Research Centre on
ZERO EMISSION
NEIGHBOURHOODS
IN SMART CITIES

THE ZEN DEFINITION – A GUIDELINE FOR THE ZEN PILOT AREAS

Version 4.0.

ZEN REPORT No. 63E – 2024

SINTEF | NTNU

Research Centre on
ZERO EMISSION
NEIGHBOURHOODS
IN SMART CITIES

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Marianne Kjendseth Wiik[1], Shabnam Homaei[1], Synne Krekling Lien[1], Igor Sartori[1], Solveig Meland[1], Hampus Karlsson[1], Anandasivakumar Ekambaram[1]
[1] SINTEF Community

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https://fmezen.no

Preface

Acknowledgements

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

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

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

Researchers, municipalities, industry and governmental organizations work together in the ZEN Research Centre in order to plan, develop and run neighbourhoods with zero greenhouse gas emissions. The ZEN Centre has nine pilot projects spread over all of Norway that encompass an area of more than 1 million 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 and catalyse the development of innovations for a broader public use; This includes studies of political instruments and market design;
- Create cost effective and resource and energy efficient buildings by developing low carbon technologies and construction systems based on lifecycle design strategies;
- Develop technologies and solutions for the design and operation of energy flexible neighbourhoods;
- Develop a decision-support tool for optimizing local energy systems and their interaction with the larger system;
- Create and manage a series of neighbourhood-scale living labs, which will act as innovation hubs and a testing ground for the solutions developed in the ZEN Research Centre. The pilot projects are Furuset in Oslo, Fornebu in Bærum, Sluppen and Campus NTNU in Trondheim, Mære Agricultural school in Steinkjer, Ydalir in Elverum, Campus Evenstad, New City-New Airport Bodø, and Zero Village Bergen.

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

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FME ZEN (page)

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

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), Camille Vandervaeren (SINTEF), Helge Brattebø (NTNU), Edgar Hertwich (NTNU), Jan Sandstad Næss (NTNU), Inger Andresen (NTNU), Patricia Schneider-Marin (NTNU), Juudit Ottelin (NTNU).

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Economy: Caroline Cheng (SINTEF), Anandasivakumar Ekambaram (SINTEF), Kristin Tolstad Uggen (SINTEF), Stian Backe (NTNU), Anne Gunnarshaug Lien (SINTEF).

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

In addition, the ZEN definition guideline report was sent for internal hearing to ZEN researchers and partners. The editors would like to thank ZEN researchers and partners for their contributions.

Document History

Version	Date	Version description
Version 1.0	2018	The first version of ZEN definition guideline report provided a guideline for how the assessment criteria and key performance indicators (KPI) covered under each category of the ZEN definition may be assessed and followed up in ZEN pilot projects. The report explained relevant evaluation methodologies, source and type of data used to evaluate and document the seven ZEN categories (GHG emission, energy, power, mobility, spatial qualities, economy, and innovation) and their related KPIs. Furthermore, the report briefly illustrated the ZEN pilot projects and highlighted limitations and scope for further work.
Version 2.0	2021	This second version (version 2.0) of the ZEN definition guideline report built upon V1.0 of the ZEN definition guideline report and a series of ZEN definition reports. The report gave an updated detailed explanation of the ZEN categories and new information about the KPI tool and framework.
Version 3.0	2022	This third version (version 3.0) of the ZEN definition guideline report built upon V.1.0 and V.2.0 of the ZEN definition guideline reports and the series of ZEN definition reports. The report gives further details on the ZEN KPI tool and on ZEN KPI reference, limit, and target values. A major change involved lifting the process KPIs out of spatial qualities and incorporating them into a process guideline for designing ZENs. Details have been added to each KPI to explain to what degree it contributes to the main goal of ZEN, and examples of best practice are given. Additional power KPIs have been added. The spatial qualities category has been renamed to urban form and land use, and additional KPIs have been added.
Version 4.0	2024	This fourth and final version (version 4.0) of the ZEN definition guideline report builds upon V1.0, V2.0 and V3.0 of the ZEN definition guideline reports and the series of ZEN definition reports. This report highlights that a nZEN balance is required instead of point allocation in the GHG emissions category. Reference, limit, and target values have been added to the energy and power categories. The mobility and economic KPIs and point system have been reviewed based on testing in Ydalir, and minor adjustments have been made to the urban form and land use KPIs. The process chapter has been moved to a separate process guideline report.

Abstract

This fourth and final version (version 4.0) of the ZEN definition guideline report builds upon V1.0, V2.0 and V3.0 of the ZEN definition guideline reports and a series of ZEN definition reports. This report highlights that an nZEN balance is required instead of point allocation in the GHG emissions category. Reference, limit, and target values have been added to the energy and power categories. The mobility and economy KPIs and point system have been reviewed based on testing in the ZEN pilot project Ydalir, and minor adjustments have been made to the urban form and land use KPIs. The process chapter has been moved to a separate process guideline report.

Sammendrag

Denne fjerde og siste utgaven (versjon 4.0) av ZEN-definisjonsveilederen bygger på v.1.0, v.2.0 og v.3.0 av ZEN-definisjonsveilederne, samt en rekke andre ZEN-definisjonsrapporter. Denne veilederen fremhever at en netto nullutslippsbalanse er krevd istedenfor poengallokering i klimagassutslipps-kategorien. Referanse-, grense-, og målverdier er lagt til i energi og effekt kategoriene. Mobilitet og økonomi KPI og poengsystemer er revidert basert på testing på Ydalir, og mindre endringer er gjort på byform og arealbruk KPI. Prosesskapitlet er flyttet til en annen prosessveileder rapport.

Contents

1 Background

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

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

The ZEN research centre is organised into six work packages (WP), see Figure 1. The ZEN definition, categories, assessment criteria, and KPIs are developed in WP1 and are published in a separate series of reports (1–4). The definition work is an ongoing process throughout the programme period (2017-2024). The aim of the ZEN definition guideline developed under WP6 is to describe how the KPIs can be implemented in the various ZEN pilot projects. This is an iterative process whereby the KPIs have been continually tested and further developed through the ZEN pilot projects and the results of which are fed back into the development of the ZEN definition, assessment criteria and KPIs in WP1.

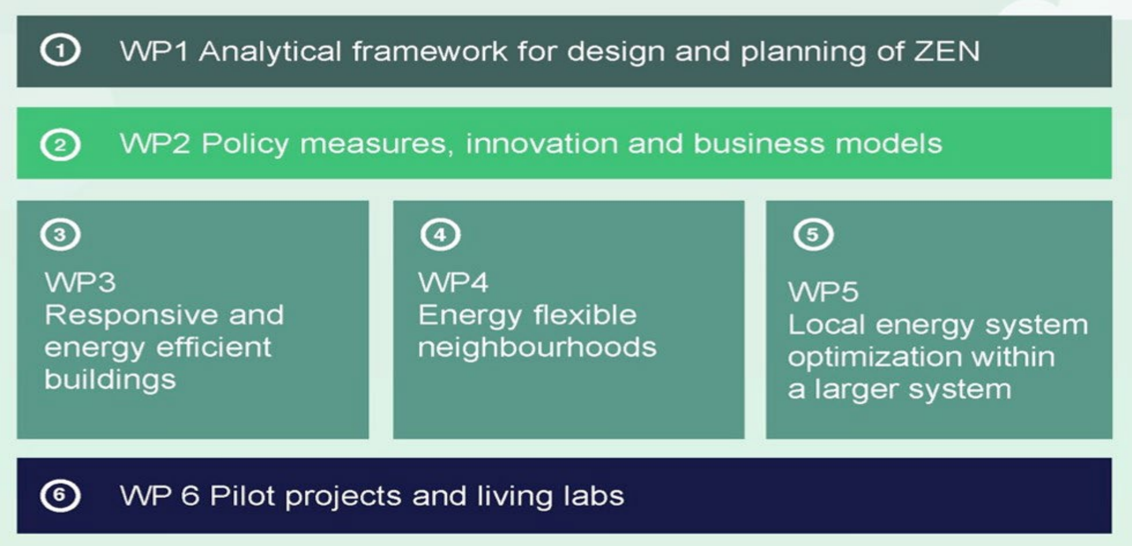

Figure 1. Work packages within the FME ZEN research centre.

1.1 The ZEN Definition

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

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

1.2 The ZEN Definition Guideline

This ZEN definition guideline report version 4.0 builds upon the previous ZEN definition guideline reports (5–7) and series of ZEN definition reports (1–4). The ZEN definition consists of six categories. Each category contains a set of assessment criteria and KPIs, as presented in Table 1. Each category in the ZEN guideline report is explained under a dedicated chapter, which outlines assessment criteria and KPIs and includes a summary table explaining how to calculate each KPI. All ZEN KPIs are mandatory. Each ZEN category, except for the GHG category, has 20 points available. The GHG category requires a net zero emission balance. More information on this is found in the ZEN category chapters and ZEN definition report.

Table 1. ZEN assessment criteria and key performance indicators (KPIs).

Category	Assessment criteria	KPI	Points
GHG	Emission reduction	*GHG1.1 Materials (A1-A3, B4)*	net zero emission balance
		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)	
	Compensation	*GHG1.7 Benefits and loads (D)*	
ENE	Energy efficiency in buildings	*ENE2.1 Energy need in buildings*	8
	Energy carrier	*ENE2.2 Delivered energy*	8

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

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

Category	**Assessment criteria**	**KPI**	**Points**
		ENE2.3 Self-consumption	2
		ENE2.4 Net load profiles	1
		ENE2.5 Colour-coded carpet plots	1
POW	Power performance	*POW3.1 Peak load*	6
		POW3.2 Peak export	2
		POW3.3 Energy stress	6
		POW3.4 Representative days	2
	Load flexibility	*POW3.5 Delivered energy difference*	1
		POW3.6 Operational cost difference	1
		POW3.7 Energy stress difference	1
		POW3.8 Peak load difference	1
URB	Density and land use mix	*URB4.1 Population density*	2
		URB4.2 Block density	1
		URB4.3 Land use mix	2
		URB4.4 Access to a diversity of amenities	2
	Building layout	*URB4.5 Dwelling type*	1
		URB4.6 Multifunctional building roofs	1
		URB4.7 Active frontages	2
	Street network	*URB4.8 Street connectivity*	2
		URB4.9 Street intersection density	1
		URB4.10 Walkable and bikeable streets	1
	Green open space	*URB4.11 Share of green open space*	2
		URB4.12 Share of green permeable area	2
		URB4.13 Preserving and planting trees	1
MOB	Access	*MOB5.1 Access to public transport*	5
		MOB5.2 Travel time ratio	8
		MOB5.3 Parking facilities	7
ECO	Socio-economic	*ECO 6.1 Investment costs*	1
		ECO6.2 Operating costs	1
		ECO6.3 Residual value	1
	Socio-environmental	*ECO6.4 Sharing economy*	3
		ECO6.5 Sustainably sourced materials	2
		ECO6.6 Circularity	2
		ECO6.7 Environmental awareness	2
	Enviro-economic	*ECO6.8 Cost of emissions saved*	8

Despite having different categories within the ZEN definition there are many synergies between categories and KPIs which all contribute to the main goal of net zero emission neighbourhoods (nZEN) either directly or indirectly. For example, results from *ENE2.2 Delivered energy* are used to calculate *GHG1.4 Operational energy use (B6),* and the same material inventory can be used to calculate GHG emissions in the GHG KPIs and costs in the ECO KPIs.

2 GHG Emissions

The main goal in the ZEN definition is nZEN. The main principle for achieving nZEN is first reduction of GHG emissions towards zero and then compensation of remaining emissions, see Figure 2. Reduction measures may include choosing locally sourced materials with lower GHG emissions, reducing energy demands or planning for low emissions. Compensation can be achieved through for example local, renewable energy production, carbon storage, or dismantling and reusing buildings. All the ZEN categories and KPIs in the ZEN definition contribute to achieving this goal. A ZEN aims to reduce its direct and indirect greenhouse gas (GHG) emissions towards zero over the analysis period. More detailed information on GHG emission calculation methodological choices can be found in (8).

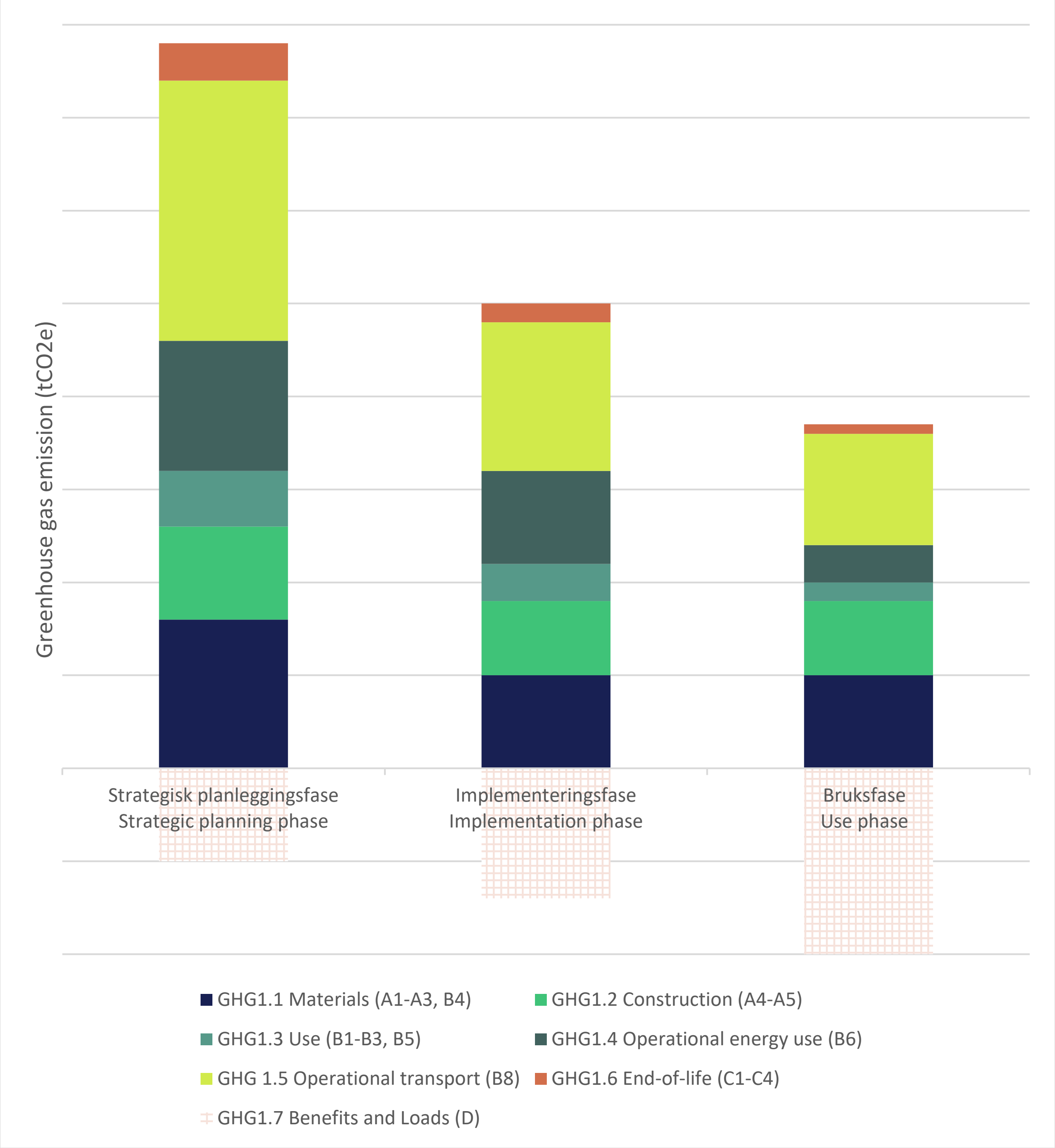


Figure 2. Main principle of nZENs – reduction, and then compensation. GHG emission results obtained from the strategic planning, implementation and use phases.

It is recommended to use GHG emission calculations as an active tool during all project phases during a typical building process to reduce GHG emissions and optimise measures. This principle is shown in Figure 3 whereby a GHG emission budget is established at the start of the project, a GHG emission estimate is calculated in the strategic planning phases, GHG emission calculations are further developed during the implementation phase, and a GHG emission account 'as-built' is delivered at handover or during the operational phase. Uncertainty and the possibility of influencing GHG emissions is greatest in the strategic planning phase.

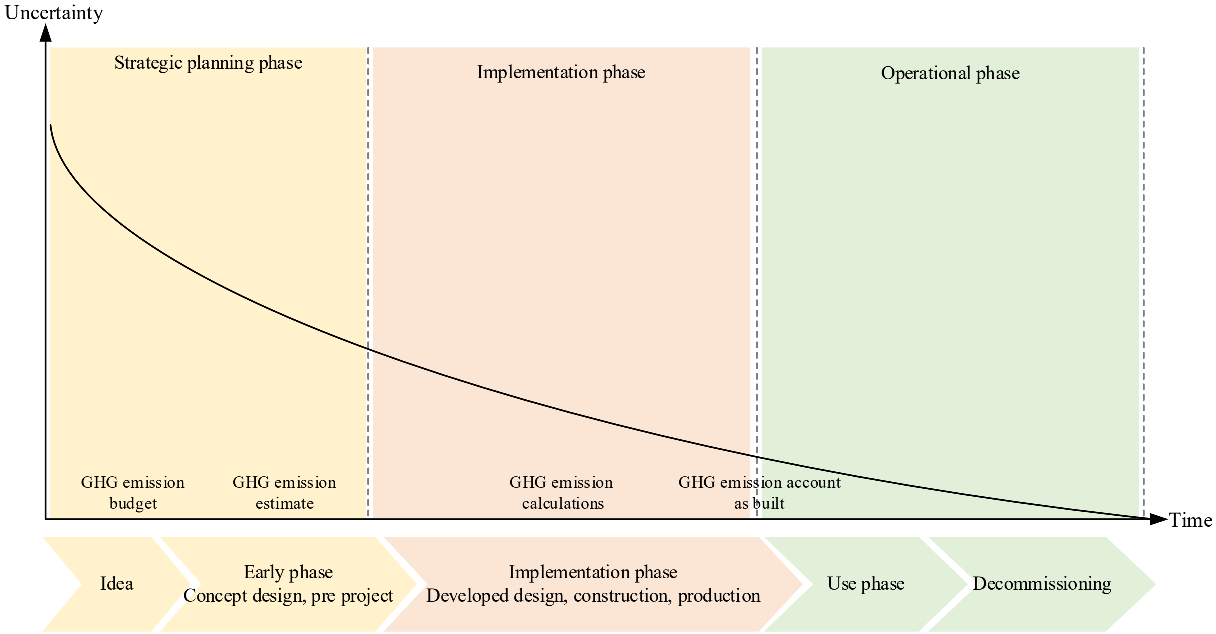


Figure 3. The relationship between GHG emission calculations and project phases in a typical building process.

Scope

In the ZEN definition, GHG emissions should be calculated at four different levels: (1) building envelope, (2) technical systems, (3) infrastructure, and (4) neighbourhood, see Figure 4.

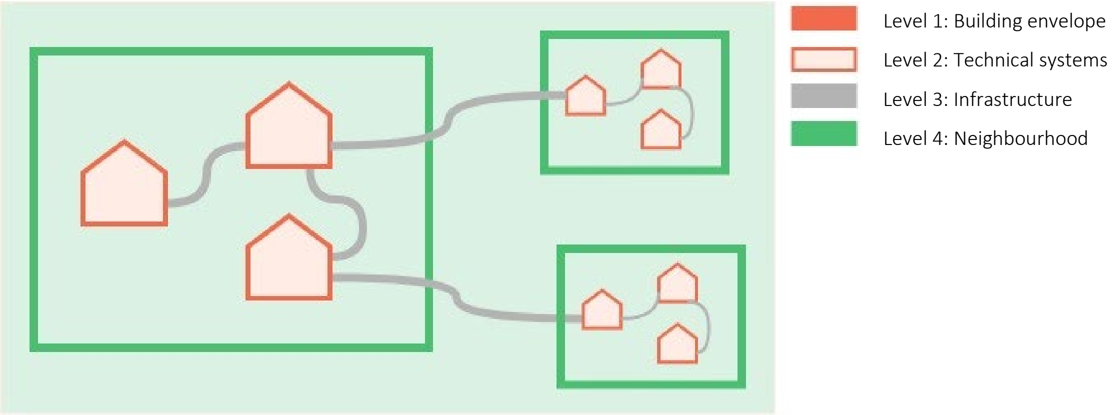


Figure 4. The four different assessment levels for the GHG emissions category in the ZEN definition.

Level 1 - Building envelope includes the building elements 21 groundwork and foundations, 22 superstructure, 23 outer walls, 24 inner walls, 25 floors, 26 roof, 27 fixed inventory, 28 stairs and balconies, and 29 building other in NS 3451 – Table of Building Elements (9). Level 2 – Technical systems include building elements 31 to 69. Level 3 - Infrastructure covers building elements 71 to 79. The neighbourhood level comprises the first three levels, hence includes building elements 21 to 79, and corresponds to the neighbourhood assessment boundary level (N). Each assessment level corresponds to a reporting unit, as detailed in the following section. The neighbourhood level also includes the GHG emissions relating to energy and mobility and correspond to B6: operational energy use and B8: operational transport (i.e., user mobility both within the neighbourhood and to and from neighbourhoods). The four ZEN GHG assessment levels are indicated in Table 2.

Table 2. Assessment levels in ZEN GHG emissions category, related building elements and reporting units.

ZEN GHG emissions assessment levels	**Included building elements (as defined in *NS 3451*)**	**Reporting unit**
Level 1: Building envelope	21 - 29	$kgCO_{2eq}/m^2_{GFA}/yr$
Level 2: Technical systems	31 - 69	$kgCO_{2eq}/m^2_{GFA}/yr$
Level 3: Infrastructure	71 - 79	$kgCO_{2eq}/m^2_{GFA}/yr$
Level 4: Neighbourhood	21 - 79 B6 B8	tCO_{2eq}

Reporting

The different types of buildings and infrastructure types within a ZEN should be described to at least a 2-digit level according to the classification of buildings described in *NS 3457-3* (10). Building areas, number of users, reference study period, system boundaries, scenario descriptions, bill of quantities, emission data sources, and results should be reported per ZEN GHG emission assessment level for each life cycle module and building part. All GHG results from the four assessment levels, i.e., Building envelope, Technical systems, Infrastructure, and Neighbourhood (Table 2), should be reported for each building element and life cycle module in a reporting matrix. The result of the assessment of GHG emissions associated to the ZEN should be reported in the following units:

1. tCO_{2eq}
2. $kgCO_{2eq}/m^2_{GFA\ (gross\ floor\ area)}/year$

The first unit expresses the total GHG emissions in terms of tonnes of carbon dioxide equivalents (tCO_{2eq}). This unit is valid for the Neighbourhood assessment level. The second unit expresses the total GHG emissions in buildings per square meter of gross floor area (*bruttoareal* in Norwegian, (m^2_{GFA}), defined in *NS 3940* as the total floor area of the building, including external walls, where the floor-to-ceiling height is at least 1.90 meter and the width of the room is at least 60 cm (11).

