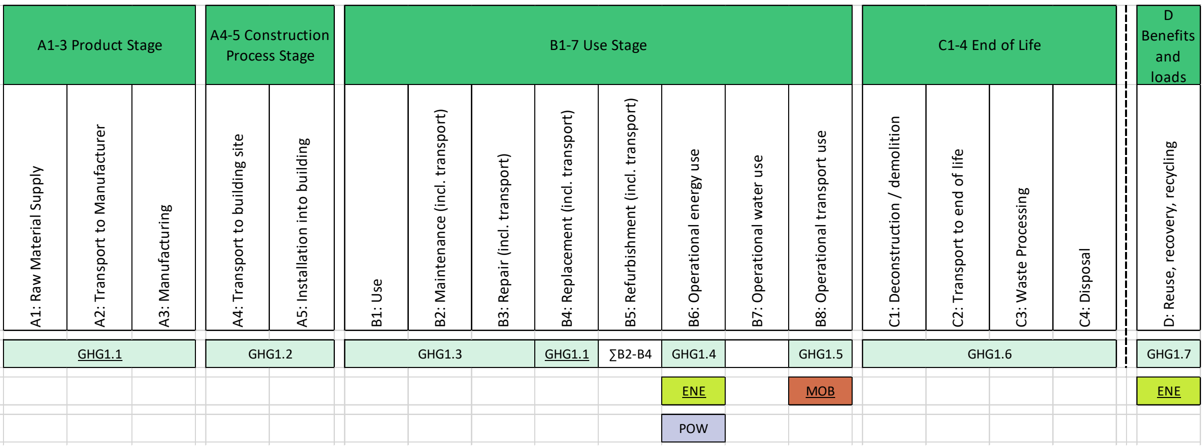

Figure 8. An overview of GHG KPIs per life cycle of buildings and infrastructure adopted from NS3720. Results from the Energy, Power and Mobility categories will feed into KPIs GHG1.4, GHG1.5 and GHG1.7, respectively

The KPIs for the GHG emission category are grouped into two assessment criteria "GHG emission reduction KPIs" and "GHG emission compensation KPI". This is the main strategy for the GHG emission category. As displayed in Figure 8, the KPIs for GHG emissions reduction are GHG1.1 Materials (A1-A3, B4), GHG1.2 Construction (A4-A5), GHG1.3 Use (B1-B3, B5), GHG1.4 Operational energy use (B6), GHG1.5 Operational transport (B8), GHG1.6 End-of-life (C1-C4). The KPI for GHG emission compensation is GHG1.7 Benefit and load (D).

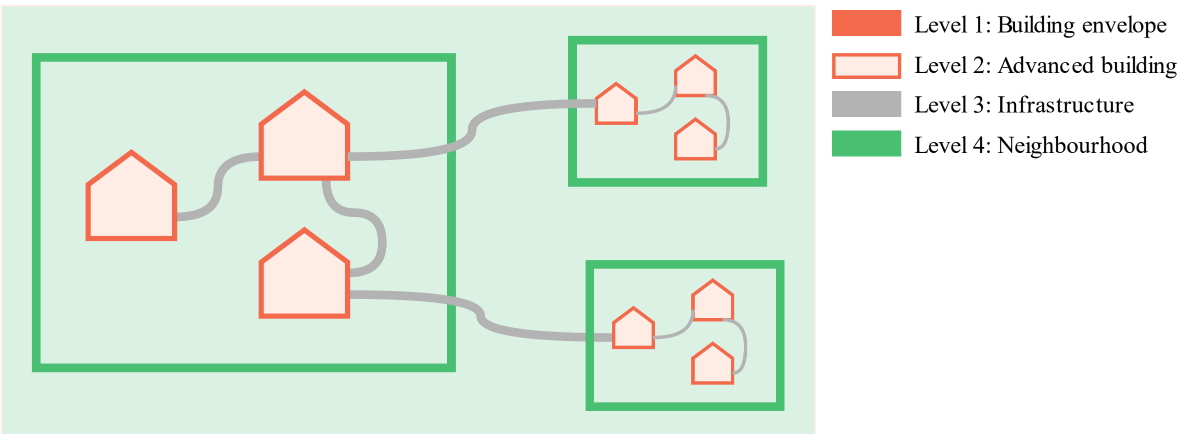

Figure 9. The four different assessment levels for the GHG emissions in ZEN definition.

GHG emissions can be calculated at four different levels: (1) building envelope, (2) advanced building, (3) infrastructure, and (4) neighbourhood (Figure 9). Table 3 shows the building elements included in each level, the correspondence with the *NS 3720* levels, and the reporting units for each level. The first ZEN level, building envelope, corresponds to the *NS 3720* Basic level, and includes the building elements 21, 22, 23, 24, 25, 26, 27, 28, 29 and 49 in *NS 3451 - Table of Building Elements* (39). Building element 49 represents materials used for local energy production systems. In *NS 3720* Advanced level is divided in two parts: the advanced building level and the infrastructure level (Table 3). At the ZEN advanced building level, building elements 21-69 should be included, which comprises the building envelope and all technical systems. The ZEN infrastructure level covers building element 71 to 79. The ZEN neighbourhood level comprises the first three levels, hence includes building elements 21 to 79. Each assessment level corresponds to a reporting unit (Table 3). When reporting, the functional unit should be reported according to the definition of a neighbourhood, defined as a group of interconnected buildings with associated infrastructure confined within a geographical area (see section 3.1). In addition, there is a series of reporting units (see Table 3).

It should be noted that the neighbourhood level also includes the GHG emissions related to B8: operational transport (i.e., user mobility both within the neighbourhood and to and from the neighbourhood), as a separate reporting unit (tCO_2e/user/year). It will be considered whether other GHG indicators should also use a reporting unit per user. The four ZEN GHG assessment levels and the correspondence with *NS 3720* levels are indicated in Table 3. Methods for assessing the land use change effects are included in the assessment methodology under basic or advanced with localisation. The reference study period is set to 60 years. The estimated service life of the buildings and neighbourhood is 60 years. Infrastructure should have an estimate service life of 100 years.

Table 3. Corresponding assessment levels in ZEN GHG emissions category and *NS 3720*, related building elements and reporting units

NS 3720 **assessment levels**	**ZEN GHG emissions assessment levels**	**Included building elements (as defined in *NS 3451*)**	**Reporting unit**
Basic, without location	(1) Building envelope	21-29 + 49	$kgCO_2e/m^2_{GFA}/yr$
Advanced, without location	(2) Advanced building	21-69	$kgCO_2e/m^2_{GFA}/yr$
	(3) Infrastructure	71-79	$kgCO_2e/m^2_{PA}/yr$
Basic or Advanced, with localisation	(4) Neighbourhood	21-79	tCO_2e
	B8: Operational transport		$kgCO_2e$/user/yr

* GFA – gross area, PA – plot area

The buildings within a neighbourhood are divided according to '*NS 3457-3*: 2013 Classification of construction works - Part 3: Building types', which covers building categories, such as apartment buildings, schools and nursing homes (40). The calculation of GHG emissions should follow the life cycle modularity principle in *NS 3720* (30). The KPIs connect the tracking and reporting of GHG emissions during the various project phases (strategic planning phase, implementation phase, and operational phase). Since the whole life cycle of the ZEN pilot area is to be included, biogenic carbon for wood and wood-based products should be calculated according to *NS-EN 16449* (44) and *NS-EN 16485* (58). Similarly, carbonation of concrete should be calculated according to *NS-EN 16757* (59).

A life cycle matrix for reporting total GHG emissions can be found in the 'ZEN guideline for the ZEN pilot areas. Version 1.0' report (11) and the Version 2.0 (12).. LCA reports for neighbourhoods should include information on building and infrastructure types, building areas, number of users, reference study period, system boundaries, scenario descriptions, bill of material quantities, emission data sources, results per building and infrastructure for each life cycle module and building part. Relevant reference values can be found in the report (60).

<u>GHG1.1 Materials (A1-A3, B4)</u>

The objective of this KPI is to minimise the total embodied GHG emission from a neighbourhood life cycle towards zero with a focus on material use across a reference period of 60 years. The goal is to reduce the embodied GHG emission from the production and replacement phases of materials (life cycle modules A1-A3 and B4) for each building and infrastructure within the neighbourhood.

GHG1.2 Construction (A4-A5)

The goal is to reduce resource use and GHG emissions from the transport to construction site, construction, building and assembly work (life cycle modules A4-A5). The system boundary for construction site activities shall be defined in accordance with *NS 3720*. Thus, the construction site activities shall include transport of materials, masses and equipment to and from construction sites; mobile and stationary machineries; energy use for heating, cooling, drying, lightning at the construction site and transport and processing of waste generated from construction site activities (see figure 9 in (12)).

GHG1.3 Use (B1-B3, B5)

GHG emissions from the operation of buildings and infrastructure (B1-B3 and B5) are direct GHG released by or captured in building elements (B1; e.g. concrete carbonation), maintenance operations (B2; e.g. cleaning, changing filters), repair (B3; e.g. fixing a broken glass pane, keeping the windows frame), and refurbishment (B5; e.g. refurbishment of a kitchen, bathroom or facade).

GHG1.4 Operational energy use (B6)

A prerequisite for GHG 1.4 KPI are the KPIs in the energy category, ENE 2.1 Energy need and ENE2.2 Delivered and exported energy. GHG1.4 KPI is used to calculate the GHG emission from energy consumption in operation phase per energy carrier. The calculation of this KPI should be completed according to *NS 3720* for life cycle module B6. The GHG emission from exported energy over the building's system boundary must be reported separately under GHG1.7 (Benefits and loads, Module D). Scenarios for GHG emissions using different energy carriers should be performed based on *NS 3720* scenario 1 (Norwegian electricity mix) and scenario 2 (European electricity mix).

The methodology outlined in *NS 3720* and *NS-EN 16258* will be used for GHG emission calculations in ZEN, this includes the energy emission factors for various energy carriers outlined in Table 4. This will be the case until ZEN-specific emission factors have been developed in work package 4. For district heating and cooling, a case specific emission factor can be developed by modelling the proportion of different energy carriers for a specific company or region from fjernkontrollen (61) (Fjernkontrollen is a website provided by Norsk Fjernvarme, Norwegian district heating, which provides an overview of energy mixes for district heating in Norway) and by using the emission factors given below. Alternatively, a national emission factor for district heating can be developed using the same modelling principles described above.

Table 4. Energy emission factors per energy carrier

Energy Carrier	**NS 3720 (gCO_2e/kWh)**
Electricity	Scenario 1 NO: 18 Scenario 2 EU28+NO: 136
Hydroelectricity	2-20
Wind power	3-41
Coal power	660-1300
Natural gas	380-1000
Solar energy (PV)	13-190
Biothermal	8,5-130
Nuclear power	3-35
Thermal power from natural gas with CCS	Ca. 100
Thermal power in Norway	450
Thermal power in EU	800

GHG1.5 Operational transport (B8)

A prerequisite for GHG1.5 KPI is that the KPI for MOB4.5 and MOB4.6 has been calculated. The mobility KPIs is used to calculate the GHG emissions from converting to fossil free and emission free transportation technologies and shifting transportation modes towards more active transport (i.e. walking, cycling) in the neighbourhood. The methodology outlined in NS 3720 and NS-EN 16258 will be used for GHG emission calculations in ZEN, this includes the well-to wheel transport emission factors for various energy carriers outlined in Table 5.

Table 5. Well-to-wheel transport emission factors per energy carrier

Energy Carrier	NS-EN 16258 and NS 3720 (gCO_2e/kWh)
Diesel	251
Petrol	248
Marine gasoil	253
Bioethanol	161
Biodiesel	163
Heavy fuel oil	234
Natural gas (LNG)	380-1000
LPG (propane and butane)	209
Electricity	Scenario 1 NO: 18 Scenario 2 EU28+NO: 136

GHG1.6 End-of-life (C1-C4)

The goal of this KPI is to increase resource efficiency and save GHG emissions by preserving existing components and materials. GHG1.6 includes emissions from demolition, waste treatment and disposal activities. The emissions from these activities are calculated using scenarios for the percentage of reuse, recycling, energy recovery and/or landfill. The GHG emissions from biogenic carbon absorbed during the production phase is released under C3-C4.

GHG1.7 Benefits and loads (D)

The goal of GHG1.7 is to increase resource efficiency and reduce GHG emissions through implementation of circular economy principles. This KPI includes the benefits and loads outside of the system boundary linked to reuse, recycling, material energy recovery from the end of waste state and/or exported operational energy resulting from production and construction stage (A1-A5), use stage (B1-B7) and end of life cycle stage (C1-C4).

4.2 Energy (ENE)

One of the most important goals for a zero emission neighbourhood is that it should become highly **energy efficient**, as the most environmentally friendly energy is the energy not used. Thus, reducing energy demand and energy use should always be the first priority in the transition towards reaching a **decarbonised energy system**, as recognised in the Energy Union's political priorities (8) and the Strategic Energy Technology Plan (SET-Plan) key actions (62).

A zero emission neighbourhood shall be powered by smart, **renewable energy** sources. This means that design and operation of a ZEN pilot area must be focused on using renewables which operate in synergy with the surrounding energy system. To achieve this, there will be a focus on energy storage, power/load management, digitalisation, smart grids and system optimisation.

The KPIs in the energy category refer solely to the energy flows in the operational phase, and thus exclude embodied energy. This is because embodied energy is already covered by the GHG emission category. However, the operational energy flows will be modelled and/or estimated in all project phases. During the operational phase the KPIs should be evaluated directly from measurement, as far as possible. During the planning and design phases the KPIs should be estimated, e.g., by means of simulations. The energy demand and energy use of the neighbourhood should be calculated/measured over one year with an hourly (or sub-hourly) resolution. These measurements should be presented as graphical information, such as load profiles, load duration curves and color-coded carpet plots.