Reference study period and estimated service life

The reference study period (RSP) of the building, infrastructure and neighbourhood is set to 50 years to align with Norwegian building code's (Byggteknisk forskrift, TEK) guideline on preparation of GHG emission calculations, the EU taxonomy, and Level(s) (12–14). The estimated service life (ESL) of the buildings, infrastructure, and neighbourhood is 50 years. Estimated service lives for materials, components and products will vary according to areas of application. The reference study period for mobility is one year.

Allocation of material and energy flow beyond the ZEN

Existing buildings and infrastructure are considered to have no GHG emissions for the original production, transportation, and installation of the building and infrastructure elements. This is in line with *NS 3720*. The impacts from changes made to existing buildings and infrastructure (e.g., through refurbishment) during the RSP should be included in the assessment.

The allocation of building materials and elements that are reused, recycled, or incinerated with energy recovery should follow the methodology described in *EN 15804+A2:2019* (15). Concerning material reuse at neighbourhood level, four types of material reuse could occur. The first type of material reuse relates to the materials kept in place without disassembly or transport. These materials are expected to have limited cleaning, repair, and reprocessing activities. The second type relates to materials relocated within the neighbourhood. The third type occurs when materials are disassembled from the neighbourhood and are transported outside the boundaries of the neighbourhood. The fourth type of material reuse occurs when external reuse materials are imported within the boundaries of the neighbourhood.

Impact assessment

All GHG emissions should be calculated according to the life cycle assessment methodology as described in *NS 3720* (16), for all project phases unless otherwise stated in the KPI description. In a strategic planning phase, generic data may be used. In the implementation and operational phases, individual Environmental Product Declarations (EPDs) developed according to *NS-EN 15804* for product-specific emission factors should be used. When no individual EPDs are available, joint EPDs (i.e., group of manufacturer's data), average EPDs (i.e., group of individual and joint EPDs), or generic data can be used, in this order. This hierarchy of emission data is illustrated in Figure 5. Generic emission factors can be used from published life cycle assessment (LCA) reports or articles. These data sources must be quality assured by an LCA expert. As a rule, specific data, including joint and average EPD data, should not be older than five years, and generic data should not be older than ten years.

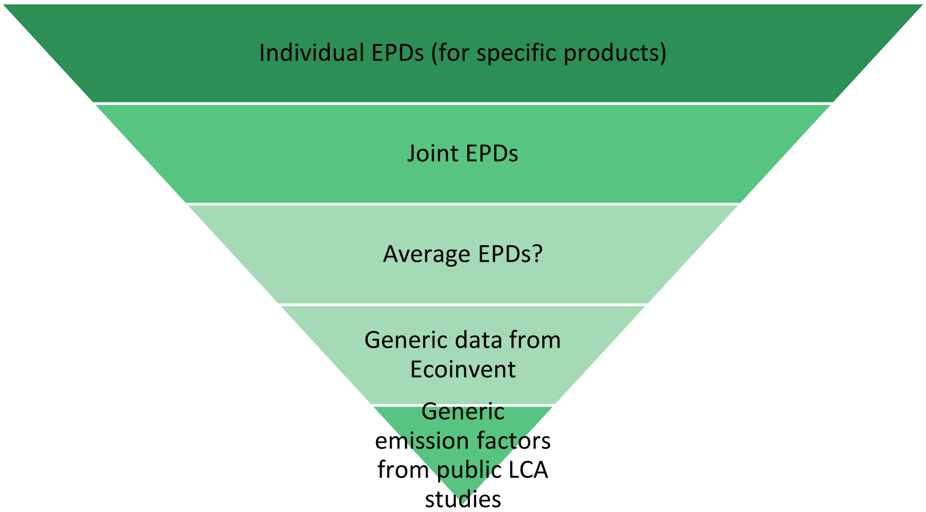


Figure 5. Order in which the emission data should be sourced in the implementation and operational phases (top-down). Emission data can be collected from a lower-ranked source only if no higher-ranked source is available.

Biogenic carbon, carbonation and land use and land use change

Since the whole life cycle of the ZEN is to be included, biogenic carbon for wood and wood-based products should be calculated according to *NS-EN 16449* (18) and *NS-EN 16485* (19). Similarly, carbonation of concrete should be calculated according to *NS-EN 16757* (20). The effects from land use and land use change (LULUC) should also be included. More details on biogenic carbon, carbonation, and LULUC are presented in (8).

2.1 Assessment Criteria

The GHG emissions category is divided into two assessment criteria "Reduction" and "Compensation". The Reduction criterion emphasises life cycle modules A to C, as defined in *NS 3720* and has six related KPIs (21). The Compensation criterion emphasises module D and is reported in *GHG1.7 Benefits and loads (D)*. Figure 6 shows how GHG KPIs relate to these life cycle stages. Note that life cycle module B7 (operational water use) is not considered in the GHG emissions category.

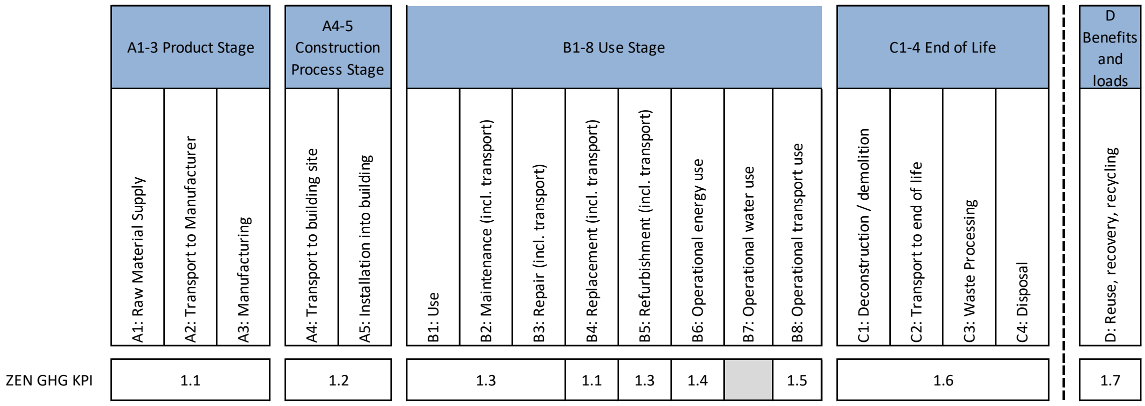


Figure 6. How KPIs relate to the life cycle stages defined in the *NS 3720* (21).

2.1.1 GHG1.1 Materials (A1-A3, B4)

The objective of this KPI is to minimise total embodied GHG emission from buildings, infrastructure, and a neighbourhood's (existing or new) life cycle towards zero with a focus on material use across a reference study period of 50 years (see Table 3). The goal is to reduce the embodied GHG emissions from the production and replacement phases of materials (life cycle modules A1-A3 and B4) for each building and infrastructure within the neighbourhood. The calculation of this KPI should be completed according to *NS 3720* Advanced for life cycle module A1-A3 and B4.

In the strategic planning phase, material quantities can be obtained from architect's and planner's drawings, from building information modelling (BIM), and from city information modelling (CIM). In the later phases, material quantities can be checked against the bill of quantities produced by the quantity surveyor, against product orders and bills from the contractor and sub-contractors, and through site inspections.

To develop realistic scenarios for material replacement, data from EPDs should be used when available. If not, the SINTEF design guideline for replacement and maintenance intervals for building parts *(Bks 700.320 intervaller for vedlikehold og utskiftninger av bygningsdeler)* (22) can be used to ascertain reference service lifetimes of construction components.

Table 3. Summary for calculating KPI GHG1.1.

GHG1.1	**Materials (A1-A3, B4)**
Objective	To minimise the total embodied GHG emissions from buildings, infrastructure, and a neighbourhood's life cycle towards zero, with a focus on material use, across a reference study period of 50 years.
Description	Reduce total embodied GHG emissions from the production and replacement phases of materials (life cycle modules A1-A3, B4) for each building and infrastructure within the neighbourhood.
Method	*NS 3720* (Method of GHG emissions calculation for buildings), *NS 3451* (Table of Building Elements), *EN 15804* (EPD methodology for construction products)
Best practice	– Use existing buildings and infrastructure where possible instead of demolishing and building new. – Use reclaimed, recovered, and recycled building materials. – Choose construction methods and materials with low embodied GHG emissions e.g., prefabricated elements, timber, low carbon concrete, recycled steel etc. – Ask for environmental product declarations (EPDs).

2.1.2 GHG1.2 Construction (A4-A5)

The objective of this KPI is to achieve waste free and emission free construction. It focuses on life cycle stages A4 (transport of material to construction site) and A5 (installation and construction), see Table 4.

The construction phase consists of a number of activities. The construction activities included in the system boundaries for a ZEN are depicted in Figure 7. It includes transport of materials, transport of construction machinery and transport of personnel to the construction site, transport of the waste generated during construction works (including packaging) to waste treatment, and its disposal, energy use (e.g. building heating and drying during the construction phase, energy use on site), internal transport, production and transport of additional materials such as glue, screws, and tape for installing construction products, storage, temporary works, as well as the operation of construction machinery on site. Water use is excluded from the system boundaries.

In the strategic planning phase, knowledge gained from previous projects may be used to estimate the life cycle inventory for construction activities. In the later project phases, the life cycle inventory for construction activities can be gathered from construction machinery and transport logs from the construction site, filled out by the contractor and sub-contractors. These data can be verified against product orders, bills, and through onsite inspections. In addition, information on transport of materials to site can be extracted and adapted from the transport scenarios provided in EPDs. An overview of the additional materials and energy used for installing products can be ascertained from installation manuals and product data sheets from manufacturers. Information on the amount and type of waste produced on site can be extracted from the waste plan ('avfallsplan') that is reported by the contractor to the local authorities. The waste plan can also be used in the strategic planning phase. The waste report shall include waste fractions in kg for untreated wood; paper, cardboard and carton; glass; iron and other metals; gypsum-based materials; plastic; concrete, brick, and other heavy building materials; electric and electronic waste; mineral wool insulation; mixed construction waste; hazardous or special waste and total construction waste sorted. It shall also include the total amount of waste generated on site (kg/m^2) and the percentage of waste fraction recycled. Waste treatment scenarios can be developed according to current waste treatment practices (23).

Table 4. Summary for calculating KPI GHG1.2.

GHG1.2	**Construction (A4-A5)**
Objective	To achieve emission free and waste free construction.
Description	An emission free construction site is a construction site that does not have any direct and indirect GHG emissions from its construction site activities. Electric or hydrogen powered construction machinery, electricity use for heating and drying, and use of zero emission vehicle transport to, from and at the construction sites are some of examples of emission free alternatives (41). A waste free construction site is defined as a construction site that doesn't generate waste from construction site activities and transport of products to and from the construction site, that go to material and energy recovery and landfill (24).
Method	*NS 3720* (Method of GHG emissions calculation for buildings), NS 3451 (Table of Building Elements), *EN 15804* (EPD methodology for construction products), *NS-EN 16258* (Methodology for calculation and declaration of energy consumption and GHG emissions of transport services), *SN/TS 3770 Emission free building and construction sites*.
Best practice	– Choose locally sourced materials with short transport distances. – Ask contractors, subcontractors, and suppliers to use electric vehicles for transport of construction materials and machinery, masses, construction workers and waste to and from construction sites. – Use emission free construction machinery and equipment for construction operations and heating and drying. – Plan for the energy use on the construction site to reduce peak loads, especially for critical construction activities that demand high amounts of energy such as groundworks and foundations or when multiple construction machineries need to charge simultaneously. – Sort and recycle construction waste. – Follow the fuel hierarchy in Figure 8.

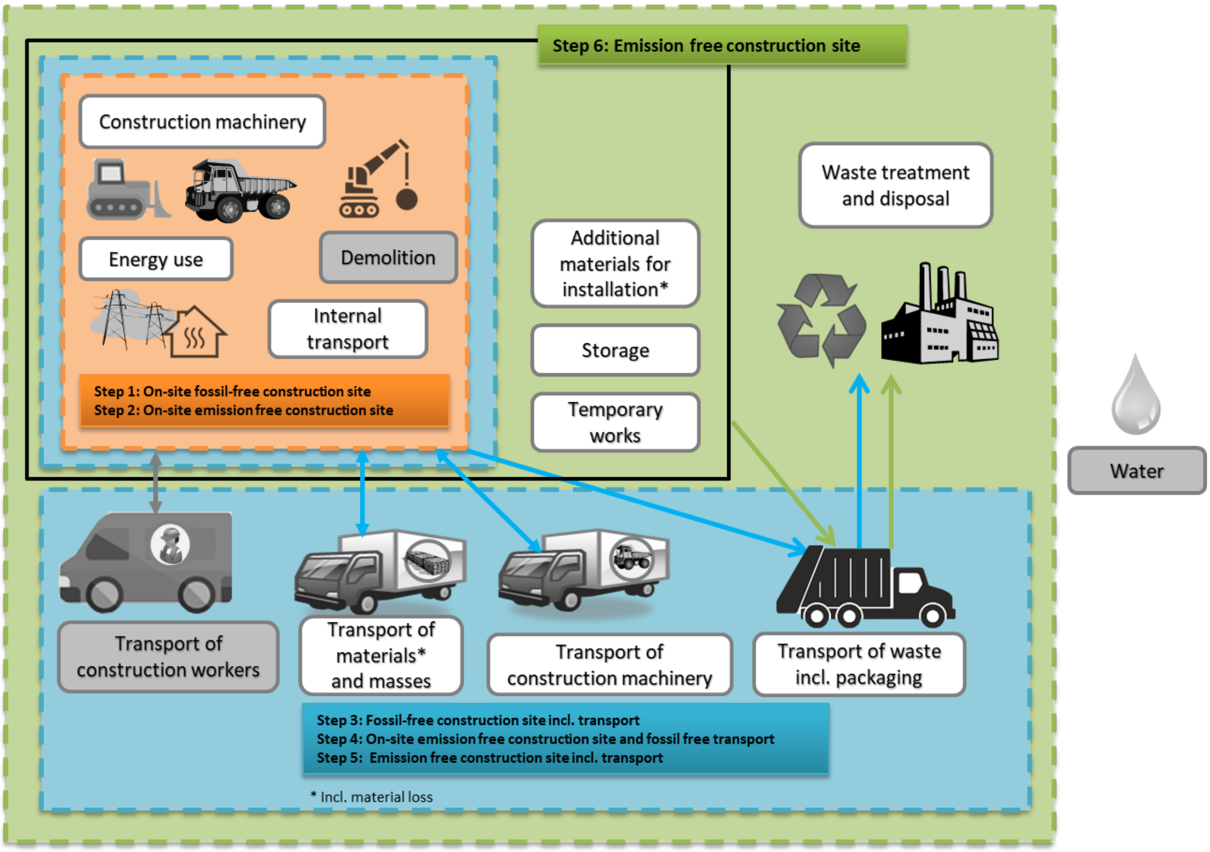


Figure 7. Overview of the system boundary for the construction phase, adapted from (25,26).

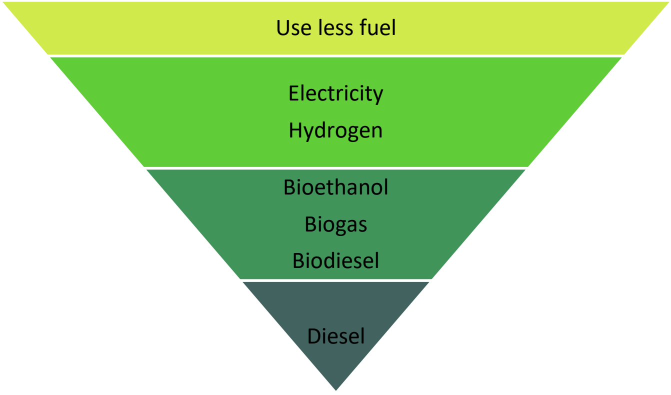


Figure 8. Fuel hierarchy, translated from (27). Electricity and hydrogen are considered emission-free, biofuels are considered fossil-free on construction sites.

2.1.3 GHG1.3 Use (B1-B3, B5)

The use (B1-B3, B5) KPI tackles the GHG emissions from the operation of buildings and infrastructure, and includes GHG emissions resulting from installed products in buildings (B1 e.g., release of GHG substances from surfaces, carbonation of concrete), maintenance operation (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 façade), see Table 5. Another important aspect of this KPI involves mapping the resources used within the neighbourhood through for example material passports, or digital twins (for example boligmappa.no) which may include information such as product documentation, lifetimes, technical performance and characteristics, warranties and guarantees, EPDs, information on management, maintenance, repairs, refurbishment, and demountability of components for future reuse.

Table 5. Summary for calculating KPI GHG1.3.

GHG1.3	**Use (B1-B3, B5)**
Objective	To reduce GHG emissions towards zero from the operation of buildings and infrastructure (life cycle modules B1-B3 and B5).
Description	This KPI involves calculating GHG emissions from B1-B3 and B5 life cycle modules, and a mapping of resources used within the building, infrastructure project or the neighbourhood.
Method	*NS 3720* (Method of GHG emissions calculation for buildings), *NS 3451* (Table of Building Elements)
Best practice	– Plan and carry out scheduled maintenance checks for your building, infrastructure, and neighbourhood. – Maintain and repair components within the neighbourhood to avoid more frequent replacement and/or refurbishment of buildings and infrastructure. – Use environmentally friendly cleaning products. – Select environmentally friendly materials that do not emit GHG substances from surfaces. – Ensure a high level of surface exposure (where appropriate) when concrete is used. – Consider repairing or replacing the broken or worn-out part of a material instead of replacing a whole component or refurbishing an entire room.

2.1.4 GHG1.4 Operational energy use (B6)

The operational energy use (B6) KPI aims to reduce GHG emissions from energy used during the operational stage of the building or neighbourhood and focuses on life cycle module B6, see Table 6. Calculating *ENE2.2 Delivered energy* is a prerequisite for this KPI and the total energy use result should be used (kWh) to avoid mixing differing definitions of area between the energy and GHG emission categories. The calculation of this KPI should be completed according to *NS 3720* for life cycle module B6. The GHG emission reductions from exported energy over the building's system boundary should be reported separately under *GHG1.7 Benefits and loads (D)*, see Figure 9.

Table 6. Summary for calculating KPI GHG1.4.

GHG1.4	**Operational energy use (B6)**
Objective	To reduce the GHG emissions from energy used during the operational stage of the building or neighbourhood.
Description	This KPI involves calculating GHG emissions relating to operational energy use. Completing *ENE2.2 Delivered energy* is a prerequisite.
Method	*NS 3720* (Method of GHG emissions calculation for buildings), *NS 3451* (Table of Building Elements)
Best practice	– Choose energy carriers with low embodied GHG emissions. – See *ENE2.2 Delivered energy*.

See (8) for guidance on the emission factor for electricity and allocation of district heating. For district heating and cooling, a specific emission factor for a specific company or region from e.g. fjernkontrollen can be used (28). Infrastructure energy use (e.g., servers, street lighting, lifts, escalators, industrial processes, and snow melting) is included at the neighbourhood level, and energy use for charging electric vehicles is included in *GHG1.5 Operational transport (B8).*

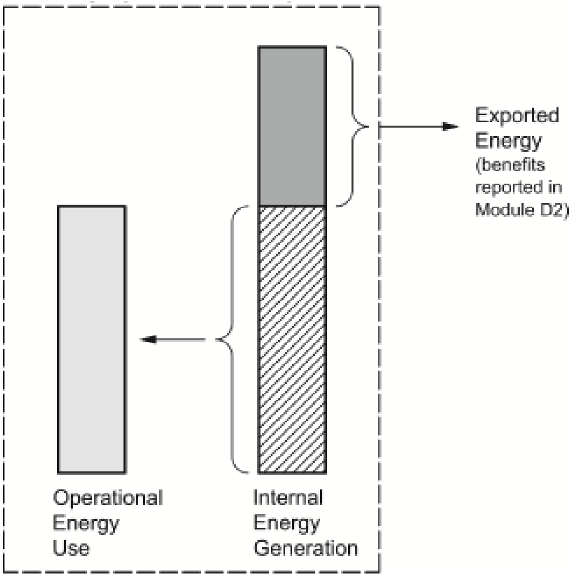


Figure 9. Diagram showing the allocation principle of operational energy use and exported energy (21).

2.1.5 GHG1.5 Operational transport (B8)

The operational transport (B8) KPI aims to reduce GHG emissions related to the mobility patterns of inhabitants, see Table 7. The calculation of this KPI should be completed according to *NS 3720* for life cycle module B8, this includes the transport emission factors for various types of vehicles in appendix C of NS 3720. The SINTEF Energimodul tool (1) can be used to ascertain distances and fuel consumption for various journeys.

Table 7. Summary for calculating KPI GHG1.5.

GHG1.5	**Operational transport (B8)**
Objective	This KPI aims to reduce the GHG emissions related to transport during operation as defined in the *NS 3720.*
Description	This KPI involves calculating GHG emissions related to the operational transport (life cycle module B8) according to the *NS 3720.*
Method	*NS 3720* (Method of GHG emissions calculation for buildings), *NS-EN 16258* (Methodology for calculation and declaration of energy consumption and GHG emissions of transport services (freight and passengers))
Best practice	– Choose modes of transport with low GHG emissions. – See *MOB KPI*

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

The goal of this KPI is to increase resource efficiency and reduce GHG emissions by preserving existing buildings, infrastructure, components, and materials, see Table 8. This KPI includes emissions from demolition and disposal activities. The emissions from these activities are calculated using scenarios for the percentage of reuse, recycling, energy recovery and/or landfill, and the emissions generated by each of these waste treatments. The calculation of this KPI should be completed in accordance with *NS 3720* for life cycle module C1-C4. Other important aspects for this KPI will involve diverting resources from their end-of-life to reuse, recycle, and recover as benefits and loads beyond the system boundary in *GHG1.7 Benefits and loads (D)*. There shall therefore be an emphasis on increasing building circularity and closing the loop.

Table 8. Summary for calculating KPI GHG1.6.

GHG1.6	**End-of-life (C1-C4)**
Objective	To increase resource efficiency and reduce GHG emissions by diverting resources from their end-of-life to reuse, recycle, and recover as benefits and loads beyond the system boundary in Module D. Materials and components that do reach their end-of-life will be deconstructed, transported, and disposed of in such a way as to reduce associated GHG emissions.
Description	The construction industry is responsible for 40% of all resource consumption. Around 22,000 existing building are demolished each year in Norway, leading to higher GHG emissions and higher resource use than renovating. In addition, the EU requires 70% of all construction waste to be recycled from 2020. Reusing material resources is simpler and more effective than demolition. High intensity carbon emitters such as cement and steel are used extensively in groundworks and foundations. It is therefore better to renovate and reuse these than to cast new foundations. There is a large untapped potential in utilising existing building stock.
Method	*NS 3720* (Method of GHG emissions calculation for buildings), *NS 3451* (Table of Building Elements)
Best practice	– Follow circular economy principles and the waste hierarchy, see Figure 10. – A reduction in waste can be achieved by prolonging service lifetimes of materials, components, buildings, and infrastructure. – A reduction and reuse of waste can be achieved by renovating and refurbishing existing buildings instead of demolishing and building new. – Recovery can involve material and energy recovery. – Design for demountability (DfD). – Use homogenous materials and components, avoid using composite materials which are difficult to recover or recycle. – Use a digital twin of the neighbourhood and material passports. – Refurbish instead of demolishing. – Dismantle the building and infrastructure for reuse on-site, or to other construction projects nearby.

Figure 10. The waste hierarchy (29).

2.1.7 GHG1.7 Benefits and loads (D)

The benefits and loads (D) KPI goal is to compensate for the remaining GHG emissions from life cycle modules A1-C4 in order to create a net zero emission balance for the neighbourhood, see Figure 2 and Table 9. It is important to note that this KPI documents avoided emissions. This will be achieved through increased resource efficiency through the implementation of circular economy principles, as well as through the export of local, renewable energy production. This includes the benefits and loads outside of the system boundary linked to reuse, recycling, material energy recovery from the end-of-waste state and the export of local, renewable energy production. The calculation of this KPI should be performed in accordance with *EN15804: 2012 +A2:2019* (15). D1 can be reported for products (e.g., recycled waste), buildings, infrastructures, and neighbourhoods (e.g., reuse of a building). Table 10 gives an example of reporting compensation of GHG emissions in a neighbourhood for an nZEN balance.

Table 9. Summary for calculating KPI GHG1.7

GHG1.7	**Benefits and loads (D)**
Objective	To compensate for the remaining GHG emissions from life cycle modules A1-C4 and create a net zero emission balance for the neighbourhood.
Description	This includes the benefits and loads outside of the system boundary linked to reuse, recycling, material energy recovery from the end-of-waste state, and the export of local, renewable energy production.
Method	*EN15804: 2012 +A2:2019*
Best practice	– See the accumulation of best practices for the GHG category. – Reuse materials – Recycle materials – Recover materials – Produce and export renewable energy

Table 10. Example of reporting compensation of the remaining GHG emissions for a nZEN balance

Measure	**Compensation (tCO_2e)**
D1a Reuse potential	
D1b Recycling potential	
D1c Recovery potential (incineration)	
D2 Exported energy potential	
Total	

3 Energy

One of the most important goals for a ZEN is that it should be become highly **energy efficient** (30), as the most environmentally friendly energy is the energy not used. Thus, reducing energy demand and energy use should always be a priority in the transition towards reaching a **decarbonised energy system**. A ZEN shall be powered by smart, **renewable energy** sources (30). This means that the design of a ZEN must be focused on using renewables which operate in synergy with the surrounding energy system. To achieve this, energy storage, power/load management, digitalisation, smart grids, and system optimisation are included.

The KPIs in the energy category refer solely to the energy flows in operation, and thus exclude embodied energy. This is because embodied energy is already covered by the GHG emission category. The operational energy flows will be modelled and/or estimated in the implementation and operational phases. During the implementation phase 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 resolution. Completion of the energy category KPIs is a prerequisite for the power category KPIs.

Boundary levels

The energy 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, harmonised with SN-NSPEK 3031:2020 (31). The neighbourhood assessment boundary level (N) is an expansion of the building assessment boundary. It also 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. Energy use from charging of electric vehicles should be reported separately from other energy use so that it can be included in the GHG emissions calculations for life cycle module B8: operational transport. Local energy generation not connected to a specific building is also considered. This should also be reported separately from energy use so that compensation from local, renewable energy generation can be included in GHG emission calculation for life cycle module D. In other words, the neighbourhood assessment boundary includes, in principle, all energy flows within the neighbourhood.

Description of ZEN (Z) and reference project (R)

In the energy category, the KPIs should be calculated for both the ZEN (Z) and a reference project (R). The reference project represents business-as-usual for the ZEN and is based on current building regulations (TEK) for new buildings (32) and relevant historical building regulations for existing buildings. A representative reference project should be tailored to each ZEN and have the same floor area and number of users. A new building will typically use direct electric heating. For some KPIs it might be necessary to calculate a reference project with district heating. Table 11 gives an example of assumptions made for a new neighbourhood and its' reference project. Table 12 lists all required documentation to be presented when calculating the energy category KPIs.

Table 11. An example reference project with electric heating, created for a ZEN.

	ZEN (Z)	Reference project (R)
Building standard	Passive house (33,34)	TEK17 minimum requirements (32)
Energy storage solutions	None.	None.
Local energy production	Photovoltaic (PV) panels with annual generation of energy equal to 10 kWh/ m^2 GFA.	None.
Heating	District/Local heating.	Electric boiler.
Transport technologies	100 % of all buses are electric in 2035.	50 % of all buses are electric in 2035.

Table 12. List of required documentation when calculating the energy KPIs.

KPI	Description	Data type	Unit	Level	Scenarios
ENE2.1 Energy need in buildings	Net/gross energy demand in buildings	Annual totals and load curves	kWh/m^2_{HFA}/ year	B	Z and R
Input for *GHG1.4 Operational energy use (B6)*	Energy use	Annual totals and load curves	kWh/h* kWh/year*	N	Z and R
Input for *GHG1.4 Operational energy use (B6)* and *GHG1.7 Benefits and loads (D)*	Energy generation	Annual totals and load curves	kWh/h* kWh/year*	N	Z and R
ENE2.2 Delivered energy. Input for *GHG1.4 Operational energy use (B6)*	Delivered energy (imported)	Annual totals and load curves	kWh/h * kWh/year*	N	Z and R
Input for *GHG1.4 Operational energy use (B6)* and *GHG1.7 Benefits and loads (D)*	Exported energy	Annual totals and load curves	kWh/h* kWh/year*	N	Z and R
ENE2.4 Net load profiles . Input for *POW3.1 Peak load* and *POW3.2 Peak export*	Net yearly load profile and load duration curve per energy carrier	Annual totals and load curves	kWh/h* kWh/year*	N	Z and R
ENE2.5 Colour-coded carpet plots	Colour-coded carpet plot of net energy use	Carpet plot	kWh/h* kWh/year*	N	Z and R
ENE2.3 Self-consumption	Self-consumption	Factor	% Electricity	N	Z
Doc. Only	Self-generation	Factor	% Electricity	N	Z

* Per energy carrier: electricity, district heating, bioenergy and other

These KPIs are not independent. Delivered and exported energy are the net values of energy use and energy generation (when generation is considered as negative) and are collected from the net yearly load profile. The load duration curve is like the net yearly load profile, only sorted from the highest to the lowest value.

Energy demand and energy use

Energy demand is a theoretical size used to describe the energy demand linked to energy services and energy needs in buildings such as the demand for energy for heating of domestic hot water, space heating, ventilation, lighting, plug loads and so on. When calculating the energy demand, losses in the system are ignored. Depending on the system boundary, the calculated energy demand is referred to as net energy demand or gross energy demand. **Energy use** is a measurable size which can be linked to both energy services and energy carriers (such as electricity, fuels, district heating etc.), which also considers losses within the system boundaries.

Energy need in buildings

The energy need (or energy demand) in buildings is considered in *ENE2.1 Energy need in buildings* and is the basis for the other documentational requirements and KPIs. See *ENE2.1 Energy need in buildings* for further details.

Energy use and energy generation

Profiles for energy use and energy generation should be calculated at the neighbourhood assessment boundary level, per energy carrier, with hourly or sub-hourly resolutions. The hourly electricity use and electricity generation is shown in Figure 11 for ZEN Ydalir. This ZEN pilot has non-electric heating and PV-panels. Only the electricity-specific energy demand is covered by electricity while the thermal energy demand is covered by another energy carrier. Electricity use is assigned a positive value, while electricity generation is assigned a negative value.

The load profiles for energy use and generation per carrier in the buildings can be calculated using building energy performance simulation tools. If only energy demand simulations are available (such as when using PROFet), assumptions must be made about the heating system (the energy carrier of the system and the system efficiency) to create the energy use profile. Energy generation may be modelled separately (for instance using PV-generation simulation tools, building simulation tools or other similar tools if the ZEN pilot has PV).

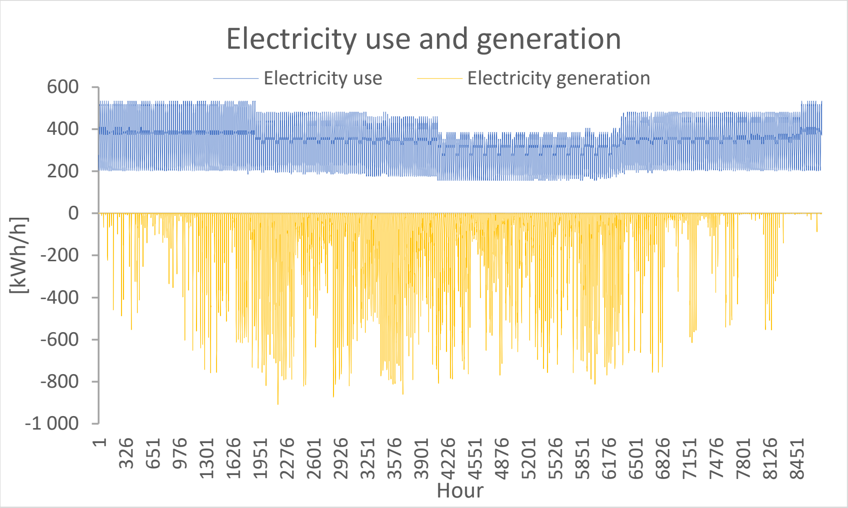


Figure 11. The hourly electricity use and electricity generation with non-electric heating and PV in ZEN Ydalir

Import and export of energy

The delivered and exported quantities of an energy carrier are two sides of the same variable, see *ENE2.2 Delivered energy* for more information on calculation of delivered energy. When we know the hourly electricity use and generation, the delivered and exported electricity can be found by subtracting the energy generated in a ZEN from the energy use for every time interval. Subtracting the electricity generated from the electricity used in Figure 11 produces the net yearly load profile shown in Figure 12. In the net yearly load profile, energy import is assigned a positive value and export a negative value. The load duration curve can be found by sorting the values of the net load profiles.

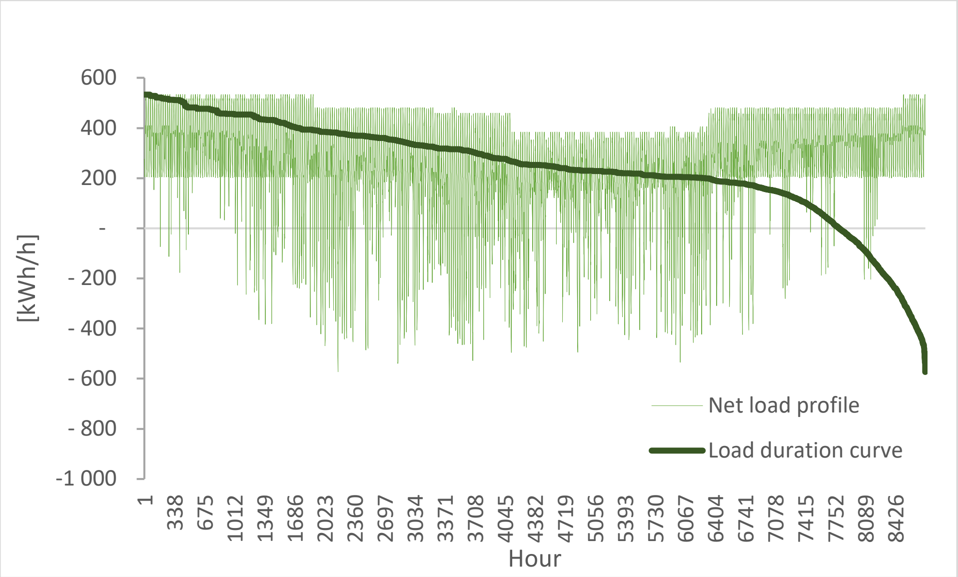


Figure 12. Hourly net load profile and load duration curve of electricity in ZEN Ydalir.

The net yearly load profile and load duration curve are calculated or measured at the neighbourhood assessment boundary level, per energy carrier, with hourly or sub-hourly resolutions. They should be calculated for the ZEN and the reference project. The value of the net load annual profile is to give an illustration of the energy flows throughout the year. The value of the net load duration curve is to provide useful information for the strategic planning and implementation of the energy system. This kind of graphical information gives an immediate visual understanding of the differences between two alternative solutions. For example, a neighbourhood with or without local, district heating would result in two substantially different yearly profiles and duration curves for electricity. The same holds true for a neighbourhood with or without extensive use of solar PV or local storage. The area under the load profiles shows the annual totals of electricity use, generation, import, and export as shown in Figure 13. Figure 14 show a summary of these annual totals.

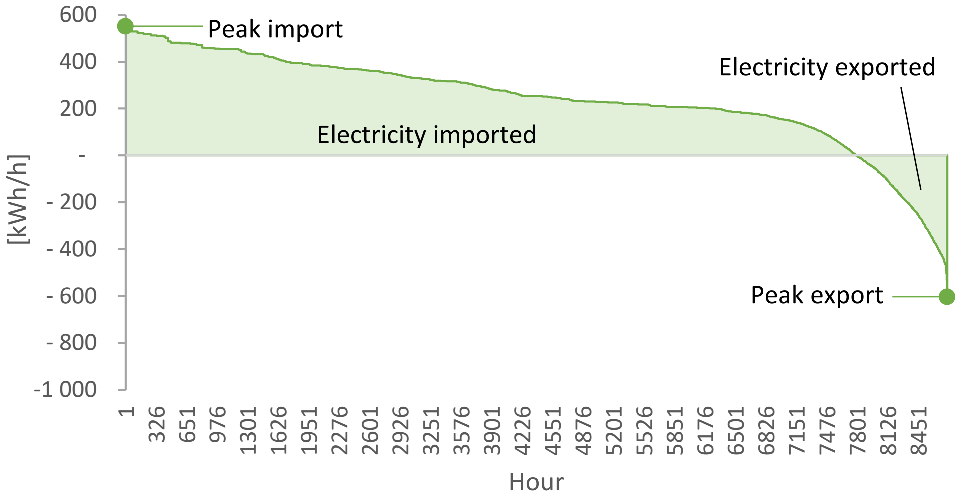


Figure 13. Explanation of the load duration curve of the net electricity use in ZEN Ydalir.

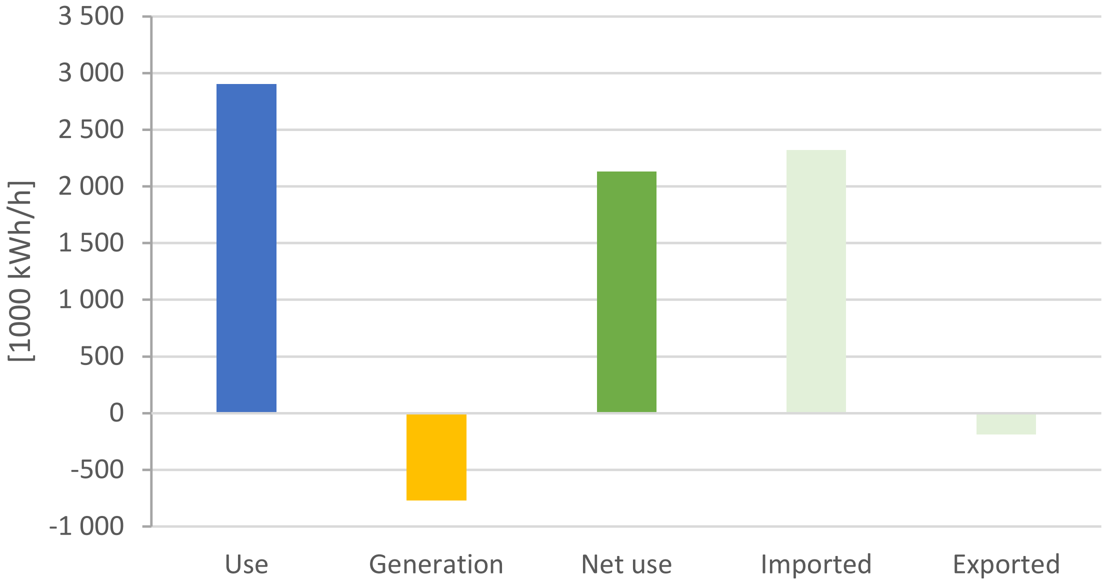


Figure 14. Annual totals of electricity use, generation, net energy use, import and export in ZEN Ydalir.

Load profiles

The level of detail and source of data may differ according to the various project phases. For example, simulation tools used in the implementation phase can be substituted by monitoring data in the operational phase, while design parameters, e.g., air tightness, may be substituted by measured values. Local storage systems, both electric (including the batteries of electric vehicles) and thermal, may already be in place or under evaluation during the strategic planning phase. This will affect the KPIs. As a result, it may be desirable to show the effect of local storage by itself, or in terms of a different control strategy, by means of presenting KPI results with and without the storage system.

Weighting factors for energy commodities

For some of the indicators in the energy and power categories, you will be asked to combine several energy commodities (such as electricity, district heating, and bioenergy) into total energy consumption for the entire area. This applies to POW2.2, POW3.1, and POW3.3. Different energy commodities have different characteristics as well as advantages and disadvantages. To reflect these differences, we use different weighting factors when combining energy commodities. The weighting factors used for this purpose are the same as those proposed by FutureBuilt in their criteria for nearly zero-energy buildings (1), which were derived from a comparison with a reference solution using local air/water heat pumps:

	Weighting factor
Electricity	1
District heating	0.43
Biofuels	0.37
District cooling	0.37

Similar to FutureBuilt's definition, a system-specific weighting factor for district heating can be used if documentation is provided. For example, the weighting factor for district heating of 0.43 can be replaced with a weighting factor based on an energy mix and technology used in the specific system the area is connected to.

Suggested workflow

Working with the energy category in a ZEN requires the collection and calculation of detailed documentation. The workflow shown in Figure 15 is recommended when calculating KPIs.

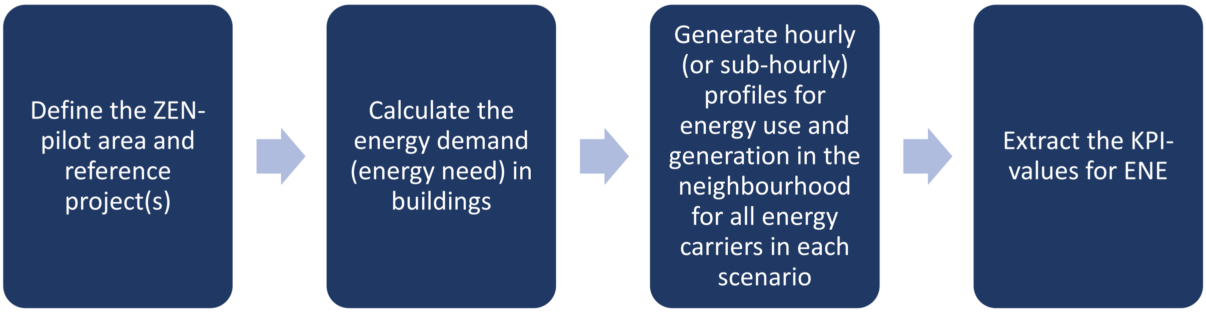


Figure 15. Suggested workflow for calculating KPIs in the energy category.

As an intermediatory step, it may be worth calculating all KPIs at the building boundary level (B). The available national and international norms only apply to the building boundary level, so it would be straightforward to take this first step. Thereafter, the calculations can be extended to the neighbourhood boundary level. This would make it possible to distinguish clearly between the effect of measures within buildings and between buildings.

3.1 Assessment Criteria

The energy category is split into two assessment criteria, namely 'energy efficiency in buildings' and 'energy carriers'. The energy efficiency in buildings assessment criteria looks at the energy performance of buildings within the building assessment level. It considers energy demand within buildings and is suitable for buildings in the implementation phase. The energy carrier assessment criteria consider energy use, energy generation, and energy flows in the ZEN at the neighbourhood assessment level. It looks at energy flow per energy carrier.

3.1.1 ENE2.1 Energy need in buildings

The energy need in buildings KPI shows the total energy demand of all buildings in a ZEN and is calculated per kWh of m^2 heated floor area (HFA) per year ($kWh/m^2{}_{HFA}/yr$) on the building assessment level for the ZEN and for the reference project. The purpose of this KPI is to reduce the energy demand of buildings as much as possible, see Table 13. The KPI will be assessed on the reduction in energy demand in the ZEN compared to the energy demand in the reference project.

Energy need in buildings is a KPI which must be simulated as it shows the energy need of the building envelope when the losses in the buildings' heating system are not accounted for. The energy need is calculated according to the *building assessment boundary*, which must be harmonised between ISO 52000 (35) and *SN-NSPEK 3031* (31). 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* (10) and *SN-NSPEK 3031*, which covers building categories, such as apartment buildings, schools and nursing homes. Local energy generation is not considered, only the *calculated energy demand* of the buildings is considered.

The energy demand in buildings should be calculated at an hourly or sub-hourly level for a period of one year. This can be calculated using PROFet (36) or other building energy performance simulation tools. Energy demand must be calculated per energy services, with a minimum resolution of splitting the energy demand for energy services for heating and electric specific energy services but can also be reported with more detailing, as described in Table 14. Figure 16 shows the calculated hourly energy demand for all buildings in ZEN pilot Ydalir, as planned.

Table 13. Summary for calculating KPI ENE2.1.