System boundary level

The energy and power KPIs are calculated at either **the building assessment boundary level (B)** or the **neighbourhood assessment boundary level (N).**

The building assessment boundary level (B) includes energy use within the buildings, harmonized with SN-NSPEK 3031:2021 (45).

The neighbourhood assessment boundary level (N) is an expansion of the building assessment boundary. It includes energy use for: people transport inside buildings (e.g., elevators, escalators), data servers, refrigeration and other industrial processes inside buildings, outdoor lighting, snow melting, and, most notably, the charging of electric vehicles, whether inside or outside of buildings. Local energy generation not connected to a specific building is also considered. In other words, the neighbourhood assessment boundary includes, in principle, all energy flows within the neighbourhood.

Description of ZEN project and reference project

In the Energy and Power category, the KPIs should be calculated for both the pilot and the pilot's reference project (sometimes referred to as reference area, project, or case). The reference project represents the business-as-usual case for the pilot area.

The reference project is a project that represents the zero emission neighbourhood if it was designed and built according to today's minimum standards (63) (or the relevant historical minimum standard for existing buildings) instead of being designed, built and managed to reduce GHG emissions towards net zero within its lifecycle. The purpose of the reference project is to act as a benchmark with reference values to document if the pilot has managed to reduce the energy use and improved the utilisation of the energy infrastructure, so that the pilot area is closer to its performance on the ZEN definition.

A representative reference project should be tailored to each pilot area, with the same floor area and number of users as the pilot area. A new reference project will typically have direct electric heating. For some indicators it might be necessary to calculate an intermediate reference project with district heating.

Assessment criteria

The Energy KPIs are split into two assessment criteria, namely *'energy efficiency in buildings'* and *'energy carriers'*.

Energy efficiency in buildings: This assessment criteria looks at the energy performance of the buildings within the building assessment level. The criteria consider energy demand within the building assessment level, and is suitable for buildings in the design phase, and is not measured in the operational phase for neighbourhoods.

Energy carriers: This assessment criteria considers the energy use, generation, and energy flows in the pilots at the neighbourhood assessment level. The criteria look at energy flow per energy carrier. The KPIs within this assessment criteria can be measured during the operational phase of the project.

ENE2.1 Energy need in buildings (*Energy efficiency in buildings)*

ENE2.1 considers the total simulated energy need (or energy demand) of all the buildings in a pilot area and is calculated as kWh/m^2 heated floor area (BRA) per year ($kWh/m^2/yr$) on the building assessment level for the ZEN project and the reference project.

Energy need in buildings is an indicator which must be simulated as it shows the energy need of the building envelope when the losses in the buildings' heating system is not accounted for. The energy need is calculated according to the *building assessment boundary*, which must be harmonised between ISO 52000 (46) and SN-NSPEK 3031 (45). This typically includes building energy need for: heating, cooling, ventilation, domestic hot water, lighting, and plug loads. The buildings are separated according to NS 3457-3 (40) and SN-NSPEK 3031, which covers building categories, such as apartment buildings, schools and nursing homes. The energy need in buildings is calculated as annual totals and is not measured in the operational phase of the neighbourhood. Local energy generation is not considered, only the *calculated energy demand* of the buildings is considered. The purpose of ENE2.1 is to reduce the energy need of buildings as much as possible, and a reduction in net energy demand in the ZEN project compared to the energy demand in a reference project.

ENE2.2 Delivered energy (*Energy carriers)*

ENE2.2 evaluates the delivered energy on the neighbourhood assessment level for all energy carriers individually. The delivered energy (imported energy) should be calculated as an hourly (or sub-hourly) mismatch between energy use and energy generation over one year. As ENE2.2 refers to the annual totals for delivered energy, it can be reported in a table format. The purpose of ENE2.2 is to reduce the delivered energy, and hence reduce climate gas emissions to the area.

ENE2.3 Self-consumption (*Energy carriers)*

Self-consumption is an indicator that tells us in what degree the electricity that is produced in an area is used directly in that area (and that does not need to be exported to the energy-grid). Self-consumption is related to the factor self-generation which tells what share of the energy use in an area is covered by self-generated energy. The purpose of ENE2.3 is to increase the degree of self-consumption in an area.

In the current version of the ZEN definition the ENE2.3 is only calculated for electricity. Self-consumption and self-generation tell us to what degree local energy production and energy use in an area co-relates. This can be better explained with reference to a graph showing daily profiles, such as in Figure 10, where electricity is considered, and PV is assumed as local generation in a single building (64). The areas A and B represent the electricity delivered and electricity exported, respectively. The overlapping part in area C is the PV electricity that is utilized directly within the building.

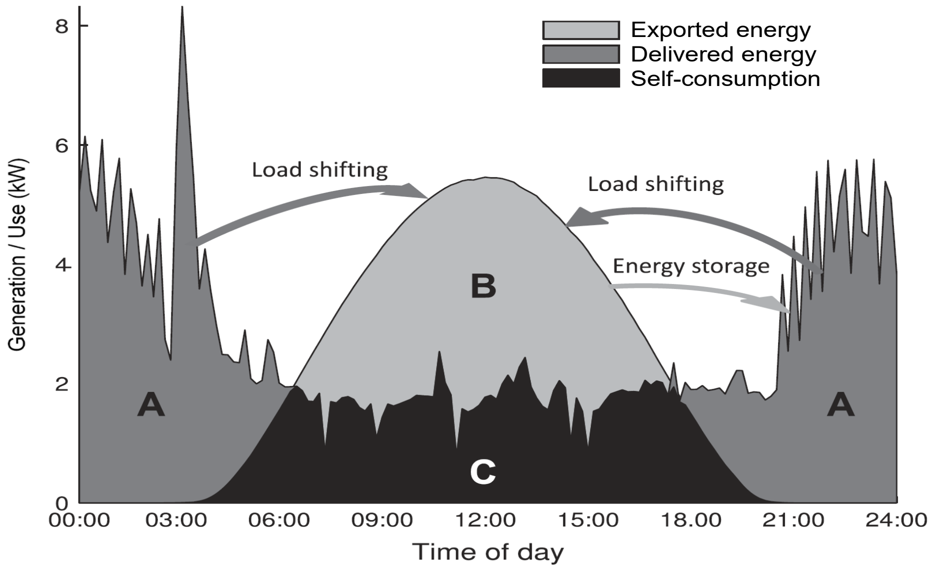

Figure 10. A schematic outline of the daily energy use (A + C), energy generation (B + C), and self-consumption (C) in a building with on-site PV. It also indicates the function of the two main options (load shifting and energy storage) for increasing self-consumption. Source: adapted from (65).