ENE2.1	**Energy need in buildings**
Objective	To increase the energy efficiency of the building envelope by reducing the energy demand of buildings as much as possible. More energy efficient buildings use less energy and have peak load requirements which will reduce GHG emissions from *GHG1.4 Operational energy use (B6)*. By reducing the peaks in the energy grid, the neighbourhood can reduce the demand for grid investments and related emissions as well as other environmental impacts.
Description	Specific total energy needs for all buildings within the building assessment level calculated per kWh of m^2 heated floor area (HFA) per year in a ZEN and in the reference project.
Method	The energy demand in buildings should be calculated at an hourly or sub-hourly level for a period of one year according to *SN-NSPEK 3031:2020*. This can be calculated using the tools PROFet or other building energy performance simulation tools. Energy demand should be calculated per energy services, with a minimum resolution of splitting the energy demand for energy services for heating and electricity specific energy services but can also be reported with more detailing.
Points available	8 points
ZEN KPI assessment	Points are awarded based on a reduction in energy demand for space and ventilation heating in the ZEN buildings (Z) compared to the reference area (R). Maximum points are achieved if the reduction in new buildings is more than

<table>
<tr><th>ENE2.1</th><th>Energy need in buildings</th></tr>
<tr><td></td><td>25% and the reduction in existing buildings is more than 50%. The point scale for the entire pilot is calculated by weighting the proportion of new and old buildings (in area), as shown in the example below. The weighted point scale must be calculated for each pilot individually.
<table>
<tr><th colspan="4">Minimum reduction in energy demand for space and ventilation heating</th></tr>
<tr><th>Points</th><th>New buildings (share of area = 75 %)</th><th>Existing buildings (share of area = 25 %)</th><th>Weighted point scale for the pilot</th></tr>
<tr><td>0</td><td>0 %</td><td>0 %</td><td>0 %</td></tr>
<tr><td>1</td><td>3 %</td><td>6 %</td><td>4 %</td></tr>
<tr><td>2</td><td>6 %</td><td>13 %</td><td>8 %</td></tr>
<tr><td>3</td><td>9 %</td><td>19 %</td><td>12 %</td></tr>
<tr><td>4</td><td>13 %</td><td>25 %</td><td>16 %</td></tr>
<tr><td>5</td><td>16 %</td><td>31 %</td><td>20 %</td></tr>
<tr><td>6</td><td>19 %</td><td>38 %</td><td>23 %</td></tr>
<tr><td>7</td><td>22 %</td><td>44 %</td><td>27 %</td></tr>
<tr><td>8</td><td>25 %</td><td>50 %</td><td>31 %</td></tr>
</table>
</td></tr>
<tr><td>Best practice</td><td>– New buildings are constructed as passive house buildings with low U-values and low energy demand.
– Existing buildings are upgraded to the current building minimal standard (or better).</td></tr>
</table>

Table 14. Energy services: level of detailing.

All energy services	**Energy Service - top level**	**Energy Service - lower level**	**Energy Services according to *SN-NSPEK 3031:2020***
Energy demand in buildings	Thermal energy need	Space heating energy need	1a Room heating
			1b Ventilation heating
		Hot water energy need	2 Hot water
	Cooling energy need*	Cooling energy need	3a Room cooling
			3b Ventilation cooling
	Electric energy need	Electric energy need	4a Fans
			4b Pumps
			5 Lighting
			6 Technical equipment

* Sometimes considered as part of electric energy need, other times as thermal.

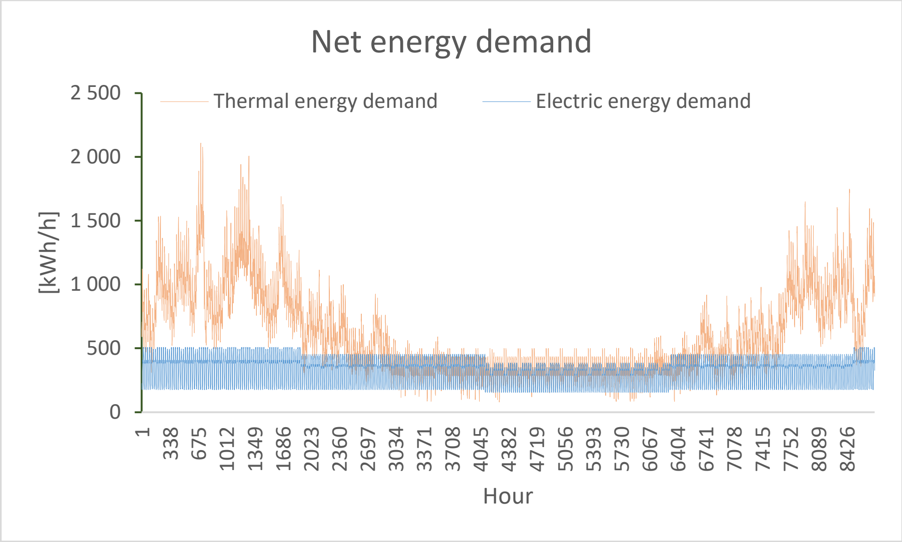


Figure 16. The hourly (net) energy demand for thermal energy (space heating and domestic hot water) and electric services in the buildings at ZEN Ydalir.

3.1.2 ENE2.2 Delivered energy

The delivered energy KPI evaluates the delivered energy at the neighbourhood assessment level for all energy carriers, see Table 15. The delivered energy (imported energy) should be calculated as an hourly or sub-hourly mismatch between energy use and energy generation. As this KPI refers to the annual totals for delivered energy, it can be reported in a table format. The purpose of this KPI is to reduce the amount of delivered energy. The results from this KPI can be used to calculate GHG emissions in *GHG1.4 Operational energy use (B6).*

Table 15. Summary for calculating KPI ENE2.2.

ENE2.2	**Delivered energy**
Objective	More energy efficient buildings use less energy and have peak load requirements which will reduce GHG emissions from *GHG1.4 Operational energy use (B6).* By reducing the peaks in the energy grid, the neighbourhood can reduce the demand for grid investments and related emissions.
Description	The delivered energy (imported energy) should be calculated as an hourly or sub-hourly mismatch between energy use and energy generation and is collected from the net load duration curve for each energy carrier which has been calculated with a weighting factor (see description earlier in the chapter). The net load profile and net load duration curve are calculated or measured at the neighbourhood assessment boundary level, per energy carrier, with hourly or sub-hourly resolutions. For this KPI, delivered energy should be reported as annual totals for all energy carriers at the neighbourhood assessment level for a ZEN and the reference project.
Method	The load duration curve for each energy carrier can be calculated using for example building performance simulation tools, energy generation tools and PROFet. It may be necessary to combine several tools.
Points available	8 points

<table>
<tr><th>ENE2.2</th><th>Delivered energy</th></tr>
<tr><td>ZEN KPI assessment</td><td>Delivered energy is calculated as the sum of electricity (net) + 0.43 * district heating + 0.37 * bioheat + 0.37 * district cooling. Points are awarded based on the change in annual delivered energy between the reference area (R) and the ZEN (Z). Maximum score is given if the reduction in delivered energy is more than 50%. The pilot is awarded the following number of points based on the change in annual delivered energy between the scenarios Z or R:
<table>
<tr><th>Points</th><th>Threshold</th></tr>
<tr><td>0</td><td>0</td></tr>
<tr><td>1</td><td>6 %</td></tr>
<tr><td>2</td><td>13 %</td></tr>
<tr><td>3</td><td>19 %</td></tr>
<tr><td>4</td><td>25 %</td></tr>
<tr><td>5</td><td>31 %</td></tr>
<tr><td>6</td><td>38 %</td></tr>
<tr><td>7</td><td>44 %</td></tr>
<tr><td>8</td><td>50 %</td></tr>
</table></td></tr>
<tr><td>Best practice</td><td>– New buildings are constructed as passive house buildings with low U-values and low energy demand.
– Existing buildings are upgraded to the current building minimal standard (or better).
– Using heat pumps and/or non-electric heating will reduce the electricity use.
– Solar panels reduce the demand for imported electricity.</td></tr>
</table>

3.1.3 ENE2.3 Self-consumption

The self-consumption KPI informs about the mismatch between energy generated locally and energy used in the neighbourhood, see Table 16. The calculation is typically carried out in two steps. First, energy use and energy generation are considered separately, i.e., without considering their interaction. The interaction between energy use and energy generation is considered on an hourly basis, and the overall result over the year is expressed numerically in terms of self-consumption and self-generation. In literature, the same concepts are presented with different names. For example, in (37) these are called 'self-consumption' and 'self-sufficiency', respectively; while in (38) they are called 'supply cover factor' and 'load cover factor', respectively. Here, the wording self-generation is chosen for consistency with 'energy generation', while the wording 'self-consumption' is chosen because it has gained a certain popularity in everyday speech (implying that energy use and energy consumption are used as synonyms). Self-consumption and self-generation express two complementary aspects of the interaction between energy use and energy generation. This can be better explained with reference to a graph showing daily profiles, such as in Figure 17, where electricity is considered, and PV is assumed as local generation in a single building. The areas A and B represent the electricity delivered and electricity exported, respectively. The overlapping part in area C is the solar energy that is utilised directly within the building.

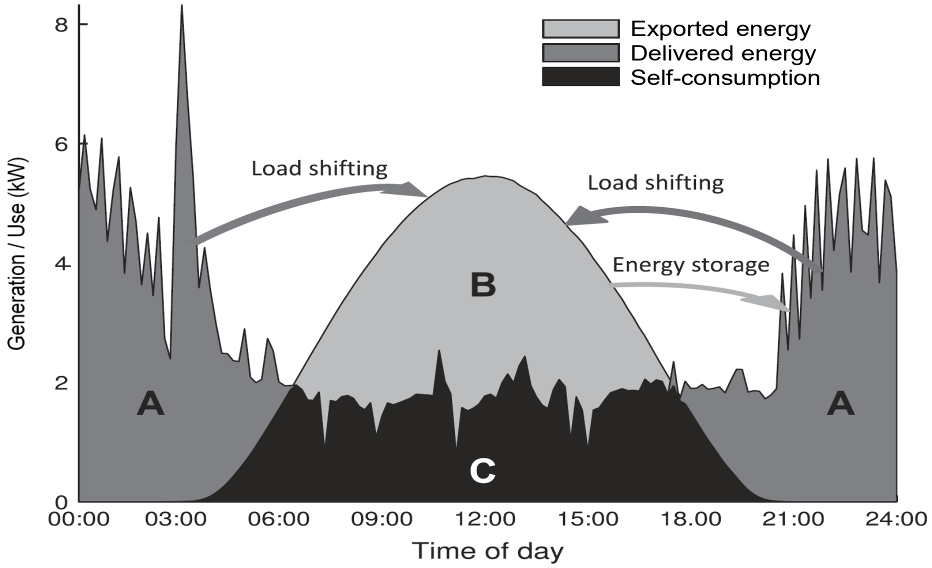


Figure 17. A schematic outline of the daily energy use (A + C), energy generation (B + C), and self-consumption (C) in a building with on-site PV. It also indicates the function of the two main options (load shifting and energy storage) for increasing self-consumption. Source: adapted from (37).

In this example (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,

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

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

The above formulas should be calculated with an hourly or sub-hourly resolution, and the effect of local storage should be considered, as shown in (37) and (39). In *ENE2.3 Self-consumption* the self-consumption should be calculated with at least hourly resolution over a period of 1 year.

Numerically, the two indicators will have the same value only when the total annual energy generation is equal to the total annual energy use, such as in the case of annual net zero energy use (for a specific energy carrier). For small amounts of generation, self-consumption will be high, close to 100%, while self-generation will be small, close to 0%. If local generation increases beyond the net zero point (for example, when the neighbourhood becomes a net annual exporter of energy), then the behaviour of the two indicators reverses, with self-generation being higher than self-consumption. However, the two will never reach extreme values. Typically, as the local generation increases, the two indicators' values change with a sort of logarithmic behaviour: faster changes at the beginning, followed by a slower rate of change. This general behaviour would be affected by using local energy storage.

Table 16. Summary for calculating KPI ENE2.3.

ENE2.3	**Self-consumption**
Objective	To increase the self-consumption of local electricity production. Introducing local electricity generation from renewable sources will reduce the need for imported energy and GHG emissions from *GHG1.4 Operational energy use (B6)*.
Description	The self-consumption KPI is calculated for electricity on an hourly or sub-hourly resolution at the neighbourhood assessment level according to formulas [1] and [2].
Method	Self-consumption is derived from hourly load profiles of electricity generation and electricity use in the ZEN. Hourly load profiles can be generated using building energy performance simulation tools, PV-generation tools and PROFet (it may be necessary to combine several tools). Where hourly measurements are not available, the self-consumption calculations can be complemented or substituted with simulations.
Points available	2 points
ZEN KPI assessment	The KPI will be assessed on the percentage (%) value for self-consumption of electricity in the ZEN. 1 point if self-consumption is 25 - 50 % 2 points if self-consumption is > 50 %
Best practice	– Storage solutions (electricity) and optimal control can increase the self-consumption by shifting electricity use to hours of electricity production. – The orientation of PV can be adjusted to better fit with the energy use of the neighbourhood.

3.1.4 ENE2.4 Net load profiles

The annual net load profile shows the net delivered and exported energy for different energy carriers for the neighbourhood over one year for every time interval, see Table 17. In the annual net load profile, energy import is assigned a positive value and export a negative value as shown in Figure 12. The load duration curve can be found by sorting the values of the net load profiles.

The annual net load profile and load duration curve are calculated or measured at the neighbourhood assessment boundary level, per energy carrier, with hourly or sub-hourly resolutions. They should be calculated for the ZEN and the reference project. The value of the annual net load profile is to give an illustration of the energy flows throughout the year. The value of the net load duration curve is to provide useful information for the implementation, and operation of the energy system. This kind of graphical information gives an immediate visual understanding of the differences between alternative solutions.

Table 17 Summary for calculating KPI ENE2.4.

ENE2.4	**Net load profiles**
Objective	To get a visual understanding of the energy flows between the neighbourhood and surrounding energy grid, and the net energy use for each energy carrier. This can help reduce the peak load and peak export of electricity and district heating to reduce the strain on the energy grid. By reducing the peaks in the energy grid, the neighbourhood can reduce the demand for grid investments and related emissions.
Description	The annual net load profile and load duration curve are calculated or measured at the neighbourhood assessment boundary level, per energy carrier, with hourly or sub-hourly resolutions. They should be calculated for the ZEN and the reference project.
Method	IEA EBC Annex 67, Engineering practices in the ZEN research centre
Points available	1 point
ZEN KPI assessment	The point is awarded for documenting the net load profile for hourly (or sub-hourly) net energy use of electricity and district heating in Z and R over one year.
Best practice	– An energy efficient building can reduce the demand for energy during the hours with the highest energy demand. – Using heat pumps and/or non-electric heating will reduce the electricity demand during the hours with the highest energy demand (compared to direct electric heating). – Solar panels reduce the demand for imported electricity but can increase the export. Increasing the self-consumption of solar energy can reduce export peaks. – Storage solutions (heating and electricity) can shift the demand for energy import at grid stress hours. – Optimal control can shift the demand for energy import at energy stress hours and create a flatter profile.

3.1.5 ENE2.5 Colour-coded carpet plots

The colour-coded carpet plot is an alternative visualisation of the delivered and exported energy flows between the neighbourhood and the surrounding energy grids and is based on the same information as the net load profiles, see Table 18. A color-coded carpet plot is a convenient graphical visualisation of the energy exchanged between the neighbourhood and the energy grids. First, delivered and exported energy are summed together into a single quantity, such as for the net load curve, assuming that export is positive and that delivery negative. This quantity may also be read from a net metering system. Hourly data are arranged on two axes, with 24 hours of a day on the *first axis*, and 365 days of the year on the *Second axis.* A colour scale is added to render the gradation between net delivery and net export of energy to and from the neighbourhood. Two color-coded carpet plot examples are shown in Figure 18 and Figure 19.

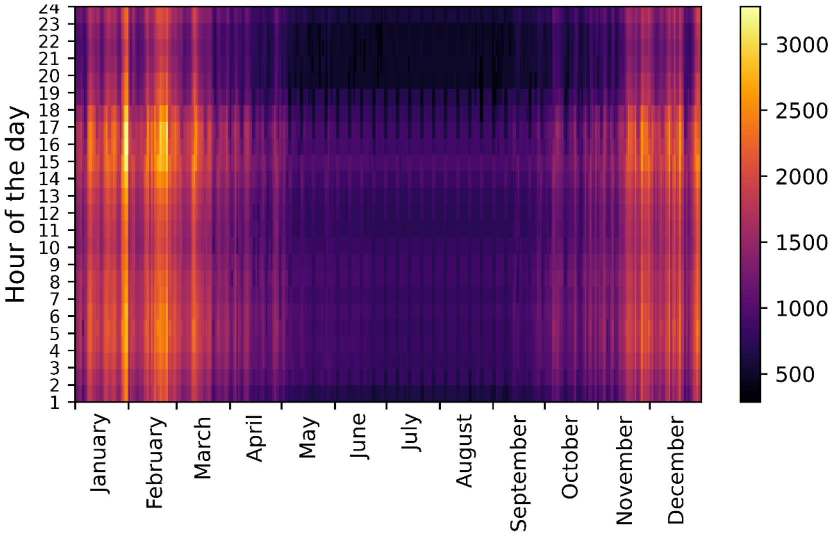


Figure 18. Colour-coded carpet plot showing the net electricity import for Ydalir in the reference project (with electric boiler) (40).

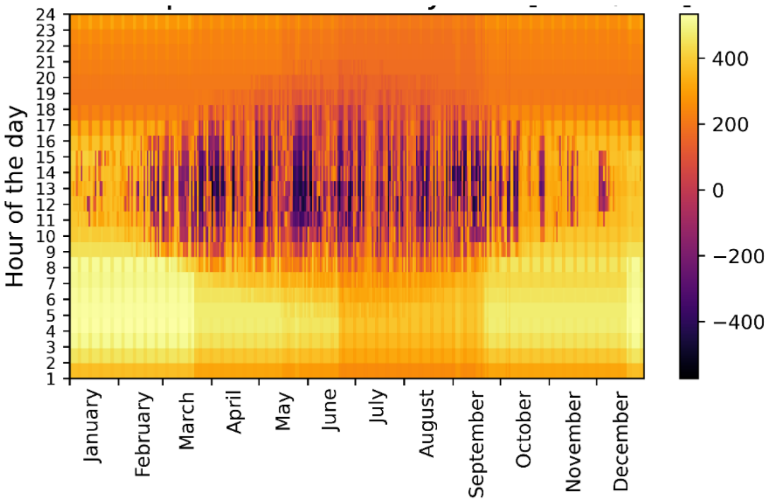


Figure 19. Colour-coded carpet plot showing the net electricity import for Ydalir as planned (with district heating and PV). Negative values indicate electricity export to the grid (40).

Table 18 Summary for calculating KPI ENE2.5

ENE2.5	**Colour-coded carpet plot**
Objective	To get a visual understanding of the energy flows between the neighbourhood and surrounding energy grid, and the energy use per energy carrier. This can help reduce the peak load and peak export of electricity and district heating to reduce the strain on the energy grid. By reducing the peaks in the energy grid, the neighbourhood can reduce the demand for grid investments and related emissions.
Description	The colour-coded carpet plot is a visualisation of the delivered and exported energies (like the net yearly load profile) per energy carrier. A color-coded carpet plot is a convenient graphical visualisation of the energy exchanged between the neighbourhood and the energy grids.
Method	IEA EBC Annex 67, Engineering practices in the ZEN research centre
Points available	1 point
ZEN KPI assessment	The point is awarded for documenting the colour-coded carpet plot for hourly (or sub-hourly) net energy use of electricity, district heating and fuels in Z and R over one year.
Best practice	- An energy efficient building body can reduce the demand for energy during the hours with the highest energy demand. - Using heat pumps and/or non-electric heating will reduce the electricity demand during the hours with the highest energy demand (compared to direct electric heating). - Solar panels reduce the demand for imported electricity. - Storage solutions (heating and electricity) can shift the demand for energy import at grid stress hours. - Optimal control can shift the demand for energy import at energy stress hours and create a flatter profile.

4 Power

A ZEN 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** through better balancing of variable renewable energy and better utilisation of existing energy infrastructure. Therefore, the ZEN definition investigates energy flows through energy grids (electricity and district heating). The KPIs in the power category refer solely to the energy flows between the neighbourhood and energy grids in the implementation and operational phases. During the implementation phase the KPIs should be estimated, e.g., by means of simulations. All KPIs are calculated with an hourly or sub-hourly resolution. All power KPIs are assessed at the neighbourhood assessment boundary level.

Description of ZEN (Z) and reference project (R) with and without optimal control

The reference project (R) represents business-as-usual and is based on current building regulations (TEK) for new buildings (32) and relevant historical building regulations for existing buildings, while the ZEN (Z) is the representation of the area as built/as planned. KPIs are presented in this chapter under the assessment criteria 'load flexibility' to assess how well the neighbourhood exchanges energy in a flexible way. For these KPI, it is necessary to define two more scenarios/references. The first one is the ZEN but without optimised control (Z-nO). The second one is the reference project, but with optimised control (R-O). In these reference scenarios, the neighbourhood is constructed as in the ZEN (Z) and in the reference project (R), but the R-O does not provide load flexibility. By introducing these scenarios, it is possible to describe whether the differences in the exchange between the neighbourhood and the energy grids are caused by energy efficiency or flexible operation/optimised control, see Table 19.

Table 19 Description of ZEN (Z) and reference project (R) with and without optimal control.

	ZEN		**Reference project**	
Optimised control	Yes, optimised control	No optimised control	Yes, optimised control	No optimised control
Abbreviation	Z	Z-nO	R-O	R

Required documentation when calculating the power KPIs

Completion of the energy category's documentational requirements and KPIs is a prerequisite for the power category's KPIs. The documentational requirements for the power category build upon the documentational requirements and KPIs for the energy category. Table 20 lists required documentation when calculating the power KPIs.

Table 20. List of required documentation when calculating the power KPIs.

KPI	**Description**	**Data type**	**Unit**	**Level**	**Scenarios**
POW3.1 Peak load	Peak load (import)	Peak value from net load duration curve	kWh/h*	N	Z and R
POW3.2 Peak export	Peak export	Peak value from net load duration curve	kWh/h*	N	Z and R
POW3.3 Energy stress	Energy stress	Net delivered energy during stress hours for the grid	kWh/year*	N	Z and R

KPI	Description	Data type	Unit	Level	Scenarios
POW3.4 Representative days	Representative days	Daily load profiles	kWh/h*	N	Z, Z-nO**, R, R-O**
POW3.5 Delivered energy difference	Delivered energy difference	Difference in delivered energy in scenarios Z and Z-nO and R and R-O	kWh/year*	N	Z, Z-nO**, R, R-O**
POW3.6 Operational cost difference	Operational costs difference	Difference in operational costs in scenarios Z and Z-nO and R and R-O	NOK/year*	N	Z, Z-nO**, R, R-O**
POW3.7 Energy stress difference	Energy stress difference	Difference in delivered energy in scenarios Z and Z-nO and R and R-O	kWh/year*	N	Z, Z-nO**, R, R-O**
POW3.8 Peak load difference	Peak load difference	Difference in delivered energy in scenarios Z and Z-nO and R and R-O	kWh/h*	N	Z, Z-nO**, R, R-O**

* For electricity and district heating

** Only for calculating the load flexibility KPIs (POW3.4 - POW3.8)

4.1 Assessment Criteria

The power category is split into two assessment criteria, namely 'power performance' and 'load flexibility'.

Power performance: This assessment criterion assesses the power performance and strain of the neighbourhood on the electricity and district heating grid. The KPIs include POW3.1 – POW3.4. For all these KPIs, the performance is measured as a difference between the ZEN (Z) and reference project (R).

Load flexibility: This assessment criterion reflects whether the neighbourhood exchanges energy with the surrounding energy system (electric and district heating) in a flexible way. The KPIs include POW3.5 – POW3.8.

Energy flexibility is defined as the ability of a building or neighbourhood to manage its demand, storage, and local generation to respond to external signals, while safeguarding user needs and comfort (41). This results in load profiles (i.e., hourly, or sub-hourly, values of net energy demand) on the grids that deviate from typical ones. The methodology for calculating the load flexibility KPIs is based on the comparison of two scenarios; one flexible, where flexibility sources are activated to achieve a goal, in response to a driver, vs. a reference scenario that is insensitive to the driver. The load flexibility KPIs will reflect the difference in load profiles in the ZEN as built/as planned (Z), and the same area but where there is limited control and demand response (Z-nO), or in some cases between the reference project with and without optimal control (R and R-O) This is described in the schematic in Figure 20.

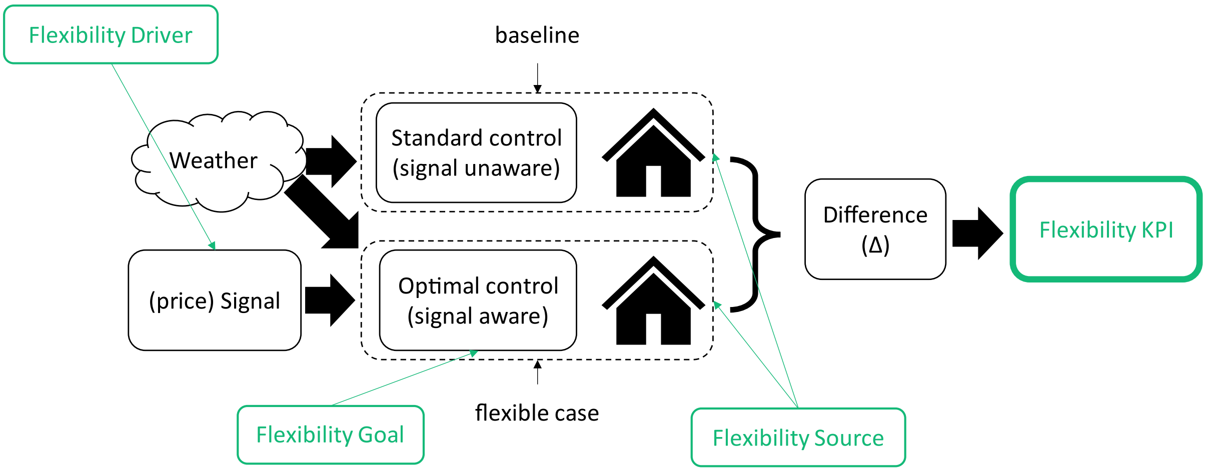
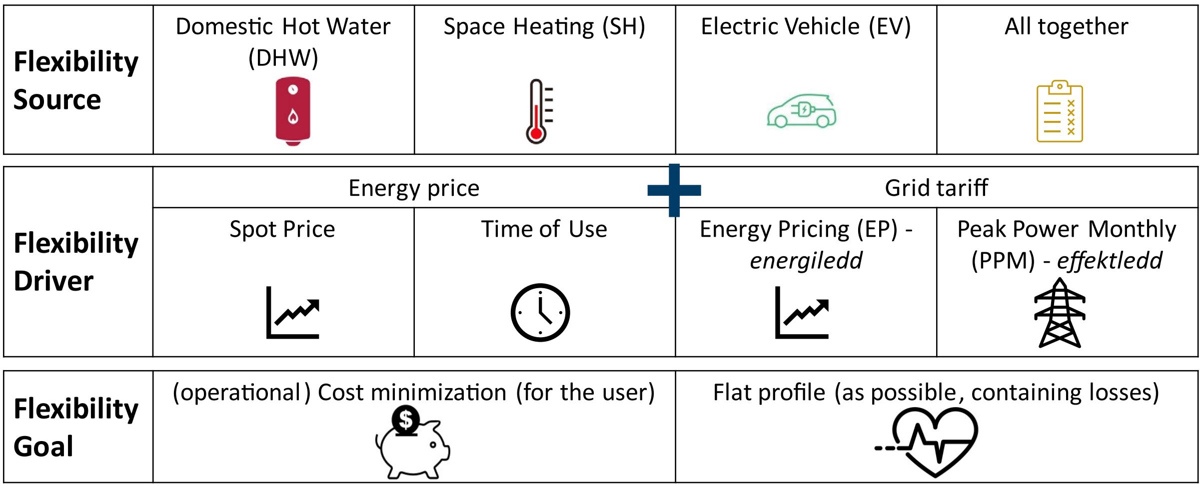


Figure 20 Schematics of the methodology for calculating the load flexibility KPIs (41).

Flexibility KPIs can be calculated for combinations of three elements: flexibility source, flexibility driver and flexibility goal. Figure 21 provides a visual summary of such combinations.



Flexibility Source	Domestic Hot Water (DHW)	Space Heating (SH)	Electric Vehicle (EV)	All together
Flexibility Driver	Energy price		Grid tariff	
	Spot Price	Time of Use	Energy Pricing (EP) - *energiledd*	Peak Power Monthly (PPM) - *effektledd*
Flexibility Goal	(operational) Cost minimization (for the user)		Flat profile (as possible, containing losses)	

Figure 21 Visual summary of flexibility drivers and goals, in combination with different flexibility sources (41).

The KPIs under the assessment criterion 'Load flexibility' can be used to evaluate the effects of short-term load shifting[3] and storage solutions, and their effectiveness in responding to signals from smart energy grids. Such signals might be price signals, information on the CO_2 content of energy produced at different hours throughout a day, as well as information on grid congestion problems, e.g., peak load hours in the (distribution) grid. The aim of this assessment criterion is to assess short-term variations and short-term storage, both thermal and electric, because this is what usually are the options in a neighbourhood. With storage we mean both physical storage, such as hot water tanks and batteries (incl. those of electric vehicles) and virtual storage, such as changing the heating pattern of a building to serve other purposes and responding to the grid's signals instead of just thermostatic control. This entails a combination of physical heat storage in the building's thermal mass and a change in the indoor temperature profile. Furthermore, both physical and virtual storage may be controlled in different ways, giving rise to different 'smart control' strategies that serve different purposes. Figure 22 illustrates an

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3) Flexibility should facilitate the transition to a decarbonised energy system and reduction of power and heat capacity requirements.

example of a single building, with PVs and battery, where the goal is to limit the net electricity export to the grid.

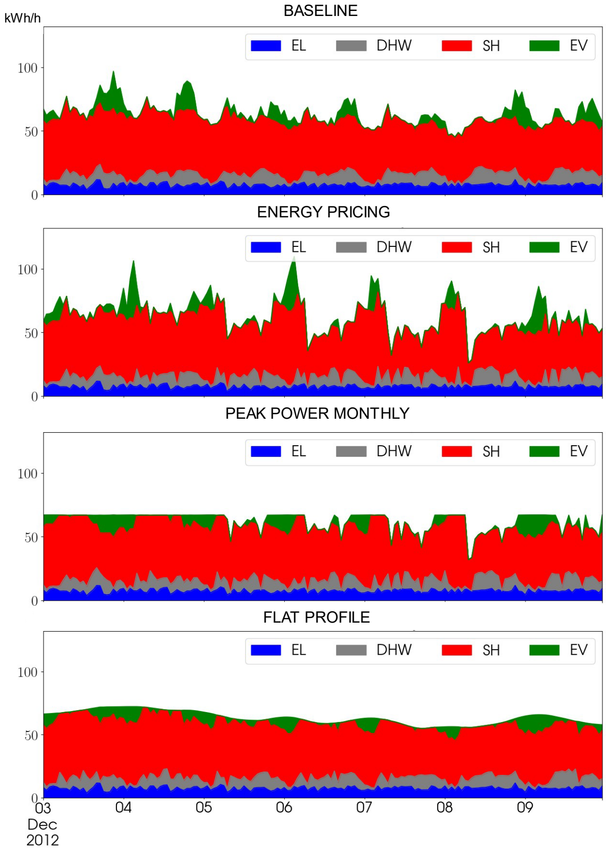

Figure 22 Apartment block with electric space heaters, winter week. Baseline scenario (on top) and flexible scenarios with different flexibility drivers/goals. EL = electric specific; DHW = domestic hot water; SH = space heating; EV = electric vehicle (41).

4.1.1 POW3.1 Peak load

The peak load KPI and *POW3.2 Peak export* are simply the extreme values of the net duration curve as illustrated in Figure 13. The peak load KPI refers to the maximum positive hourly import load of electricity and district heating to the neighbourhoods during an operational year, see Table 21. The peak load should be calculated for the ZEN and the reference project.

Table 21. Summary for calculating KPI POW3.1.

<table>
<tr><th>POW3.1</th><th>Peak load</th></tr>
<tr><td>Objective</td><td>To reduce the peak load of electricity and district heating to reduce strain on the energy grid. By reducing the peaks in the energy grid, the neighbourhood can reduce the demand for grid investments and related GHG emissions.</td></tr>
<tr><td>Description</td><td>Hourly or sub-hourly peak load of electricity and district heating at the neighbourhood assessment level is calculated for the ZEN and reference project.</td></tr>
<tr><td>Method</td><td>IEA EBC Annex 67, Engineering practices in the ZEN research centre</td></tr>
<tr><td>Points available</td><td>6 points</td></tr>
<tr><td>ZEN KPI assessment</td><td>A common load profile for the entire area is created by adding electricity + 0.43 * district heating per hour throughout the year. Then, the highest value – the peak load – during the year is identified. This is done for the reference area (R) and the ZEN (Z). Maximum score is given if the reduction in peak load is more than 50%. Points are awarded according to the following table:
<table>
<tr><th>Points</th><th>Threshold</th></tr>
<tr><td>0</td><td>0 %</td></tr>
<tr><td>1</td><td>8 %</td></tr>
<tr><td>2</td><td>17 %</td></tr>
<tr><td>3</td><td>25 %</td></tr>
<tr><td>4</td><td>33 %</td></tr>
<tr><td>5</td><td>42 %</td></tr>
<tr><td>6</td><td>50%</td></tr>
</table></td></tr>
<tr><td>Best practice</td><td>– An energy efficient building can reduce the demand for energy during the coldest hours of the year.
– Using heat pumps and/or non-electric heating will reduce the electric peak load (compared to direct electric heating).
– Solar panels reduce the demand for imported electricity.
– Storage solutions (heating and electricity) can shift the demand for energy import at peak load hours.
– Optimal control can shift the demand for energy import at peak load hours and create a flatter profile.</td></tr>
</table>

4.1.2 POW3.2 Peak export

The peak export KPI refers to the maximum net hourly export load of electricity (when the electricity production is higher than the electricity use) from the neighbourhood during an operational year, see Table 22. If there is no net export, then the peak export is equal to zero. Export of district heating is currently not considered in this KPI as export of heat is more complicated than the export of electricity.

Table 22. Summary for calculating KPI POW3.2.

POW3.2	**Peak export**
Objective	The peak export should not exceed the peak load (import) and should not be the dimensioning factor for the electricity grid. By reducing the peaks in the energy grid, the neighbourhood can reduce the demand for grid investments and related GHG emissions.
Description	Hourly or sub-hourly peak export at the neighbourhood assessment level in the ZEN during a period of one year.
Method	IEA EBC Annex 67, Engineering practices in the ZEN research centre
Points available	2 points
ZEN KPI assessment	2 points are awarded if: Peak export of electricity < Peak load of electricity in the ZEN
Best practice	Storage solutions (electricity) and optimal control can increase the self-consumption by shifting electricity use to hours of electricity production.

4.1.3 POW3.3 Energy stress

The energy grid will experience a higher energy demand during a few hours of the day, due to increased demand that occurs simultaneously. In Norway, this typically occurs in the early morning (7 - 9am) and late afternoon during workdays (4 - 6pm), see Table 23. These hours are 'stress hours' and if a neighbourhood can reduce its energy demand during these hours, then the energy stress may be reduced on the energy grids. In Figure 23, a ZEN is using optimised control to reduce electricity loads during stress hours. By reducing the stress on the energy grid, the neighbourhood can reduce the demand for grid investments and related GHG emissions.

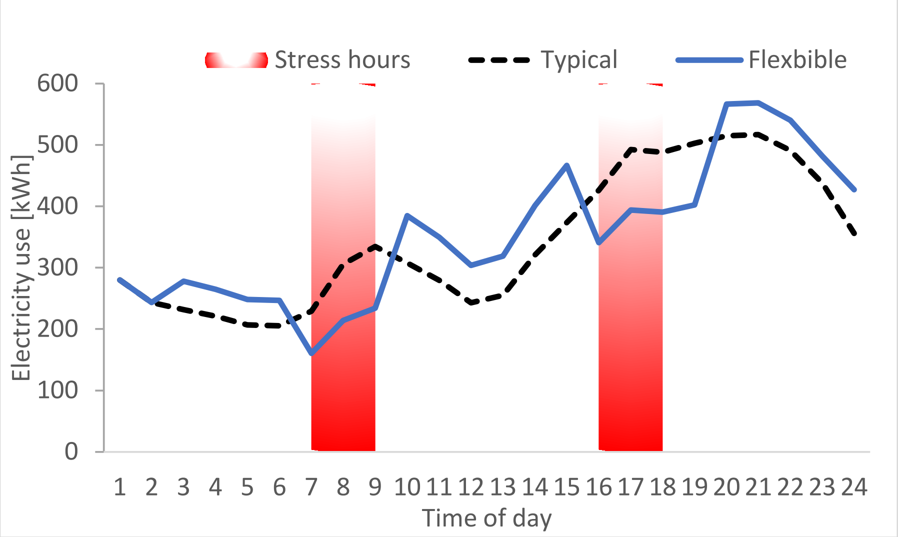

Figure 23 Alternative load profiles in a neighbourhood with (flexible) and without optimal control (typical) to reduce energy in the stress hours.

Table 23 Summary for calculating KPI POW3.3.

<table>
<tr><th>POW3.3</th><th>Energy stress</th></tr>
<tr><td>Objective</td><td>The energy grids will experience a higher energy demand during a few hours of the day. This typically occurs in the morning and evening hours, due to increased demand that occurs simultaneously. These hours are 'stress hours' and if a neighbourhood can reduce its power demand during these hours, then energy stress may be reduced on the grid. By reducing the stress on the energy grid, the neighbourhood can reduce the demand for grid investments and related GHG emissions.</td></tr>
<tr><td>Description</td><td>The difference in energy consumption (electricity and district heating) during the hours of 7-9am in the morning and 16-18pm in the afternoon in winter (December-February) in the ZEN (Z) compared to the reference area (R).</td></tr>
<tr><td>Method</td><td>IEA EBC Annex 67, Engineering practices in the ZEN research centre</td></tr>
<tr><td>Points available</td><td>6 points</td></tr>
<tr><td>ZEN KPI assessment</td><td>A combined load profile for the entire area is created by adding together electricity + 0.43*district heating per hour throughout the year. Then, the sum of net energy consumption during peak hours (hours 7, 8, 16, and 17 in December - February) is found. This is done for the reference area (R) and the ZEN (Z). Points are then awarded based on the extent of the reduction in the total energy consumption during peak hours in Z compared to R. Maximum score is given if the reduction in energy consumption during peak hours is more than 50%.
<table>
<tr><th>Points</th><th>Threshold value</th></tr>
<tr><td>0</td><td>0 %</td></tr>
<tr><td>1</td><td>8 %</td></tr>
<tr><td>2</td><td>17 %</td></tr>
<tr><td>3</td><td>25 %</td></tr>
<tr><td>4</td><td>33 %</td></tr>
<tr><td>5</td><td>42 %</td></tr>
<tr><td>6</td><td>50%</td></tr>
</table>
</td></tr>
<tr><td>Best practice</td><td>– An energy efficient building can reduce the demand for energy during the hours with the highest energy demand.
– Using heat pumps and/or non-electric heating will reduce the electricity demand during the hours with the highest energy demand (compared to direct electric heating).
– Solar panels reduce the demand for imported electricity.
– Storage solutions (heating and electricity) can shift the demand for energy import at grid stress hours.
– Optimal control can shift the demand for energy import at energy stress hours and create a flatter profile.
– If control systems are used to shift loads away from peak hours, energy consumption in the hours before and after stress hours may increase. This could lead to an increase in peak load (POW3.1).</td></tr>
</table>

4.1.4 POW3.4 Representative days

Representative day charts show the average net import of electricity and district heating in a neighbourhood in different scenarios, see Table 24. They can be made as an average of the entire year or for different seasons and days separately. As an example, the representative daily profile for net delivered electricity (electricity use minus electricity production) on winter workdays for different scenarios in one of the pilots is shown in Figure 24. The figure shows the representative electricity use for the ZEN with district heating (ZEN) and the reference area (R) with district heating and electric heating. The lines in the figure show the average winter workday net electricity profile, while the shaded area around these lines show the variation in electricity use (on winter workdays) from the 5th - 95th percentile interval.

The figure shows that the representative net delivered electricity on winter workdays have a morning peak and an afternoon peak. This is due to the high share of residential buildings in this pilot, where there is typically a morning peak caused by energy use before the residents leave for work, and the afternoon peak caused by cooking, lighting, equipment, charging of electric vehicles and heating (in the Reference EL-scenario). The reference area with electric heating shows a much higher electricity use during winter workdays compared to the other scenarios. This is due to the electricity being used for heating in this scenario. There is also a larger variation in daily electricity use in this scenario due to the link between electricity used for heating and the outdoor temperature. The pilot area and reference area with district heating have a similar representative electricity use profile on winter weekdays, but the net delivered electricity is lower in the ZEN scenario during the middle of the day due to electricity generation from PV. On some days, there is even export of electricity during winter workdays in the ZEN scenario.

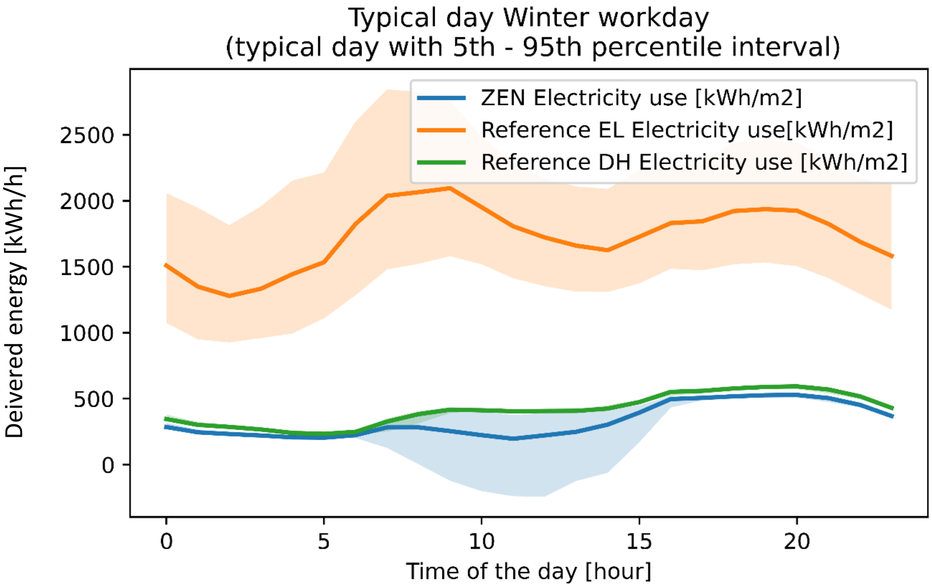

Figure 24. Representative net delivered electricity in one of the pilots on winter workdays.

Table 24. Summary for calculating KPI POW3.4.

POW3.4	**Representative day**
Objective	To get a better understanding of the energy flows between the energy grid and the neighbourhood.
Description	Representative daily load profiles for every hour of an average day of net import of electricity and district heating to the neighbourhood from the grid.
Method	IEA EBC Annex 67, Engineering practices in the ZEN research centre
Points available	2 points
ZEN KPI assessment	1 point for one graph for Z and R. 2 points for different seasons/weekday graphs for Z, R and Z-nO and R-O.
Best practice	– An energy efficient building can reduce the demand for energy during the coldest hours of the year. – Using heat pumps and/or non-electric heating will reduce the electric peak load (compared to direct electric heating). – Solar panels reduce the demand for imported electricity. – Storage solutions (heating and electricity) can shift the demand for energy import at peak load hours. – Optimal control can shift the demand for energy import at peak load hours and create a flatter profile.

4.1.5 POW3.5 Delivered energy difference

Delivered energy difference focuses on the difference in total energy use between the ZEN with and without optimal control (Z and Z-nO) and the reference project with and without optimal control (R and R-O). This allows a person to quantify explicitly the impact of load flexibility, see Table 25.

Table 25.Summary for calculating KPI POW3.5.

POW3.5	**Delivered energy difference**
Objective	The neighbourhood exchanges energy with the surrounding energy system in a flexible way that reduces the total energy use of the neighbourhood. Reducing the delivered energy can help reduce GHG emissions from *GHG1.4 Operational energy use (B6).*
Description	The difference between energy use in the ZEN (Z) and reference (R) is calculated in *ENE2.2 Delivered energy*. This indicator refers to the difference between the ZEN with and without optimised control (Z and Z-nO). The difference in net delivered energy use when the hourly or sub-hourly load profile for electricity and district heating is calculated at the neighbourhood assessment level for the ZEN and reference project (Z) and the not-optimised ZEN (Z-no) over a period of one year.
Method	IEA EBC Annex 67, Engineering practices in the ZEN research centre
Points available	1 point
ZEN KPI assessment	The point is awarded for documenting the difference in energy use (kWh/year) for Z and Z-nO and R and R-O for electricity and district heating.
Best practice	– Storage solutions (heating and electricity) can shift the demand for energy import at peak load hours. – Optimal control can shift the demand for energy import at peak load hours and create a flatter profile.