In this example (figure, the daily self-consumption KPI is calculated as the self-consumed part (area C) of locally generated energy relative to the total generation (area B+C), while the self-generation KPI is the self-consumed part (area C) relative to the total energy use (area A+C). For example,

$$\text{Self-consumption} = \frac{\textit{local energy generation consumed on premices}}{\textit{total local energy generation}} = \frac{C}{B+C} \quad [1]$$

$$\text{Self-generation} = \frac{\textit{energy use covered by local energy generation}}{\textit{total energy use}} = \frac{C}{A+C} \quad [2]$$

In ENE2.3 the self-consumption should be calculated with at least hourly resolution over a period of 1 year, and the effect of local storage should be considered.

4.3 Power (POW)

A zero emission neighbourhood manages the energy flows within and between buildings and exchanges with the surrounding energy system in a **flexible** way, responding to signals from smart energy grids, and facilitates the transition towards a **decarbonised energy system**. Therefore, the ZEN definition shall have a strong focus on energy flows through energy grids with a strong focus on the peak loads (electricity and district heating). The KPIs in the power (POW) category refer solely to the energy flows between the neighbourhood and energy grids in the operational phase. However, the operational energy flows should be estimated in all project phases. During the operational phase, the POW-KPIs should be evaluated directly from measurement (as far as possible). During the planning and design phases the KPIs should be estimated, e.g., by means of simulations. All POW-KPIs are calculated with an hourly or sub-hourly resolution. The Power KPIs should be calculated in combination with the Energy KPIs. The documentational requirements for the Power category are the same as the requirements for the energy category, and the same boundary levels and reference areas applies to both categories.

The category is split into two assessment criteria, namely 'power performance' and 'load flexibility'. Both assessment criteria have a series of KPIs.

Power performance: This assessment criteria contains the dimensioning peak load and peak export and evaluate the strain of the peak loads of the pilot on the electricity and district heating grid.

Load flexibility: This assessment criteria reflects whether the neighbourhood exchanges energy with the surrounding energy system (electric and district heating) in a flexible way. Since the coordination of energy flows with smart grids (both electric and thermal) occur at an hourly or sub-hourly level, the focus is on the optimisation of the net load profiles on typical days, distinguishing between seasons (e.g., winter, summer) and weekdays (e.g., weekday, weekend). The load flexibility indicators will reflect the difference in load profiles in the ZEN and in a reference project, where there is limited control and demand response.

There is currently three Power KPIs. The Power key performance indicators are calculated according to the *neighborhood assessment boundary* level for electricity and district heating (which are energy carriers supplied by a grid). In addition to the calculation of the Power KPIs there are requirements set to document the net annual load profile and the load duration curve for electricity and district heating. The KPI "Utilisation factor" was previously a KPI in the power category but has been removed as a KPI in the category after testing it on some of the pilots, as it proved to not be a good indicator of the utilization of the grid (66).

POW3.1 Peak load (*Power performance)*

The peak load KPI and the peak export KPI are simply the extreme values of the net duration curve. The peak load indicator refers to the maximum positive hourly (or sub-hourly) import load of electricity/district heating to the neighbourhood during an operational year and can be found by finding the extremes on the net load profile/load duration curves of electricity/district heating net energy use over one year, as shown in Figure 11. The objective of POW3.1 is to reduce the peak load of electricity and district heating to reduce the strain on the energy grid.

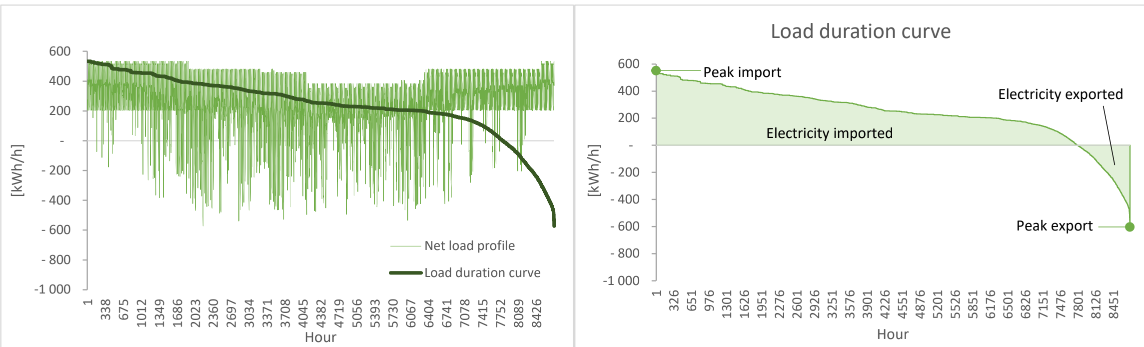

Figure 11. The net load profile and load duration curve of electricity in a pilot.

POW3.2 Peak export (*Power performance)*

The peak export indicator refers to the maximum net hourly (or sub-hourly) export load of electricity (when the electricity production is higher than the electricity use) from the neighbourhood during an operational year. If there is no net export, then the peak export is equal to zero. Export of district heating is currently not considered in POW3.2 as export of heat is more complicated than the export of electricity, but it may become relevant in future versions of the ZEN definition.

<u>POW3.3 Load flexibility indicators (Load flexibility)</u>
The load flexibility indicator(s) will reflect how well the neighbourhood exchanges energy with the surrounding energy system (electric and district heating) in a flexible way. These KPIs will be developed in subsequent versions of the ZEN definition and will likely be calculated at either the neighbourhood assessment level or building assessment level, with an hourly or sub-hourly resolution. Since the coordination of energy flows with smart grids (both electric and thermal) occur at an hourly or sub-hourly level, the focus is on the optimisation of the net load profiles on typical days, distinguishing between seasons (e.g., winter, summer) and weekdays (e.g., weekday, weekend). The load flexibility indicators will reflect the difference in load profiles in a reference project, where there is limited control and demand response. Key performance indicators for 'load flexibility' will be tested and eventually included in the ZEN definition, as they emerge either from in-house development during the ZEN research centre or from external sources.

4.4 Mobility (MOB)

The ZEN definition of mobility includes both residents' and other users' daily transport patterns within and to/from the area, as well as freight and utility transport. So far in ZEN mobility case studies, there has primarily been a focus on residents' daily travel activity and mobility, while mobility-related conditions related to residents' holidays, visitors to the area, and goods and service deliveries to the area have not been involved in the activities. However, these aspects may be included in new ZEN cases.

When key indicators of mobility in a zero-emission area were to be defined, there was a strong desire from ZEN partners to choose relevant indicators from existing indicators from BREEAM Communities (9) and relevant national studies (67). To achieve the goal of a zero-emission area, the area should promote **sustainable transport patterns** and smart mobility systems both locally and regionally. This can be achieved through good physical planning and good logistics.

Sustainable transport patterns can be achieved through overall site design and integrated traffic planning, which is supported by smart mobility systems. These aim to reduce the environmental impact of transport in the area and improve the quality of life for users. In addition, smart mobility systems contribute to reductions in travel time, emissions, and congestion. At the same time, they promote and encourage healthier and more sustainable travel choices (68). However, an important precondition for achieving sustainable mobility related to a ZEN neighborhood is the project's location, including distance to the city centre and local centres, and quality of public transport in the area. These are factors that should be considered at an early stage, <u>before</u> choosing a project location. The key indicator describing the travel time ratio between bus and car may be used to illustrate the competitive relationship between the modes of transport and the extent to which public transport may represent a real alternative to a car in the planned neighbourhood location.

Changing shopping patterns in the population, with an increase in e-commerce and home delivery of goods and services, have consequences for both passenger travel and transport patterns for goods and benefit transport. New modes of transport (e.g., micromobility, car sharing, "Mobility as a Service" - MaaS) are examples of shared transport solutions that represent an increased possibility of "tailoring" mobility services to individual transport needs. Increased use of and adaptation to digital meeting places (e.g., Teams, Zoom, etc.) allows for more flexible solutions in working life, with increased use of home office, "near-office" etc. These trends affect both how often one needs to travel, where/how far one needs to travel, and what transport options one has at one's disposal, and thus gives an impact on changing mobility patterns for the population. Similarly, these trends also affect the operation and organisation of commercial transport, both related to logistics and delivery of goods, and the operation of conventional and new transport solutions with associated infrastructure.

Traditionally, the National Travel Survey (NRVU) is the most comprehensive source of information about the population's mobility and travel patterns (50). This survey provides information about the population's "daily travels" and is based on information about all trips the participants make in a single day. Taken together, the survey will provide a representative picture of the population's travel activity per day, Monday - Sunday. However, the survey provides limited information on the consequences of recent years' developments in new forms of transport and developments in e-commerce/home delivery, sharing economy and digital solutions in working life, as there is a certain backlog from data collection to the data material being made available for analysis. These are conditions and developments that will be of particular interest to ZEN pilots. A development with steadily declining participation in the survey over several years, and increased geographical bias in the sample, represents an additional challenge in terms of how data from this survey can best be used in analyses and calculations.

In order to include mobility consequences of new services and infrastructure offered in the pilot areas of ZEN, in KPI calculations and assessments in the project, more knowledge is needed about how these new forms of transport and services that emerge from digital development affect mobility patterns and logistics services. Access to more empirical data collected with this in mind would strengthen the mobility-related analyses in ZEN, and it should be considered whether this is something that partners in ZEN can contribute to, e.g., by facilitating data collection among residents/employees in areas where such offers have already been launched/established.

So far, the work on key indicators of mobility has primarily included conditions related to daily passenger journeys during the use phase, and not to freight and utility transports that will also be a natural part of the use phase of the pilot areas. Transport in the construction phase is part of the GHG1.2 Construction phase.

Mobility KPIs are MOB4.1 Access to public transport, MOB4.2 Travel time ratio, MOB4.3 Parking facilities, MOB4.4 Car ownership, MOB4.5 Mobility pattern, MOB4.6 Passenger and vehicle mileage, MOB4.7 Freight and utility transport. KPIs are calculated according to the system limit for neighbourhood assessment and do not include transport inside buildings (e.g., elevators and escalators).

<u>MOB4.1 Access to public transport</u>

The objective of this key indicator is to facilitate frequent and easily accessible public transport, as a climate-efficient transport choice in the ZEN pilot areas. The key indicator will consider links to existing and planned transport nodes (such as trains, buses, trams, or metro), as well as links to local city centres. The distance from a building within the ZEN pilot area to the nearest transport key, as well as the transport frequency in peak and low times in urban and rural areas, as specified in BREEAM communities technical manual, can be used as a reference (9). NRVU includes questions about distance from dwelling to stop and frequency of departures from the stop. Based on these two conditions, a qualitative variable is calculated that describes public transport access on a five-stage scale from Very good to Very poor (69). If local data from NRVU are available for the pilot area, these can be used directly as an indicator. If such data do not exist, the procedure described in the NRVU 2018/19 key report can be used to calculate this indicator. However, both ways of identifying an indicator are based on "current" public transport services, and do not capture any changes in e.g., frequency or stop location as a result of the establishment of the ZEN pilot. The likelihood of such adjustments must be considered when calculating KPI values for the completed pilot area.

MOB4.2 Travel time ratio

The objective of this indicator is to consider the competitive relationships between private motorised transport, public transport and active transport options for movements between the pilot area and the city centre and/or closer local centres and transport hubs. Travel time information can be obtained from travel planners such as EnTur and the equivalent offered by the various local public transport companies, possibly in combination with information from map-based services such as Google Maps. Travel times and travel time conditions can be calculated/retrieved for both rush and low traffic periods, to capture any queue problems, and should include walking times to/from the stop/parking lot. Travel times by public transport can be adjusted for changes in the need to change bus/train and associated waiting times, related to changes in public transport routes caused by the pilot project. The likelihood of such adjustments must be considered when calculating KPI values for the completed pilot area. The key indicator is calculated e.g., as a travel $time_{bus}$ / travel $time_{car}$, and if relevant travel $time_{bus}$ / travel $time_{bike}$ for each origin-destination relation. If relevant, calculations can be made for several locations within the pilot area.

MOB4.3 Parking facilities

The parking norm specifies local regulations for how many parking spaces should/can be established/offered to residents or workplaces in an area. In areas with low parking capacity and/or high costs associated with parking, this may incur restrictions on residents' ability to own a car themselves. Parking options can be specified as the number of parking spaces available per unit, possibly in combination with the cost of using the parking facilities. This KPI will be further developed in the next version (version 4.0) of the ZEN definition and may also include topics such as charging facilities for electric vehicles.

MOB4.4 Car ownership

Car ownership is an important explanatory factor for both the extent of travel activity and the use of travel modes. NRVU provides information about car ownership in households and can be used alone or in combination with e.g., information about parking facilities and the correlation between parking facilities and car ownership to calculate expected car ownership per household in the ZEN neighborhood. NRVU also provides information about energy carriers (e.g., petrol, diesel, electric, and various hybrid variants) for the vehicle fleet. This KPI will be further developed in the next version (version 4.0) of the ZEN definition and may also include access to vehicles included in car sharing schemes.

MOB4.5 Mobility pattern

The purpose of this key indicator is to calculate the total trip production (number of daily trips per person) for residents, and how these trips are distributed according to active modes of travel (e.g., on foot and bicycle), public transport (e.g., bus, tram, boat, train and track) and private motorised means of transport (e.g. private car). NRVU can be used directly or in combination with information about parking facilities and car ownership to calculate expected trip production and distribution by mode of transport adapted to the ZEN pilot areas. Key indicators are the total number of trips/person/day; number of trips/person/day by mode of transport, and % share of trips by each mode of transport. Changes in trip length and mode choice due to shifts in spatial quality and availability of local services and attractions, can be considered based on KPIs under the Spatial qualities category. This KPI will be further developed in the next version (version 4.0) of the ZEN definition.