4.1.6 POW3.6 Operational cost difference

Operational cost difference focuses on the difference in operational cost due to energy use between the ZEN with and without optimal control (Z and Z-nO) and the reference project with and without optimal control (R and R-O). This allows a person to quantify explicitly the impact of load flexibility, see Table 26.

Table 26 Summary for calculating KPI POW3.6.

POW3.6	**Operational costs difference**
Objective	The neighbourhood exchanges energy with the surrounding energy system in a flexible way that reduces the operational energy cost for the neighbourhood.
Description	The operational cost of the ZEN (Z) is calculated in *ECO6.2 Operating costs*. This indicator refers to the difference in operational energy cost between the ZEN with and without optimised control (Z and Z-nO). The difference in operational cost due to energy use when the hourly or sub-hourly load profile is calculated at the building or neighbourhood assessment level for the ZEN and reference project (Z) and the not-optimised ZEN (Z-no) over a period of one year.
Method	IEA EBC Annex 67, Engineering practices in the ZEN research centre
Points available	1 point
ZEN KPI assessment	The point is awarded for documenting the difference in cost (NOK/year) for Z and Z-nO and R and R-O for electricity and district heating.
Best practice	– Storage solutions (heating and electricity) can shift the demand for energy import until hours with lower energy costs and/or reduce energy use for some loads (load shedding). – Optimal control can shift/shed the demand for energy import at hours with high energy costs.

4.1.7 POW3.7 Energy stress difference

Energy stress difference looks into the difference of energy stress between the ZEN with and without optimal control (Z and Z-nO) and the reference project with and without optimal control (R and R-O). This allows a person to quantify explicitly the impact of load flexibility, see Table 27.

Table 27 Summary for calculating KPI POW3.7.

POW3.7	**Energy stress difference**
Objective	The neighbourhood exchanges energy with the surrounding energy system in a flexible way that reduces the energy use during hours that are predefined as stressful for the energy system, e.g., peak load hours for the grid, typically occurring in early morning and late afternoon during workdays, in Norway. By reducing the stress on the energy grid, the neighbourhood can reduce the demand for grid investments and related GHG emissions.
Description	The difference in energy stress between the ZEN (Z) and reference (R) is calculated in *POW3.3 Energy stress.* This indicator refers to the difference in energy stress between the ZEN with and without optimised control (Z and Z-nO). The difference in energy use during hours that are predefined as stressful

POW3.7	**Energy stress difference**
	for the energy system, e.g., peak load hours for the grid, typically occurring in early morning and late afternoon during workdays, in Norway when the hourly or sub-hourly load profile for electricity and district heating is calculated at the neighbourhood assessment level for the ZEN and reference project over a period of one year.
Method	IEA EBC Annex 67, Engineering practices in the ZEN research centre
Points available	1 point
ZEN KPI assessment	The point is awarded for documenting the difference in energy stress (kWh/year) for Z and Z-nO and R and R-O for electricity and district heating.
Best pactice	– Storage solutions (heating and electricity) can shift the demand for energy import at grid stress hours. – Optimal control can shift the demand for energy import at energy stress hours and create a flatter profile.

4.1.8 POW3.8 Peak load difference

Peak load difference focuses on the difference in peak load between the ZEN with and without optimal control (Z and Z-nO) and the reference project with and without optimal control (R and R-O). This allows a person to quantify explicitly the impact of load flexibility, see Table 28.

Table 28 Summary for calculating KPI POW3.8.

POW3.8	**Peak load difference**
Objective	The neighbourhood exchanges energy with the surrounding energy system in a flexible way that reduces the peak load of the neighbourhood (usually referring to imported energy but may apply also to exported energy). By reducing the stress on the energy grid, the neighbourhood can reduce the demand for grid investments and related GHG emissions.
Description	The difference in peak load between the ZEN (Z) and reference project (R) is calculated in *POW3.1 Peak load* and *POW3.2 Peak export.* This indicator refers to the difference in peak load between the ZEN with and without optimised control (Z and Z-nO). The %-difference in peak load (maximum of the peak import and peak export) when the hourly or sub-hourly load profile for electricity and district heating is calculated at the neighbourhood assessment level for the ZEN and reference project (Z) and the not-optimised ZEN (Z-no) over a period of one year.
Method	1 point
Points available	The point is awarded for documenting the difference in peak load for Z and Z-nO and R and R-O for electricity and district heating.
ZEN KPI assessment	The KPI will be assessed based on the percentage (%) reduction in peak load (kWh/h) in the ZEN (Z) compared to the peak load in the not-optimised ZEN (Z-nO)
Best practice	– Storage solutions (heating and electricity) can shift the demand for energy import at peak load hours. – Optimal control can shift the demand for energy import at peak load hours and create a flatter profile.

The load flexibility KPIs can be summarised in a graph which shows the effects of the flexibility on all the flexibility indicators together as shown in Figure 25. The example shows the flexibility indicators calculated for three different school buildings (one regular, one energy efficient and one very energy efficient). The example shows that while the operational cost difference (Δcost), energy stress difference (Δenergy stress) and peak load difference (Δpeak load) are reduced, the delivered energy difference (Δenergy) increases when optimal control is introduced.

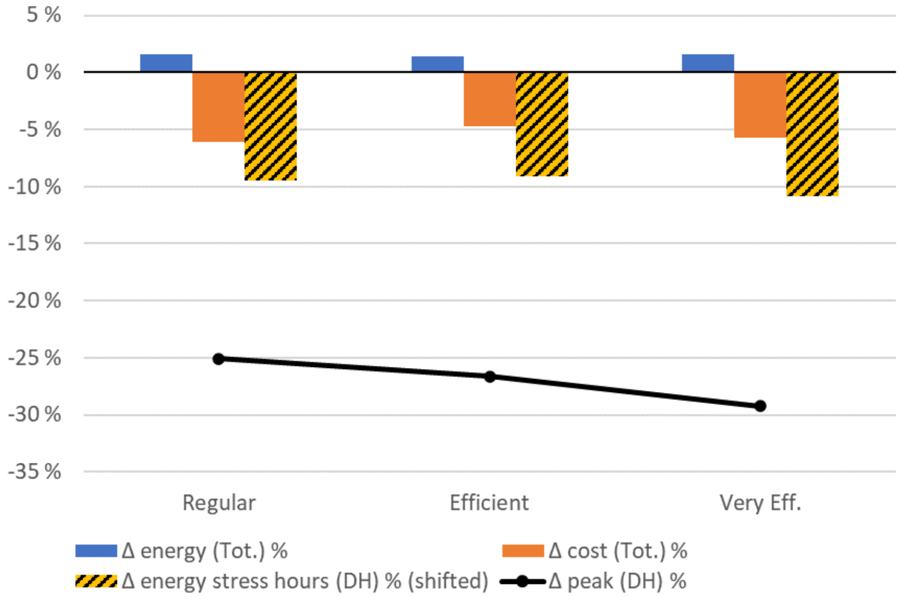

Figure 25 Example results on the energy flexibility indicators in three different school buildings.

5 Urban Form and Land Use

When planning a zero emission neighbourhood, each local context will have unique challenges and opportunities. Research has shown that some urban form and land use characteristics provide more decisive conditions for mitigating GHG emissions than others within the city boundary. According to the International Panel on Climate Change (IPCC) (42), compact urban development with high density and land use mix in combination with good access to amenities, walkable streets, and a sufficient share of green space, are of special importance for low energy use per capita, especially within the transport and building sector. Indirectly, these urban form characteristics also save valuable resources and enhance natural carbon uptake by increasing land use efficiency and open green space.

Urban form and land use refers to the spatial structure, land use patterns and the shape of buildings, street networks and open public space. The following KPIs for urban form and land use have been selected based on their influence on mitigating GHG emissions but also to their co-benefits concerning quality of life, climate adaption, biodiversity, health, and social equity. The urban form and land use KPIs are focused on locations within urban regions and may not translate well to neighbourhoods located outside of the urban boundary. Urban form and land use KPIs are valid for the neighbourhood assessment boundary level. The KPIs are defined to be able to be used both reactively and proactively. Reactively to assess a completed plan and proactively to provide guidance and form the basis for further planning decisions at an earlier stage of either the work on the municipal sub-plan or zoning plan.

5.1 Assessment Criteria

The urban form and land use assessment criteria can be seen as a summary of the ZEN spatial indicators work and highlights the most fundamental aspects of urban form and land use (43–45). 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 geographic information system (GIS) software. The required background data are usually available from Norwegian municipalities in either the early planning phase (masterplan) (URB4.1 - URB4.4) or late planning phase (regulation plan) (URB4.5 - URB4.13). These KPIs are valid for the strategic planning phase. Basic knowledge in GIS is required for compiling the KPIs. The term 'plan area' is defined as the geographical system boundary of the ZEN and is used for all URB KPIs. The KPIs are grouped under four assessment criteria, namely: Density and land use mix, Building layout, Street network and Green open space.

Density and land use mix

The density and land use mix assessment criteria contains four KPIs, namely: URB4.1 Population density, URB4.2 Block density, URB4.3 Land use mix, and URB4.4 Access to a diversity of amenities.

5.1.1 URB4.1 Population density

High density of both residents and workplaces within walking distance increases service supply and provides better conditions for shared mobility, such as public transport and car sharing solutions that can contribute to lower GHG emissions from transport including the production of vehicles, see Table 29. Fewer cars per housing unit can also contribute to reduced GHG emissions from the building sector due to building less car parking spaces (46). Population density is calculated as the total of number of proposed residents and workplaces within the plan area together with surroundings within 1000 metres distance, see Figure 26. The value can either be calculated from a central location in the plan area or by the average for each block. Distance threshold should be within walking distance measured along convenient and safe routes (not air distance). If only the floor area of buildings (and not estimates of population) is known use 50 square metres gross floor area per person for residents and services and 20 square metres gross floor area for office space. The summary value for the plan area can either be calculated from a central location in the plan area or by the average for each building.

Figure 26. Map showing the proposed population density from the ZEN pilot area at Fornebu (45).

Table 29. Summary for calculating KPI URB4.1

URB4.1	**Population density**
Objective	To support public transport, provide a market for local services which are important for peoples' daily lives and well-being and to increase the potential for walking and cycling. Population density is also important for sharing economy services such as car sharing, smart charging, and smart grids.
Description	The total number of residents and workplaces within 1 km walking distance. Average for the plan area.
Method	GIS mapping with Place syntax tool (47).
Points available	2 points
ZEN KPI assessment	Points are awarded for the average population density (number of residents and employees) within 1 km walking distance within the plan area: 2 points: > 10 000 users/km 1 point: 5 000 – 10 000 users/km 0 points: < 5 000 users/km

5.1.2 URB4.2 Block density

High density at the block level provides efficient land use in combination with densification on hard surfaces which saves the need to exploit green space or farmland. High block density and a balance of residential and office floor area provides conditions for smart energy solutions that reduce the per capita GHG emissions from the energy sector, see Table 30. High block density is a prerequisite for efficient district heating and cooling networks by smart thermal grids and provides an advantage for electrical grid balance, including electric public transport (42). Block density is calculated through the percentage of gross floor area divided by the plot area, see Figure 27. The percentage of gross floor area can be found in the plan proposal. If a plot area is not defined, the area can be defined as a space for construction of buildings separated from other plots or public spaces by the street pattern.

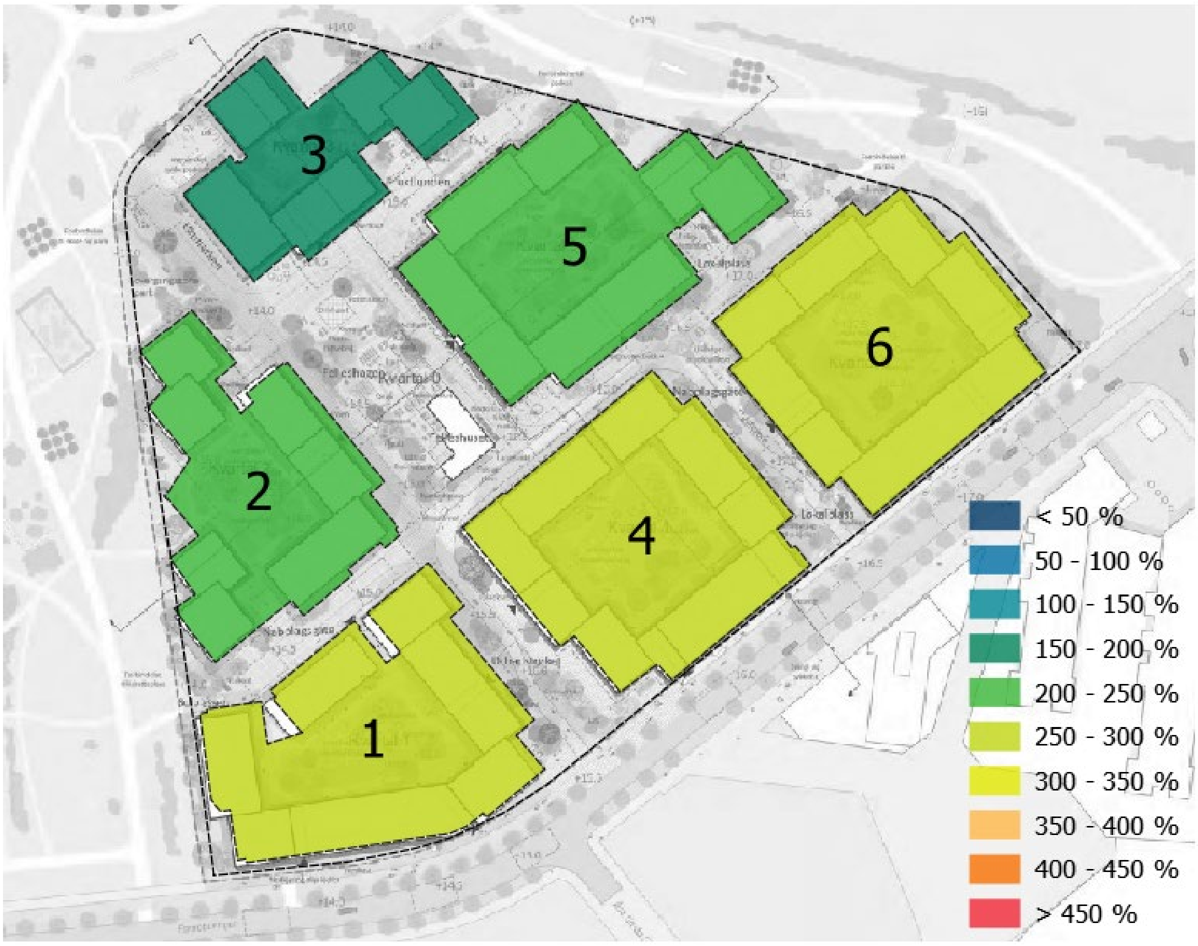

Figure 27. Map showing the calculated block density at Nansenløkka at the ZEN pilot area at Fornebu (48).

Table 30. Summary for calculating KPI URB4.2

URB4.2	**Block density**
Objective	To provide conditions for lower GHG emissions by saving green assets and reducing material consumption within buildings and infrastructure per capita. A certain density is necessary for both accessibility to a diversity of amenities and a customer base for these amenities.
Description	The allocation of points awarded are based on urban plots that include dwellings. Note that there is an important contrast between density and housing quality.
Method	GIS mapping.
Points available	1 point
ZEN KPI assessment	Points are awarded for block density (gross floor area GFA[4] / plot area PA): 1 point: 100 - 250 % 0 points: less than 100 or more than 250 %

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[4] The total floor space encompassed by the building, as measured up to the outer surface of its exterior walls.

5.1.3 URB4.3 Land use mix

Land use mix assesses the balance between residents and workers within the neighbourhood within 500 metres walking distance, see Table 31. The UN Habitat highlights the importance of a certain mix of residents and workers (49). A balance is important for co-use, level of service, social safety, and increased potential for sustainable transportation. A balance of 40 - 60 % can be considered very good, while a balance of less than 10 - 90 % is not good. Figure 28 shows the number of residents and workers within 500 metres walking distance from the ZEN pilot area at Fornebu, and Table 32 shows the share of residents and workers.

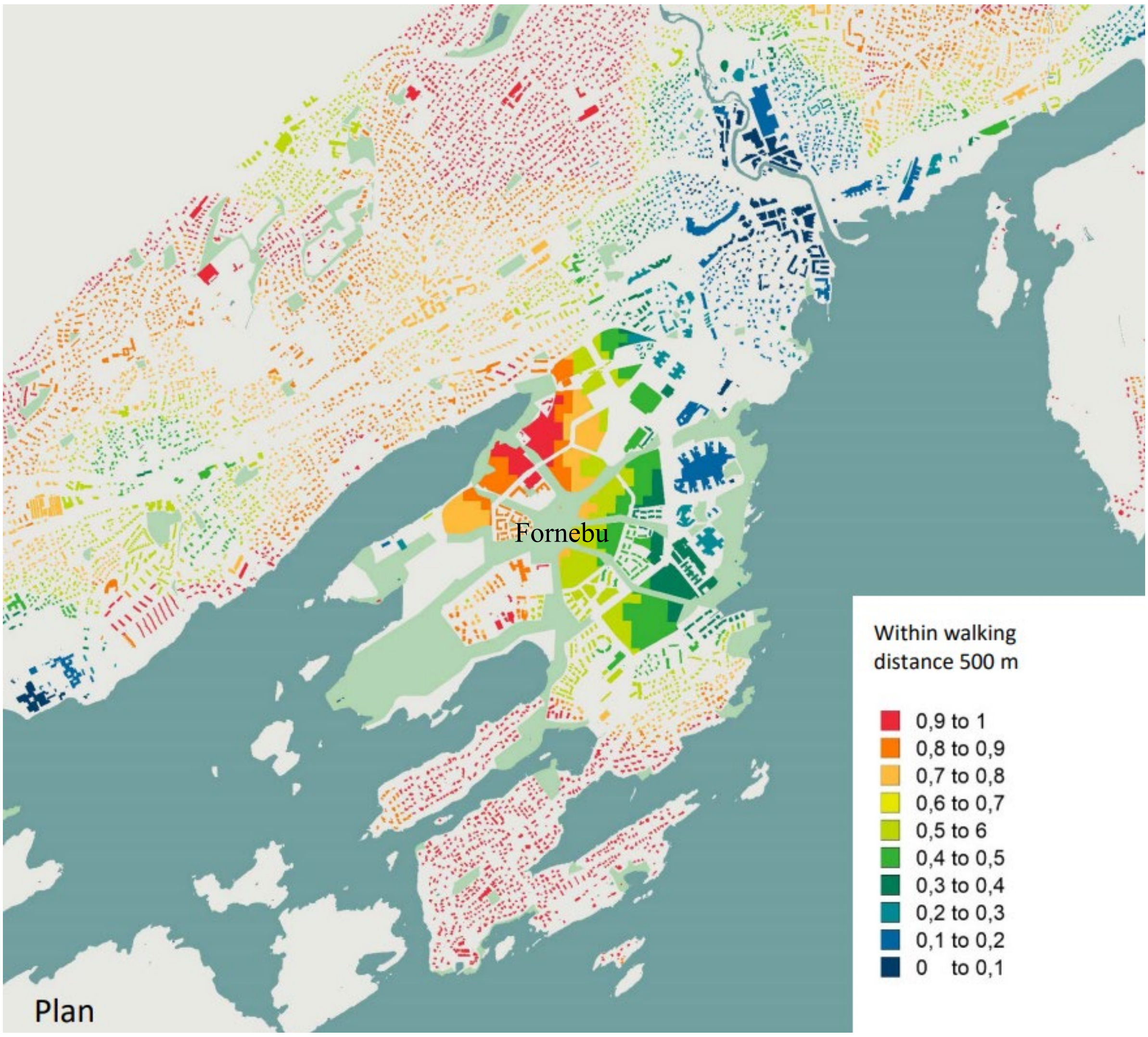


Figure 28. Map showing the land use mix ratio within 500 metres walking distance from the ZEN pilot area at Fornebu (45).

Table 31. Summary for calculating KPI URB4.3

URB4.3	**Land use mix**
Objective	To encourage a mix of residents and workers, it is important to facilitate for co-use, level and amount of service and amenities, social safety, and increased potential for sustainable transportation, which will in turn reduce GHG emissions from sharing services and transport. According to UN Habitat the share of non-resident gross floor area should preferably be between 40 and 60 % (49).
Description	Total number of residents and workers or share of gross floor area for residents within a 500 metre walking distance.
Method	GIS mapping with Place Syntax Tool (47). Calculated as the share of residents compared to the total number of residents and workplaces within 500 metres walking distance. The distance threshold should be calculated as the walking distance measured along convenient and safe routes (not air distance). The summary value for the plan area can either be calculated from a central location in the plan area or by the average for each building.
Points available	2 points
ZEN KPI assessment	Points are awarded for the balance between resident and workers: 2 points: 40 - 60 % residents 1 point: 20 - 40 or 60 – 80 % residents 0 points: less than 20 or more than 80 % residents

Table 32. Existing and planned share of residents and workers within the ZEN pilot area at Fornebu (45).

Type of user	**Existing**		**Planned**	
	Amount	**Share**	**Amount**	**Share**
Residents	2 741	22%	13 685	48%
Workers	9 718	78%	14 825	52%
SUM	12 459	100%	28 510	100%

5.1.4 URB4.4 Access to a diversity of amenities

The access to a diversity of amenities KPI categorises amenities into five groups: local public transport, fast regional transport, educational facilities, local service cluster and green open public spaces, see Table 33. Local public transport is defined as having at least one departure every 15 minutes during the daytime. Fast regional public transport is defined as transit on rails or BRT (bus rapid transport). Educational facilities are identified as secondary schools, primary schools, and nurseries. For the local service cluster, services are are often located along a street or in a local centre. Services may include for example, grocery store, pharmacy, café or restaurant, health care or package pickup/post, and should include at least 3 types of local service. Green open public space is defined in *URB4.10 Share of green open space.* Access to local services is important for social equality and urban attractiveness. Figure 29 provides an example of how these urban attractions can be mapped within 1 km from the ZEN and Table 34 gives an example of the walking distances to each category of urban attractions. This KPI is to be assessed during the strategic planning phase, whilst *MOB5.1 Access to public transport* considers access to public transport in the implementation and operational phases.