MOB4.6 Passenger and vehicle mileage
NRVU provides distance information for the daily travels. This is used alone or in combination with trip lengths derived from KPIs under Spatial quality, together with calculated trip production and distribution of transport alternatives (KPI MOB4.5) to calculate the total annual mileage for passengers (person km/year) and private motorised vehicles (vehicle km/year) for the neighborhood residents. Vehicle mileage can further be split into mileage with fossil fuel carriers and with zero-emission alternatives respectively. This will be input to greenhouse gas calculations in GHG1.5 Transport in operation.

MOB4.7 Freight and utility transport
This KPI will be further developed in the next version (version 4.0) of the ZEN definition.

4.5 Spatial qualities (QUA)

Within this report, we see spatial qualities as qualities of a neighbourhood perceived by its users and influenced by the built environment. A spatial quality may for example be accessibility; a close distance to different types of attractions, such as parks, public transport, services, nurseries or schools. It is important to pay attention to the different qualities of urban space, since it affects both the overall attractiveness and environmental, social, and economic aspects of sustainability. The spatial qualities category within ZEN covers both process and urban form.

Process
The importance of an inclusive **process** with regard to citizen involvement and inclusion of all parties is lauded in global and regional development agendas as the United Nations (UN) 2030 Agenda for Sustainable Development (36), New Urban Agenda (NUA) (70) or the European Urban Agenda for the European Union (71). Positive effects of citizen involvement both to the process and the outcome of participation are documented in academic literature (72,73).

The aim of the sub-category/assessment criterion of **process** under the category of spatial qualities is to provide KPIs that will help stakeholders involved to plan, facilitate, and evaluate a process that foster the participation of users and the consideration of their needs and demands within a ZEN development. The developed KPIs are building on existing KPIs in e.g. BREEAM Communities (9) or CityKeys (10). Ideally, the described process enables co-creation between stakeholders involved to realize a higher output of innovation and satisfaction – regarding realisation of a successful neighbourhood development among the involved stakeholders and especially users of the neighbourhood. This assessment criteria ensures that the developed strategic plans for the neighbourhood are based on local demographic trends and priorities, as well as the users' needs, ideas, and knowledge. By assessing and incorporating the users' needs, the quality and acceptability of the development throughout the design and construction processes, are ensured.

Urban form
According to the IPCC (52), urban form and land use, i.e the size, shape, and configuration of an urban area or its parts, are strongly linked to GHG emissions and energy demand. This is especially the case when it comes to transportation demand and amount of car driving. Based on a world-wide research consensus, the IPCC have pointed out that density, land use mix, connectivity and accessibility are some of the key drivers for reducing GHG emissions (52). In addition, sufficient green space is also an important part of the built environment for climate adaptions and carbon sequestration (74) as well as for leisure and wellbeing (75) . Interestingly, from a ZEN perspective, there are many overlaps

between the urban form variables that reduce GHG emissions and the ones that are important for creating attractive locations for residents as well as workplaces (76,77). According to research, urban form also influences social integration and the potential for co-presence in public space (78).

The KPIs for spatial quality that concerns urban form and land use have been developed through previous work with the ZEN toolbox "Spatial indicators". ZEN spatial indicators are a set of metrics that measure the potential for sustainable and attractive neighbourhoods according to recommendations from UN Habitat (53) and IPCC (52). The aim has been to evaluate plans and urban development proposals and support further stages of urban design by GIS elaborations and policy recommendations. The ZEN spatial indicators have so far been adapted to early phase of planning ("Kommundelplaner"). Upcoming further development will be concentrated on spatial Indicators focusing on later planning phase ("Reguleringsplaner"). and a closer scale such as design of street, public space or building facade

The ZEN KPIs for urban form can be seen as a summary of the ZEN spatial indicators and highlight some of the most fundamental aspects of urban form and land use. The spatial indicators have been developed in close collaboration with ZEN pilot projects in Trondheim, Bærum and Bodø. All metrics used can be measured with open-source GIS software to be easily operated. The required background data are usually available at Norwegian municipalities (alternative methods for measuring the KPI value, if the assessor is not familiar with GIS, have also been proposed in the definition guideline report).

The current selection of ZEN spatial indicators and KPIs for urban form and land use has been developed by the research group ZEN-SMS (spatial morphology studies in ZEN) at NTNU-AD (Faculty of architecture and design at NTNU).

QUA5.1 Demographic analysis

A demographic analysis should be implemented at an early stage of ZEN development to define the scope of the proposed development regarding current demographic and user profiles and future trends of the neighbourhood and the larger region.

QUA5.2 Stakeholder analysis

A stakeholder analysis identifies the neighbourhoods' users and stakeholders that are important to include in the process to ensure high quality spatial qualities in the ZEN neighbourhood.

QUA5.3 Needs assessment

A need assessment must be provided to identify actual and future needs and requirements of the users of the ZEN neighbourhood. The need assessment is building on the results of QUA 5.1 and 5.2, where relevant current and future users were identified.

QUA5.4 Consultation plan

A consultation plan should be developed and implemented over the lifetime of the ZEN neighbourhood to ensure the inclusion of the users' needs and requirements in the ZEN development process as well as the operation of the neighbourhood. The aim of the consultation plan is to ensure that the needs, ideas, and knowledge of the community are used to improve the quality and acceptability of the ZEN development throughout the design and construction processes and into the operation phase.

<u>QUA5.5 Urban accessibility</u>
QUA5.5 Urban accessibility is the access to the following five categories of urban attractions within 1 km walking distance for at least 90 % of the residents and workers in an area: local public transport, fast regional public transport, elementary school, local service cluster, and attractive open public spaces.

<u>QUA5.6 Street connectivity</u>
QUA5.6 Street connectivity is the number of spatially integrated streets and walking distance to surrounding neighbourhoods.

<u>QUA5.7 Land use mix</u>
QUA5.7 Land use mix is the balance between residents and workers within the neighbourhood and a buffer area of 500 metres air distance.

<u>QUA5.8 Green space</u>
QUA5.8 Green space is the share of valuable green open public space of all land area within the neighbourhood and a buffer area of 500 metres air distance.

4.6 Economy (ECO)

As specified above, economic sustainability will be an important pillar of consideration if ZEN pilot areas were to be mainstreamed. Developing a group of interconnected buildings into a Zero Emission Neighbourhood will likely entail increased capital costs during the construction phase, but these will be offset by lower operational costs during the operational phase, with possible savings during the operational phase. Economic KPIs are therefore important and relevant and they are also included in evaluation frameworks in neighbourhood approaches, such as Sustainable Positive Energy Neighbourhoods (SPENs) (79) and research networks such as IEA EBC Annex 83 Positive Energy Districts Subtask C (80).

In this category, that focuses on economic sustainability, costs will be considered from the perspective(s) of a prioritised selection of neighbourhood stakeholders. As ZEN development is a long-term undertaking, prioritisation may need to be done by phases (strategic planning phases, implementation phase and operational phase) where each phase must consider its prioritised selection of neighbourhood stakeholders. The ZEN research centre is interested in harmonising life cycle costing (LCC) methodology *NS 3454* (54) with the ZEN GHG emission methodology. Harmonising will also allow the two categories – economy and GHG emission – to rely on the same system boundaries. Such an approach will save time and effort on data collection, as the same life cycle inventory data can be applied in both instances.

Three key performance indicators are recommended; ECO6.1 capital costs, ECO6.2 operating costs and ECO6.3 overall performance, to demonstrate the economic performance of each ZEN pilot.

<u>ECO6.1 Capital costs</u>
This indicator captures capital costs calculated according to *NS 3454* (54). Capital costs refer to building construction cost and the cost of assets or items that are purchased or implemented with the aim of improving the carbon emissions of the neighbourhood. It is expected that there will be a higher investment in more energy-efficient and low to net zero emission buildings and infrastructure. This indicator will be assessed at both the building and neighbourhood level and will ascertain costs associated with, amongst other things, the energy system and material procurement.

ECO6.2 Operating costs
This indicator captures annual operating costs, such as management, operation, maintenance, replacement, development, consumption and cleaning costs. In other words, operating costs refer to capital-related annual costs for those assets or items purchased or implemented for reducing the carbon emissions of the neighbourhood. This indicator will be assessed at both the building and neighbourhood level.

ECO6.3 Overall performance
This indicator will outline a set of indicators that provide an evaluation to selected stakeholders of the relative benefits of a particular choice of zero emission strategies and/or measures. This set of indicators will summarise both the capital and operational costs in a single indicator. As the ZEN research centre is interested in the cost/benefits of implementing zero emission strategies and/or measures in order to reach the ZEN definition (81), one preliminary plan is to look at the cost of implementing different zero emission strategies and/or measures in a neighbourhood in terms of NOK/CO_2e saved. This set of indicators can also consider additional indicators such as payback period or return on investment (ROI) that are familiar to investors.

Drawing from a life cycle costing approach, further work will build on these three key performance indicators, in collaboration with ZEN partners, so that these indicators can contribute to making environmentally responsible investment decisions in the development of zero emission neighbourhoods.

5 Innovation (INN)

There are inherent difficulties in assigning KPIs for the evaluation of innovation-related activities. Firstly, innovation is complex and uncertain; secondly, innovation impacts can only be appraised in the long term; thirdly, innovation causes complex and multiple effects that do not evolve linearly.

Developing a performance measurement for innovation in ZENs would also require identification of indicators that can be validated, which have potential for comparability, are highly aggregated, and are useful when creating a ZEN (82). The aforementioned information does not exist due to the novel nature of the ZEN concept to date, and hence Innovation in ZENs does not have a performance metric attached.

With that said, in the ZEN Research Centre, innovation is a critical success criterion, and innovation activities in ZEN reflect user needs for new solutions in the market to realise the vision of zero emission neighbourhoods.

A methodology outlining how to work with innovation in ZENs may be required until knowledge around developing ZENs becomes commonplace. Challenges of replicability and scalability of solutions may result in innovation remaining important in ZEN creation (at least for some time). A prescribed methodology could assist stakeholders in the planning, development, and operation of a ZEN across aspects including Greenhouse gas emissions, (GHG), Energy (ENE), Power (POW), Mobility (MOB), Economy (ECO), and Spatial Qualities (QUA).

A complex network of stakeholders is necessarily involved in a ZENs' planning, implementation and operation. Social innovation (83) can help facilitate creation of context responsive ZENs whereby unique demographics and stakeholder/user needs are incorporated. Innovation as a mindset, and social innovation, both seek to boost a culture of innovation where the focus is people-centric, cross-disciplinary and collaborative.

A holistic approach to innovation for ZENs should incorporate three core elements. That is innovation as an outcome; a process; and as a mindset (84), see Figure 12 and Table 6. Excellence in outcomes arise from excellence in an innovation process which is heightened by innovative mindsets. Such a comprehensive approach to innovation will increase innovation success (84). These three core elements can assist stakeholders in creating a ZENs.

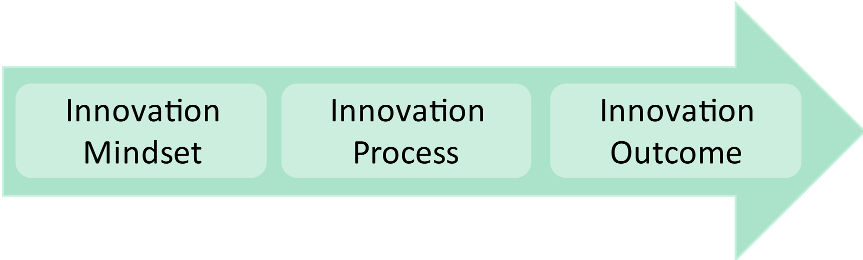

Figure 12. Holistic approach to innovation considers mindset, process, and outcome.

Mindset (culture) - Innovation is doing something better than it currently is. It requires a good understanding of what is currently being done and a change in thinking. An innovation mindset aligns stakeholders and manifests the culture needed for innovation to happen. Encompassing a mindset that predisposes stakeholders to be risk taking, cross-disciplinary, and open to varied ways of thinking will help to establish the state necessary for innovation. 'State' implies something habitual and lasting. It is about instilling and ingraining a mindset that prepares the stakeholders for innovation so that there is proper engagement in the innovation process to achieve the desired innovation outcome.

Process (management) - Process innovation involves the management mechanisms which affect how an innovation idea is nurtured from inception to potential results exploitation. Management mechanism aims to accelerate the speed and number of good ideas that add value creation to stakeholders, and in turn maximise innovative output. There is a strong link between good/successful innovation processes and subsequent outcomes. In ZENs, there is an advantage in leveraging a streamlined innovation management framework which does not add too much complexity. One could argue that bigger innovation management programs with KPIs, and complex assessment criteria, can significantly delay the time between major delivery points of the innovative idea.

Outcome (for impact) – Innovation as an outcome addresses the end goals which are sought and encompasses the utilisation/exploitation by the market (and society) of innovations. Innovation as an outcome in a ZEN emphasis the following innovation type: business model; organisational structure; process; product; marketing methods. Each type of outcome has the potential to range from incremental to radical in nature.

Table 6. Methodology for innovation in ZENs ***(adapted from*** **(84)*)***

ZEN Development phases	Innovation	Strategic Focus	Strategic Question	Consideration
Planning	Innovation is a **mindset**	Current State	What should be encouraged and imbedded to prepare for the what and the how?	– Individual mindset (society) – Public organisation mindset – Private organisation mindset – Research institute mindset
Implementation	Innovation is a **process**	Ways & means	How will you make it happen?	– Discover, develop, deliver – Monitoring and management – Innovation readiness levels
Operational	Innovation is an **outcome**	Impact	What do you want to happen?	– Product innovation – Process* innovation – Marketing innovation – Business model innovation – Organisational innovation

* Process here refers to: Cost efficiency, material savings, emission reductions, changes in laws/regulations, definitions, planning processes and construction processes.