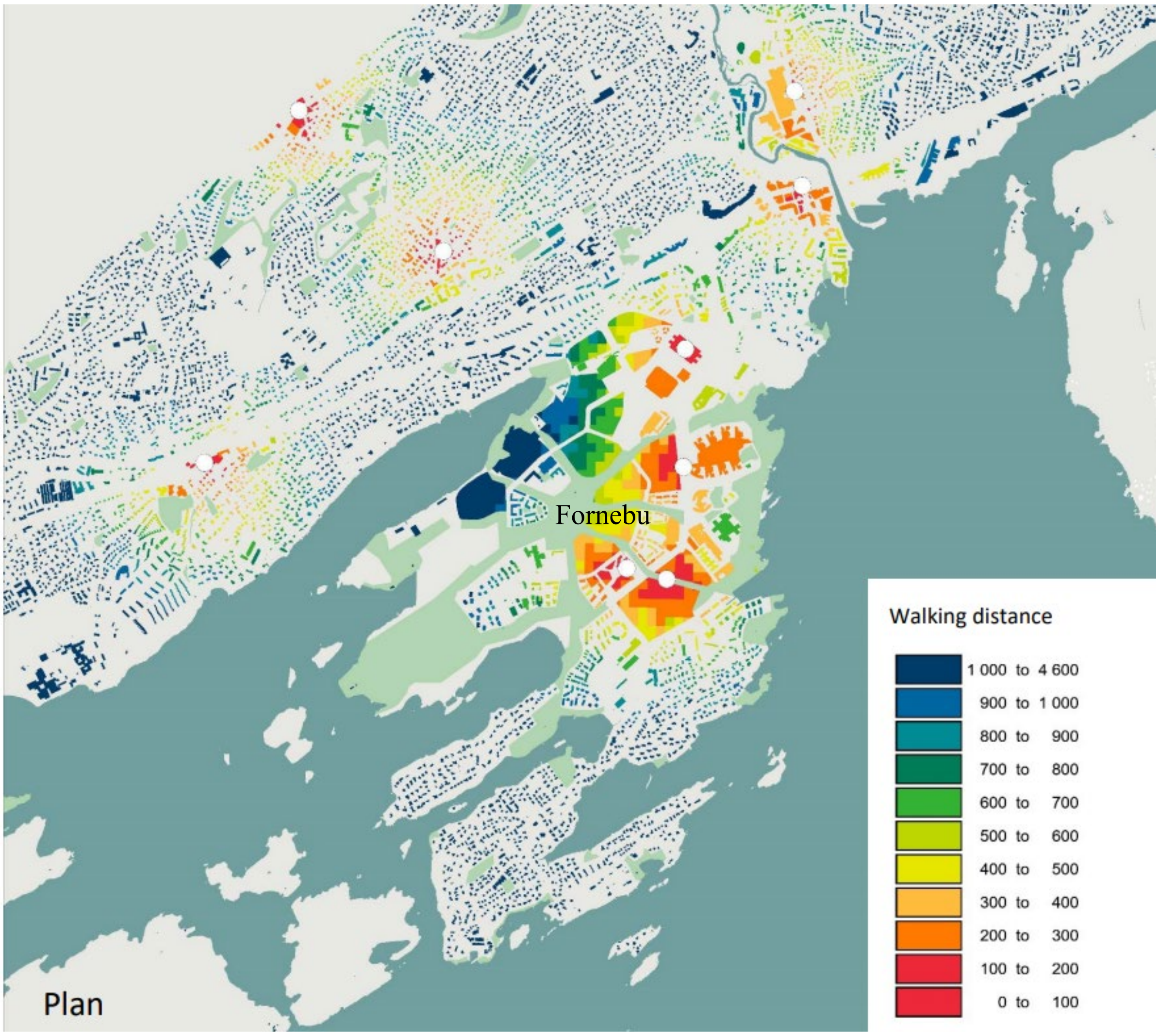


Figure 29. Closeness to local centre given as walking distance in metres for the ZEN pilot area at Fornebu (45).

Table 33. Summary for calculating KPI URB4.4

URB4.4	**Access to a diversity of amenities**
Objective	The access to a variety of amenities within walking distance has shown to be important for social equality and urban attractiveness (50) as well as for increasing the share of sustainable transport patterns (49) which will in turn decrease GHG emissions from transport.
Description	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: 1. Local public transport 2. Fast regional public transport 3. Educational facilities 4. Local service cluster 5. Green open public space

URB4.4	**Access to a diversity of amenities**
Method	GIS mapping with Place Syntax Tool or other GIS applications that can measure walking distance (alternatively walking distance can be measured manually in Google Maps or other map services and reported in Table format) (47). GIS map showing facilities within 1 km walking distance.
Points available	2 points
ZEN KPI assessment	Points are awarded for the number of accessible facilities: 2 points: > 4 accessible categories 1 point: 3 accessible categories 0 points: 0 - 2 accessible categories

Table 34. Walking distances to each category of urban attraction, example taken from Fornebu (45).

Urban attraction	**Walking distance – existing (metres)**	**Walking distance – planned (metres)**
Local public transport	497	277
Fast regional public transport	2418	436
Educational facilities	1107	588
Local service cluster	924	433
Green open public space	158	105

Building layout

The building layout assessment criteria contains three KPIs: *URB4.5 Dwelling type, URB4.6 Multifunctional building roofs* and *URB4.7 Active frontages.*

5.1.5 URB4.5 Dwelling type

The layout and use of buildings strongly influence life and living (51). Building types are closely related to plot dispositions which in turn influences sustainability, such as the amount of green space versus the number of concrete constructions and amount of private car driving, see Table 35. According to Naturskyddsföreningen, parking spaces in Sweden take more space than the actual living space (46). Figure 30 gives an example of calculating the share of detached and semi-detached houses.

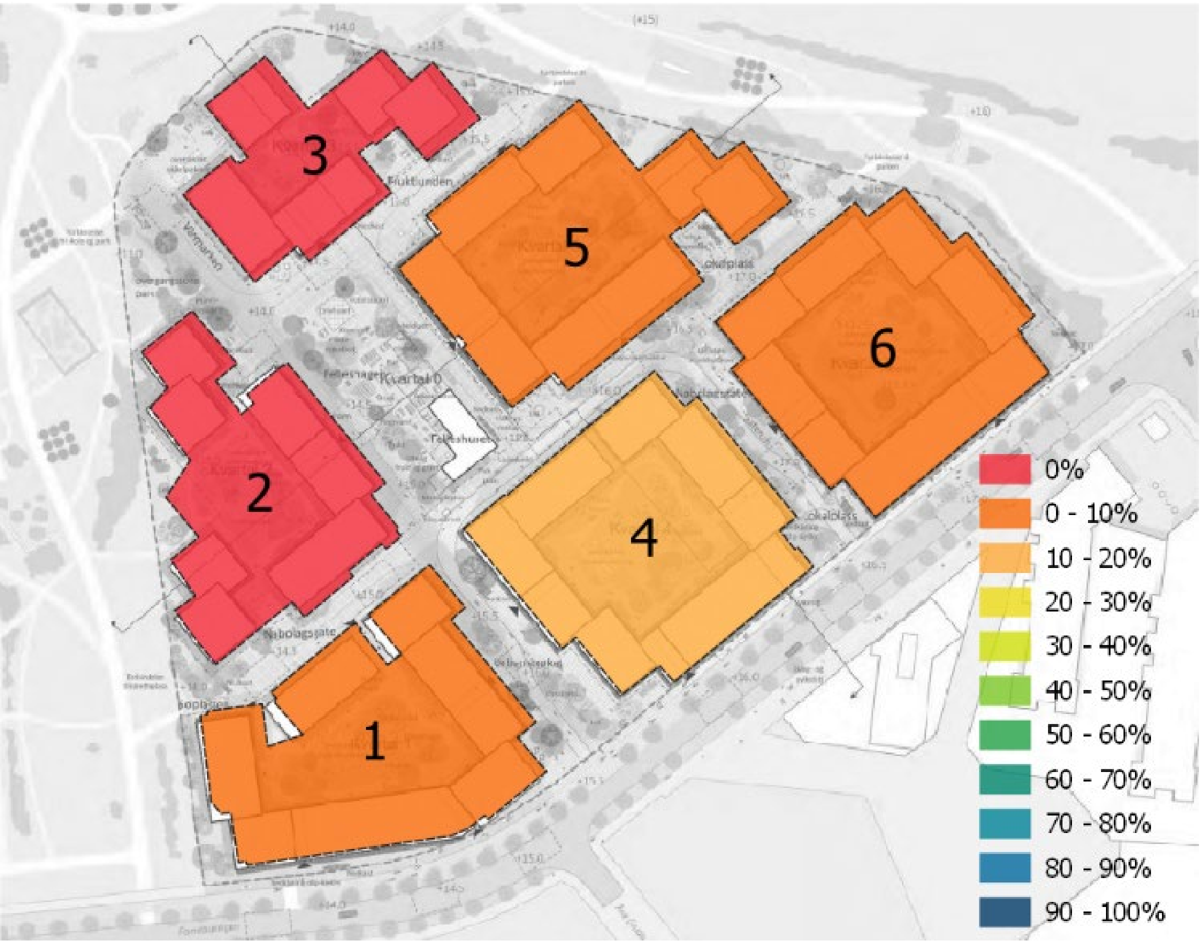


Figure 30. Map showing the calculated share of detached and semi-detached houses at Nansenløkka at the ZEN pilot area at Fornebu (48).

Table 35. Summary for calculating KPI URB4.5

URB4.5	Dwelling type
Objective	Dwelling type influences floor area per person and the area of building envelope per floor area and thereby GHG emissions per capita during the implementation and operation phases. A high share of detached houses increases the amount of private car driving.
Description	Share of detached and semi-detached houses of all dwelling units, including apartments.
Method	Count of detached and semi-detached houses divided by the total count of dwelling units, including apartments within the plan area.
Points available	1 point
ZEN KPI assessment	Points are awarded for share of detached and semi-detached houses: 1 point: < 30 % 0 points: > 30 %
Best practice	– Optimisation of building floor area. – Prioritise multi-family homes over single-family buildings. – Shared space solutions for reducing the total floor area per dwelling. – Fewer parking spaces per housing unit or workplace.

5.1.6 URB4.6 Multifunctional building roofs

Building roofs can include building integrated renewable energy production, social spaces, and green spaces, see Table 36. Renewable energy production integrated into building roofs can include, but is not limited to, solar thermal collectors and photovoltaic systems. Social spaces are considered as shared spaces. Green roofs can mitigate climate emissions directly through carbon uptake and indirectly by inducing a biophysical cooling effect that reduces energy demand in buildings and energy demand for water treatment (42). Figure 31 shows the roof areas for social functions and green spaces at Nansenløkka, Fornebu.

Figure 31. Map showing the roof areas for social functions and green space at Nansenløkka at the ZEN pilot area at Fornebu (48).

Table 36. Summary for calculating KPI URB4.6

URB4.6	**Multifunctional building roofs**
Objective	The layout of roof areas can be designed for renewable energy production, carbon storage by plants, and/or providing outdoor areas for social activities and recreation.
Description	The share of building roof that is used for either energy production, social functions, or green space.
Method	Share of building roof for these purposes out of the total area of the building footprint.

URB4.6	**Multifunctional building roofs**
Points available	1 point
ZEN KPI assessment	Points are awarded for share of building roof (total for all functions): 1 point: > 50% 0 points: < 50%
Best practice	– Plan for renewable energy production within the building roof – Plan for social functions – Plan for green spaces, see *URB4.11 Share of green open space, URB4.12 Share of green permeable area*

5.1.7 URB4.7 Active frontages

The building layout can support street life and social safety for pedestrians by facilitating active building frontages (52), see Table 37. To calculate active building frontages, each ground level building façade is defined within the categories A - E according to Table 38. This classification is based on entrance density, function mix and façade transparency. A function is defined as a type of dwelling, amenity, or office. Only facades towards main roads are mapped. A main road is defined as a major road with a large amount of traffic. A façade must fulfil all three requirements in Table 38 to receive that category rating. Blind and passive facades are defined as facades with no entrances or windows. See Figure 32 for an example of how active frontages can be calculated.

Figure 32.Map showing the categorised building frontages at Bryggerikvartalet in Bodø (48).

Table 37. Summary for calculating KPI URB4.7

URB4.7	**Active frontages**
Objective	Active building frontages at ground level with access from the street is important for providing conditions for *URB4.3 Land use mix, URB4.4 Access to a diversity of amenities*, the local economy, and socially safe and attractive streets.
Description	The share of active building frontages due to entrance density, function mix and facade transparency along main streets through or within the neighbourhood.
Method	GIS mapping or manually measured in Google Maps or other map services and reported in a table format. Each façade line is defined within the categories A - E according to entrance density, function mix and façade transparency. Only facades towards main roads are mapped.
Points available	2 points
ZEN KPI assessment	Points are awarded for share of facades: 2 points: > 80% of facades in category A, B, or C 1 point: 40 - 80 of facades in category A, B, or C 0 points: < 40% of facades in category A, B, or C
Best practice	

Table 38. Categories of building frontages in terms of entrance density, function mix and façade transparency, adapted from (52).

Criteria for active building frontages		
Category A		
15 – 20 entrances per 100 m	> 3 types of function	No blind or passive facades
Category B		
10 – 14 entrances per 100 m	> 2 types of function	Few blind or passive facades (< 20 %)
Category C		
6 – 9 entrances per 100 m	> 1 type of function	Some blind or passive facades (< 40 %)
Category D		
2 – 5 entrances per 100 m	No mix of functions	Mostly blind or passive facades (> 80 %)
Category E		
0 – 2 entrances per 100 m	No mix of functions	100% Blind or passive facades

Street network

The street network assessment criteria contain three KPIs, namely: *URB4.8 Street connectivity, URB4.9 Street intersection density* and *URB4.10 Walkable and bikeable streets.*

5.1.8 URB4.8 Street connectivity

The structure of street networks and how they support the perception of closeness and create potential for natural movement between neighbourhoods impact the long-term development of density and amenities patterns (53). Street connectivity, measures how well neighbourhoods are linked to each other based on sight lines along the street network, see Table 39. This indicator has a significant effect on social segregation (54), natural pedestrian movement (56) and perceived closeness within the urban fabric. A neighbourhood lacking well-connected streets to surrounding neighbourhoods can be considered a spatially segregated enclave. Figure 33 provides an example of a map showing the street network within the ZEN pilot at Bodø, and Table 40 shows the share of well-integrated streets.

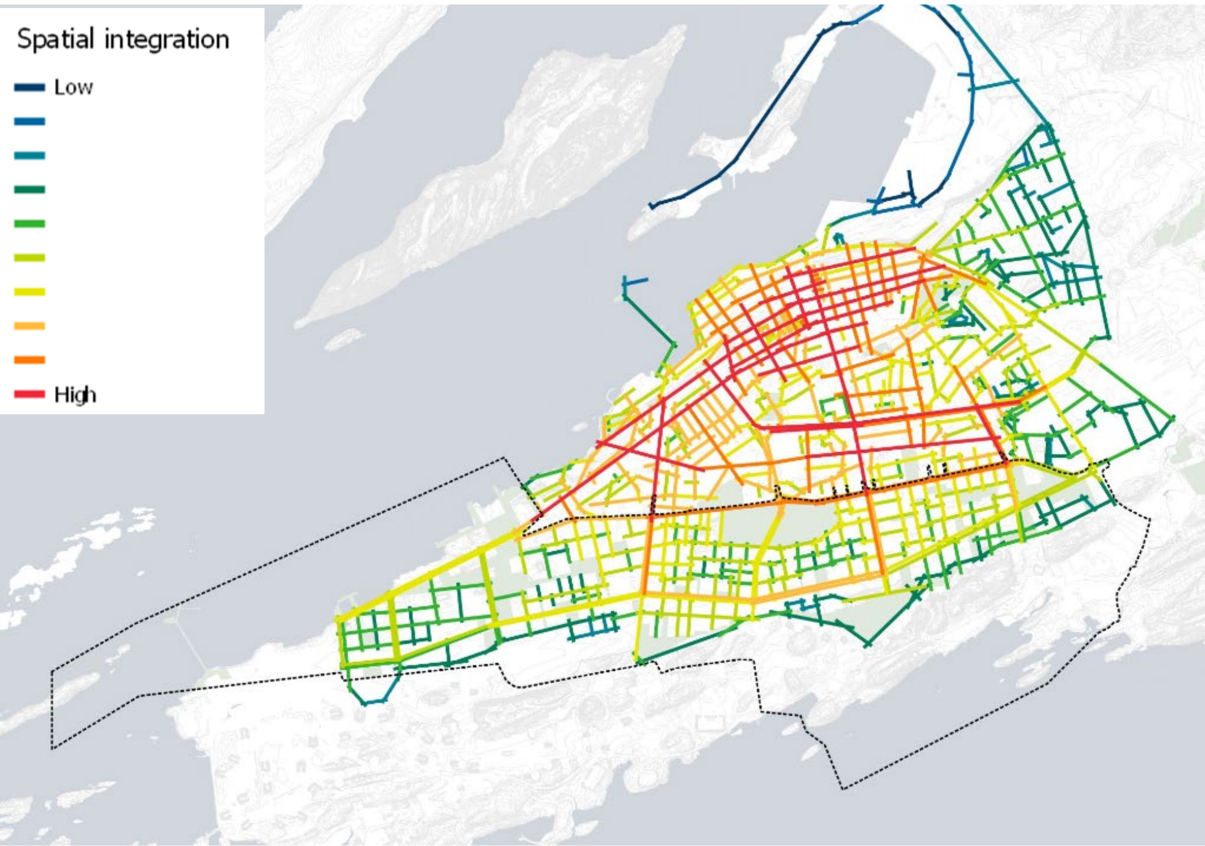


Figure 33. A map showing street network within the ZEN pilot area at Bodø (46)

Table 39. Summary for calculating KPI URB4.8

URB4.8	**Street connectivity**
	To encourage walkability as well as social and economic exchange with surrounding neighbourhoods to increase the share of active mobility and thereby reduce GHG emissions from *GHG1.5 Operational transport (B8).*
Description	Mapping to what extent the project is connected to the surrounding neighbourhoods by direct routes, particularly for walking and bicycling. Street connectivity assesses the distance to surrounding neighbourhoods as well as the number of streets that connect to the neighbourhood. Street connectivity is defined by the number of well-connected streets to surrounding neighbourhoods (along the neighbourhood district border). A well-connected street is characterised by visual overview and close walking distance from one local central place (could be a main street or square) to another local central place within a surrounding neighbourhood.
Method	Examine map and mark the routes that are continuous from central/well integrated streets within the plan area to central/well-integrated street(s) in surrounding neighbourhood within 1km air distance.

URB4.8	**Street connectivity**
Points available	2 points
ZEN KPI assessment	2 points: All relevant surrounding neighbourhoods are well connected to the plan area. 1 point: > 50% of the relevant surrounding neighbourhoods are well-connected to the plan area. 0 points: Relevant surrounding neighbourhoods are poorly connected to the plan area.

Table 40. Share of the relevant surrounding neighbourhoods that are well connected to the plan area

Total number of relevant surrounding neighbourhoods	Number of relevant surrounding neighbourhoods that are well connected to the plan area
3	2

5.1.9 URB4.9 Street intersection density

Intersection density is also one of the most important characteristics for traffic safety when it comes to street design (57), see Table 41. A well-connected street network encourages walkability as well as social and economic exchange with surrounding neighbourhoods. In addition to spatial integration, street intersection density can support voluntary modal shifts to walking, cycling, and transit when street networks are transformed or extended (43). An example of calculating street intersection density is given in Figure 34.

Figure 34. Calculated street intersection density for two plan proposals within the ZEN pilot area Sluppen (45).

Table 41. Summary for calculating KPI URB4.9

URB4.9	**Street intersection density**
Objective	To provide conditions that stimulate walking and cycling as well as increase traffic safety based on traffic calming effects. Intersection density is a measure of "network-grid-size" that influences origin-destination distances for multi-purpose trips and is therefore important for achieving neighbourhoods of short distances.
Description	Distance between pedestrian crossings along streets with vehicle traffic (not including pedestrian streets or walkways).
Method	Based on a map of the street network. Lengths between pedestrian traffic junctions are measured within the plan area and include the closest junction on all routes out of the plan area. Street intersection density is calculated as the measure of average street length between junctions for the plan area.
Points available	1 point
ZEN KPI assessment	Points awarded for mean average distance between street intersections: 1 point: < 150 metres 0 points: > 150 metres
Best practice	– Allow for mixed traffic that is convenient for walking and cycling

5.1.10 URB4.10 Walkable and bikeable streets

Walkable and bikeable streets tend to be more common in compact urban developments with high levels of street connectivity due to higher pedestrian movements and better bicycle accessibility, see Table 42. Continuous routes of high quality for cycling characterise many of the best bicycle cities in the world (58). For supporting accessible and competitive public transport, street design should prioritise transit vehicles above private vehicle traffic. Streets that spatially prioritise walking, bicycling and transit are also more transport efficient since more people can move per hour in rush hour traffic than through streets prioritized for cars (59). Criteria for walkable and bikeable streets is listed in Table 43, and an example of walkable and bikeable streets for Nansenløkka, Fornebu is presented in Figure 35.