6 ZEN KPI tool framework

The ZEN KPI tool conceptual framework aims for implementation of the ZEN definition in ZEN pilot areas by testing the ZEN definition based on real data from the ZEN pilot areas (85). The information obtained from mapping of existing tools used by ZEN stakeholders is used as a background to develop a ZEN KPI conceptual framework. The testing of the ZEN definition and KPI tool will be a continuous, iterative process, where the process partly will involve determining suitable minimum requirements, ambition levels, reference values, threshold values, weighting and benchmarking for the successful implementation of a ZEN KPI tool. A conceptual framework has been developed for the ZEN KPI tool based on information and experiences from the work with the ZEN definition, ZEN pilot areas, ZEN stakeholders and existing tools, see Figure 13. It builds upon the initial ZEN toolbox framework developed by Houlihan Wiberg and Baer in (86).

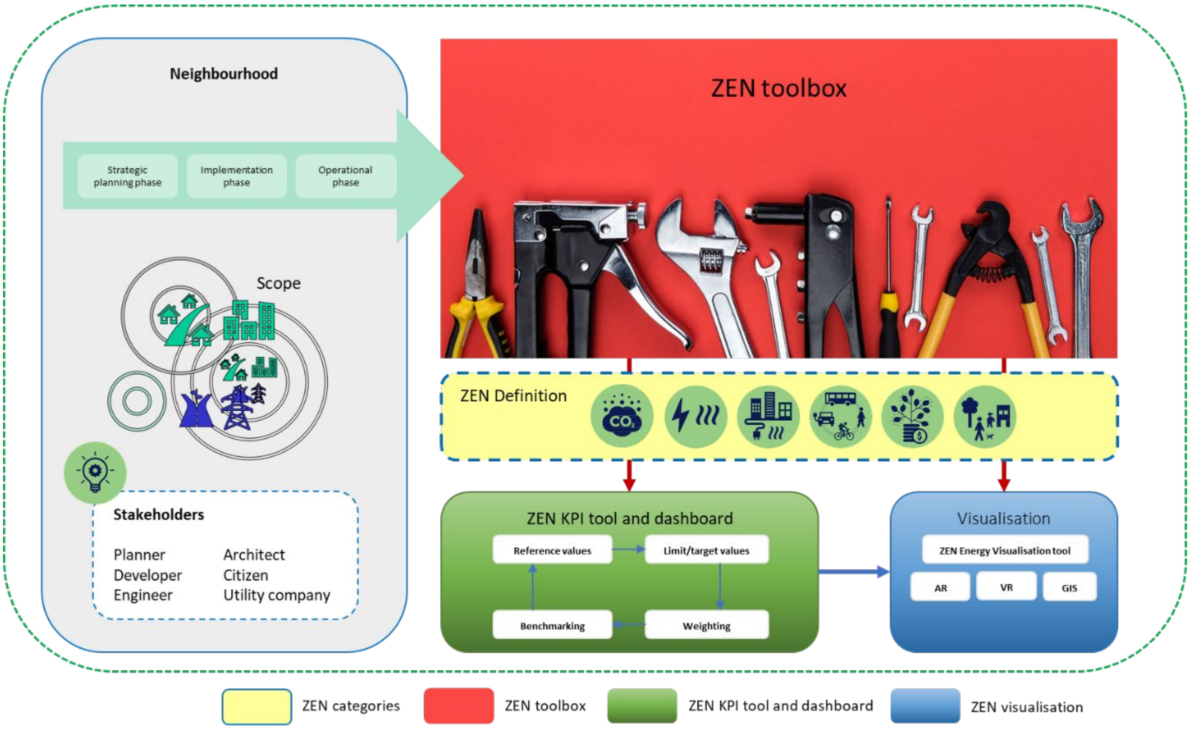

Figure 13. ZEN KPI tool conceptual framework developed from (86).

The framework will be applied in different contexts and will consider the different project phases, scope, and stakeholders. The main components of the framework are:

- the ZEN toolbox which consists of existing tool that can calculate the results for specific KPIs
- the ZEN assessment criteria and KPIs as described in this report
- the ZEN KPI tool which will compile the information on individual KPIs from the tools in the ZEN toolbox and structure it according to the ZEN categories
- visualisation of the results in the form of dashboard, GIS, AR or VR solutions that can be developed in the ZEN project

Within the ZEN KPI tool there is an iterative process that will take place, which involves gathering and setting reference values and threshold value for individual KPIs and defining a weighting and benchmarking within and across the ZEN categories and KPIs. More information on the ZEN KPI tool framework can be found in the ZEN guideline report version 2.0 (12).

7 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 third 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:

- KPIs for the mobility, economy and spatial qualities categories will be further developed and tested in the ZEN pilots. This shall include amongst other things a common workshop between the mobility and spatial qualities – urban form expert groups to ensure there is not any overlap between MOB4.1 and QUA5.5. The mobility expert group shall evaluate MOB4.3 and MOB4.4 to see if bicycle parking, bicycle use, electric cars, electric bicycles and charging shall also be included. A definition of 'user' for the mobility category and GHG emission category GHG1.5 shall also be developed.
- Innovation methodology will be further explored in terms of its importance and usefulness in steering ZENs. Possible limitation in replicability and scalability of ZEN innovations founded in the Research Centres lifetime can mean that innovation remains important in ZEN creation, at least until it is mainstreamed.
- Baseline reference values (and reference projects / base cases) for the KPIs will be developed to facilitate comparison between the ZEN pilot areas.
- A semi-automatic monitoring and evaluation system to systematically measure qualitative and quantitative data collected during the project period will be designed in collaboration with the work on the ZEN definition and ZEN guidelines.
- Further development of the ZEN KPI framework
- Further development of the ZEN KPI tool
- *Weighting and benchmarking system* (85)*:* Not every KPI is suitable for weighting or benchmarking in the ZEN KPI tool, but can be useful information to document and use in some of the other KPIs. It may also be difficult to implement ambition levels and goals in accordance with the ZEN definition when many of the ZEN pilot areas has started and have already set their own goals for reaching ZEN. Existing goals and ambitions in the pilots will have to be harmonised with the ZEN research centres definition. For the weighting and benchmarking it is important to find methods that make it possible to assess and compare different design alternatives so that they can be compared in order to find the best solutions. In order to weight the different KPI's by the simplest method is the simple additive weighting (SAW) model where:

$$v(x)=\sum_{i=1}^{n} w_i v_i(x_i)$$

- v is the overall value of the evaluation object x,
- xi is the measurement of object x on attribute i,
- vi is the single-attribute value function,
- wi is the weight of attribute i,
- n is the number of attributes

- *Data resolution* (85)*:* Another issue that needs to be resolved in the ZEN KPI tool is the requirements for data resolution. Examples can be the detail level of the GHG emissions in the different phases of the project.

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