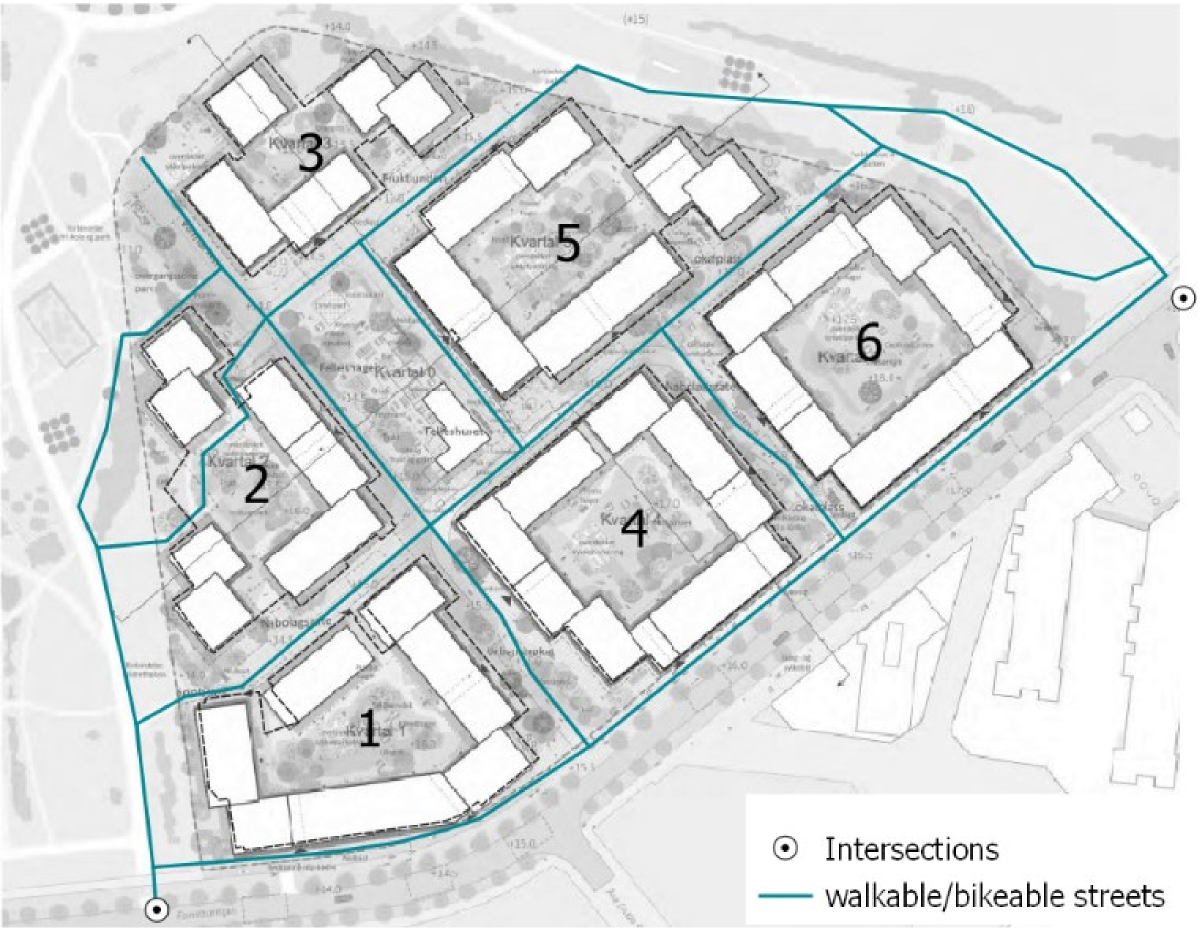


Figure 35. Walkable and bikeable streets at Nansenløkka, the ZEN pilot area at Fornebu (1).

Table 42. Summary for calculating KPI URB4.10

URB4.10	**Walkable and bikeable streets**
Objective	To provide conditions for more walking and cycling while at the same time increasing the potential for a more land use efficient transport system.
Description	Share of street network that is walkable and bikeable.
Method	Based on maps of the plan area, total lengths of all streets and share of streets being convenient and safe for walking and cycling based on the criteria listed in Table 43.
Points available	1 point
ZEN KPI assessment	Points awarded for walkable and bikeable streets: 1 point: 100 % of streets within the neighbourhood 0 points: < 100 % of streets within the neighbourhood
Best practice	Characteristics for walkable and bikeable streets (besides *URB4.9 Street intersection density*) include (59): – Measures to prevent high traffic speeds. – Wide pavements. – Wide and separate cycle tracks (if the vehicle traffic volume is high). – Safe intersections. – - Provide separate bus lanes and/or protected bus stops.

Table 43. Criteria for walkable and bikeable streets (59).

Walkable street	**Walkable intersection**
Pedestrian street or low speed street prioritised for pedestrians (pedestrian street at same height as the road for vehicles).	Clearly prioritised street intersections for pedestrians. Traffic overview not obscured by obstacles.
Or	*Or*
Streets with a speed limit of 30 km/h or more: At least 2.5 metre wide pedestrian lane on a separate height level from vehicles and a marked border towards bicycle lanes.	Intersection with signal less than 4 meters wide. Traffic overview not obscured by obstacles.
Bikeable street	**Bikeable intersection**
Bicycles in mixed traffic on streets with maximum 30 km/h speed limit and less than 1 500 vehicles per day	Mixed traffic on streets with maximum 30 km/h speed limit and less than 1 500 vehicles per day. Traffic overview not obscured by obstacles.
Or	*Or*
Streets with a speed limit of 30 km/h or more: At least 2 metre wide cycle track clearly separated from vehicles, a marked border towards pedestrians and a minimum buffer of 1 metre towards parked cars.	Intersection with marked space for cyclists. Traffic overview not obscured by obstacles.
Street section space for pedestrian and bicyclists	
At least 50 % of the street section should be prioritised for pedestrians, cyclists, or public transport (tram or bus lane) or green space. If a street or an intersection contains more than one pedestrian or cycle lane (pavement) or one pedestrian or cycle crossing, then the lowest standard is mapped.	

Green open space

The green open space assessment criteria consists of three KPIs, namely: *URB4.11 Share of green open space, URB4.12 Share of green permeable area* and *URB4.13 Preserving and planting trees.*

5.1.11 URB4.11 Share of green open space

Beside carbon uptake, green infrastructure can also reduce mitigate climate emission by reducing energy need within the building sector (43). Green roofs have been shown to have beneficial effects in stormwater reduction and can also reduce building heating demands (43). If implemented at appropriate scales, green open spaces also have several co-benefits: Preserving and enhancing biodiversity, water quality and supply, air quality, soil fertility, food and wood security, livelihoods, resilience to droughts, heat stress, floods, and other natural disasters. Green open spaces also contribute to recreational qualities, air quality, ecosystem health and human well-being (43).

The share of green open public space is measured as the total ground surface land area within 500 metres air distance (clearly public qualitative green areas that are at least 0.2 hectares (2000m^2) in size), see Table 44. Green open public space is defined as a green outdoor area that is clearly public (physically and mentally accessible to all), permeable (where water can permeate though the soil) and larger than 0.2 hectare. Green spaces smaller than 0.2 hectares and green spaces with unclear boundaries (such as privately owned courtyards with unclear borders between private and publicly owned and managed green space) are not included. Schoolyards can be regarded as green open public space if they are accessible to all after school hours and have more than 50 % permeable green area. Green roofs and facades are not included. Figure 36 shows green open public space within 500 metres for each building within the ZEN and Table 45 shows the average values of % green open public space for the existing situation and the planned situation for the ZEN.

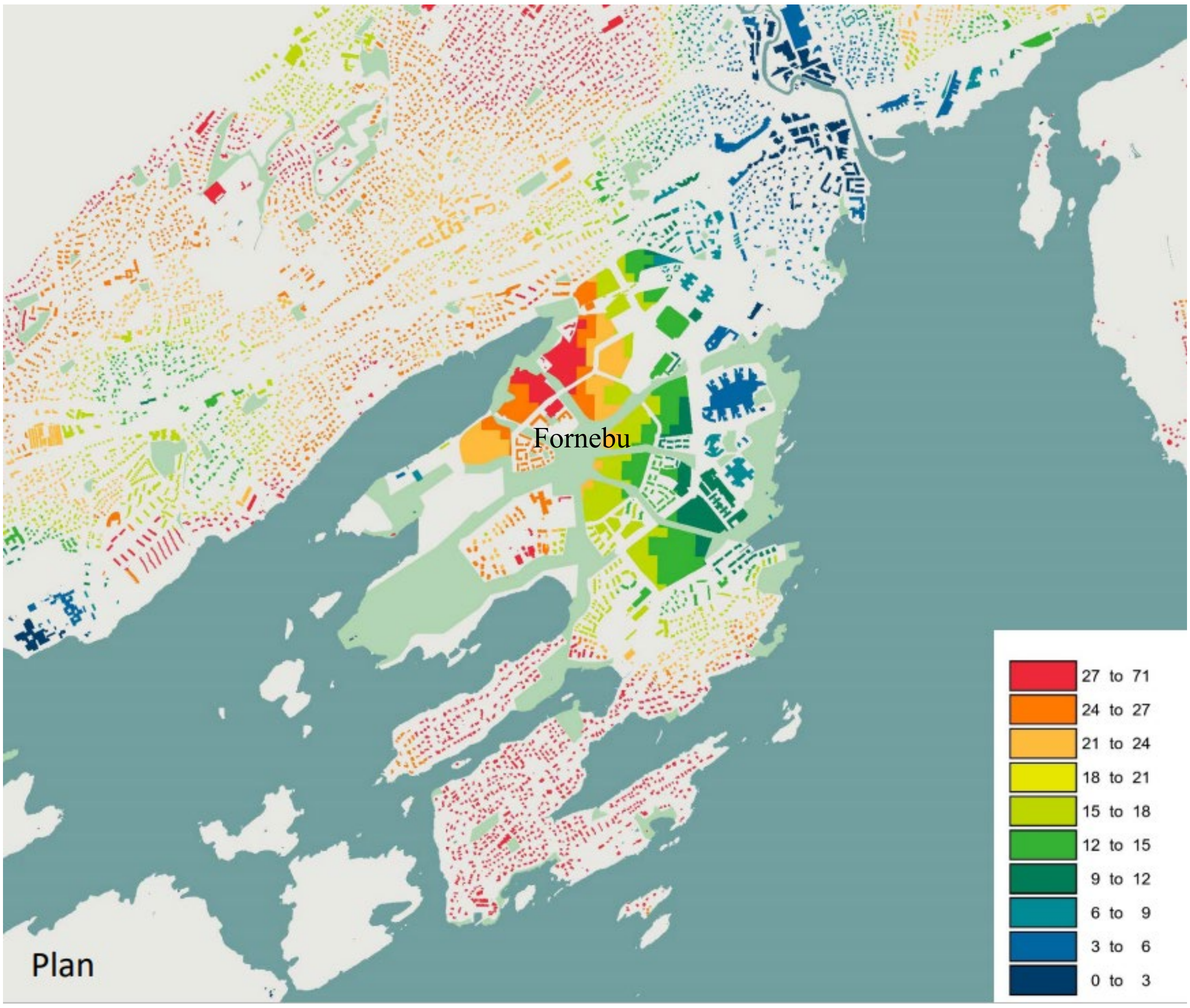


Figure 36. Percentage of green open public space within 500 metres for the ZEN pilot area at Fornebu (46).

Table 44. Summary for calculating KPI URB4.11

URB4.11	**Share of green open public space**
Objective	Green and permeable open public space provide conditions for natural carbon uptake, climate adaption and provide co-benefits regarding people's health and well-being.
Description	The share of green open public space is measured by the share of all land area within the neighbourhood including a buffer area of 500 metres air distance from each building, see Table 45.
Method	Green open public space is calculated by the percentage share of green open public space within a buffer area of 500 meters air distance for each building/block within the neighbourhood. Green roofs and façades are not included in this KPI since these are already covered in *URB4.6 Multifunctional building roofs.*
Points available	2 points
ZEN KPI assessment	Points are awarded for the share of green open public space: 2 points: > 15% 1 point: 10 - 15% 0 points: < 10 %
Best practice	Green open public space includes various options, ranging from: – Moors and forests. – Parks. – Play areas. – Green corridors

Table 45. Share of green open public space within 500 meters air distance, average value for plan area

Type of space	**Existing - Area (m^2)**	**Proposed - Area (m^2)**
Share of green open public space	19%	20%

5.1.12 URB4.12 Share of green permeable area

Green permeable areas contribute to carbon uptake and preservation and enhancement of biodiversity, water quality and supply, air quality, soil fertility, resilience to droughts, heat stress, floods and other natural disasters as well as contributing to ecosystem health and human wellbeing by air quality (43), see Table 46. Figure 37 gives an example of calculating green permeable area for Nansenløkka, Fornebu.

Figure 37. Green permeable area at Nansenløkka at the ZEN pilot area at Fornebu (49).

Table 46. Summary for calculating KPI URB4.12

URB4.12	Share of green permeable area
Objective	Green and permeable areas provide conditions for natural carbon uptake, climate adaption and provide co benefits on people's health and well-being.
Description	The share of green and permeable area, excluding artificially built-up surfaces with greenery such as green roofs but not limited to areas that are accessible for people, of the total plan area.
Method	GIS mapping or manually measured in Google Maps or other map services and reported in a Table format. Share of green permeable space within the plan area.
Points available	2 points
ZEN KPI assessment	Points are awarded for share of green permeable space: 2 points: > 30% 1 point: 15- 30 % 0 point: < 15%

5.1.13 URB4.13 Preserving and planting trees

Preservation, management and extension of forests and parks is a key issue for cities looking to mitigate climate change due to the potential of trees to store large amounts of carbon on a small piece of land and doing so for a long period of time, see Table 47. Street trees have an especially positive impact on air quality, provide sun shelter and can help balance the urban climate. Street trees can also be used as a tactic for lowering vehicle speed (43). Figure 38 gives an example of reporting the number of trees at Nansenløkka, Fornebu.

Figure 38. Number of trees at Nansenløkka at the ZEN pilot area at Fornebu (1).

Table 47. Summary for calculating KPI URB4.13

URB4.13	**Preserving and planting trees**
Objective	Trees enhance carbon uptake while providing a variety of co benefits such as air quality, balancing temperature, recreational values, biodiversity, and traffic calming at the same time.
Description	Planting of new trees and care of existing trees should be a central part of the project. An overall plan for preserving existing trees and instructions for planting of new trees.
Method	Mapping of existing trees in GIS or manually measured in Google Maps or other map services.
Points available	1 point
ZEN KPI assessment	Points are awarded for planned strategies for preserving existing and planting of new trees: 1 point: The project includes a plan for preserving existing trees and instructions for planting of new trees

URB4.13	**Preserving and planting trees**
	0 points: No plan for preserving existing trees and planting of new trees
Best practice	– Preserve existing trees – Plant native trees

6 Mobility

Travel behaviour relating to a project is the combined result of a range of factors, some of which can be captured in calculations/assessments in the planning phases of a project, and some which cannot. For instance: Demographics of the residents in terms of age/occupation activity, household composition (e.g., with young children) affect the number and types of necessary daily out-of-home activities to be carried out, while the location and distance between residences and the activity-related destinations, combined with the available and realistic travel alternatives for these relations, form the basis for the residents' day-to-day choices of travel behaviour, including choice of transport mode. To add to the complexity, recent development in technology provides a substantial share of the working population with the option to work from home on an occasional or regular basis. Furthermore, climate and topography, car ownership and quality of transport services available vary between regions and urban areas.

There should be access to data on how travel habits are affected by technological developments as described above to capture these factors and provide a project-specific baseline required to assess the effects of mobility-related ZEN measures for travel habits during the operational phase. Further, data on travel behaviour representing local conditions (e.g., local samples from the National Travel Survey (NRVU) see ZEN memo no. 37 (60)), rather than on data describing national averages should be used. The development of scope and geographic resolution of data collected in the NRVU the past ten years has been more challenging. To give a value on how more 'untraditional' services should be integrated into a ZEN project (for example, collective electric car services, micromobility, home office etc.) will affect mobility patterns, empirical data is needed on who is using these services, and how they affect travel patterns. Currently, little data is available to be used in such evaluations.

The ZEN definition focuses on promoting sustainable transport patterns and smart mobility systems both locally and regionally. This can be achieved through good physical planning and good logistics. The KPIs for mobility are limited to cover aspects the developer can influence directly through their own choices and decisions given the lack of empirical data for evaluating consequences of users travel habits. Mobility KPIs will be assessed at the neighbourhood assessment boundary level. It should be noted that the basic conditions for urban form and land use that relate to sustainable transport patterns and smart mobility systems are addressed within the urban form category.

6.1 Assessment Criteria

The mobility category has one assessment criterium, namely 'access'. Key performance indicators include *MOB5.1 Access to public transport, MOB5.2 Travel time ratio* and *MOB5.3 Parking facilities*

6.1.1 MOB5.1 Access to public transport

MOB5.1 Access to public transport considers links to existing and planned transport nodes (such as trains, buses, trams, or metro), see Table 48. In an implementation phase access to public transport can be based on the current public transport available in the proposed area plan, and distances can be calculated based on estimates from an estimated centre of gravity within the plan area. Information on the distance from a building within the ZEN to the nearest transport node, as well as transport frequency in high and low traffic periods for the actual area can be gathered from for example travel planners such as EnTur or other map services such as Google Maps. The procedure described below can be used to calculate access to public transport for existing or planned stops and services.

Access to public transport services is classified according to the method used in NRVU (NRVU 2018/19 key report (61)), combining the number of departures per hour on weekdays and the distance from home to the station or stop normally used, in order to calculate a qualitative variable that describes public transport access on a 5-point scale from very poor to very good (see Table 49). To follow is an explanation of the five-point scale:

1. *Very poor or no access:* No public transport service within 1.5 km from home, or departures less frequent than every second hour and 1-1.5 km to the station or stop.
2. *Poor access:* Departure every second hour or less frequent and less than 1 km to the station or stop, or 1 departure per hour and 1-1.5 km to the station or stop
3. *Medium quality access:* 1 departure per hour and less than 1 km to the station or stop, or 2-3 departures per hour and 1-1.5 km to the station or stop.
4. *Good access:* 2-3 departures per hour and less than 1 km to the station or stop, or at least 4 departures per hour and 1-1.5 km to the station or stop.
5. *Very good access:* At least 4 departures per hour and less than 1 km to the station or stop.

Table 48. Summary for calculating KPI MOB5.1.

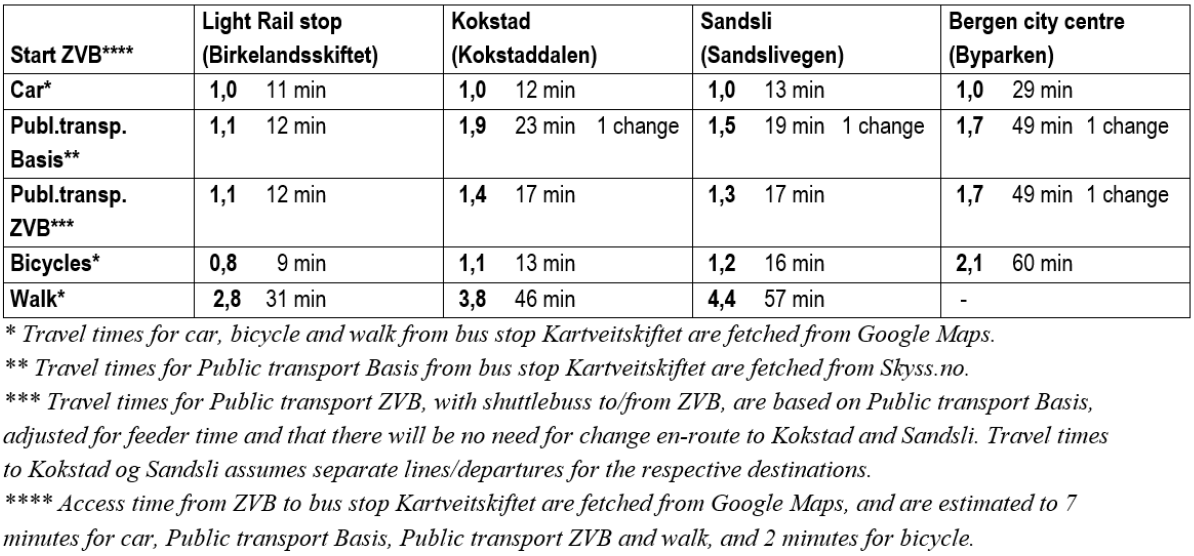
MOB5.1	**Access to public transport**
Objective	To facilitate frequent and easily accessible public transport, as a climate-efficient transport choice in the ZEN and reduce GHG emissions from *GHG1.5 Operational transport (B8).*
Description	A qualitative variable is calculated based on public transport access on a five-point scale from very poor to very good, based on the distance from the neighbourhood to the station or stop normally used, and frequency of departures from the station or stop.
Method	NRVU
Points available	5 points
ZEN KPI assessment	See Table 49
Best practice	– Project located within short distance to stops with high-frequency public transport services. – Construction of new stop(s) with high-frequency public transport services close to neighbourhood.

Table 49. Access to public transport

Distance to the stop **Frequency, departures**	**< 1 km**	**1 – 1.5 km**	**> 1.5 km**
At least 4 per hour	5	4	1
2-3 per hour	4	3	1
1 per hour	3	2	1
Less frequent	2	1	1

6.1.2 MOB5.2 Travel time ratio

This KPI considers the competitive relationship between private motorised, public transport and active transport options for movements between the ZEN and the closest local centre that covers daily service requirements such as groceries, pharmacy, and hairdresser, see Table 50. Figure 39 shows an example for the ZEN pilot Zero Village Bergen (ZVB) that also includes other types of amenities such as public transportation hubs and busy workplace areas. Low travel time ratio is desired. The KPI for travel time ratio is calculated in all project phases.



Start ZVB****	**Light Rail stop (Birkelandsskiftet)**	**Kokstad (Kokstaddalen)**	**Sandsli (Sandslivegen)**	**Bergen city centre (Byparken)**
Car*	**1,0** 11 min	**1,0** 12 min	**1,0** 13 min	**1,0** 29 min
Publ.transp. Basis**	**1,1** 12 min	**1,9** 23 min 1 change	**1,5** 19 min 1 change	**1,7** 49 min 1 change
Publ.transp. ZVB***	**1,1** 12 min	**1,4** 17 min	**1,3** 17 min	**1,7** 49 min 1 change
Bicycles*	**0,8** 9 min	**1,1** 13 min	**1,2** 16 min	**2,1** 60 min
Walk*	**2,8** 31 min	**3,8** 46 min	**4,4** 57 min	-

** Travel times for car, bicycle and walk from bus stop Kartveitskiftet are fetched from Google Maps.*

*** Travel times for Public transport Basis from bus stop Kartveitskiftet are fetched from Skyss.no.*

**** Travel times for Public transport ZVB, with shuttlebuss to/from ZVB, are based on Public transport Basis, adjusted for feeder time and that there will be no need for change en-route to Kokstad and Sandsli. Travel times to Kokstad og Sandsli assumes separate lines/departures for the respective destinations.*

***** Access time from ZVB to bus stop Kartveitskiftet are fetched from Google Maps, and are estimated to 7 minutes for car, Public transport Basis, Public transport ZVB and walk, and 2 minutes for bicycle.*

Figure 39. Estimated travel times and travel time ratios (in bold) for car vs. respectively public transport, bicycle and walk, for ZEN ZVB (60).

Travel time information can be obtained from travel planners such as EnTur and the equivalent offered by various local public transport companies, possibly in combination with information from map-based services such as Google Maps. In the strategic planning phase travel times can be based on estimates from the centre of gravity for the plan area. Travel times and travel time conditions can be calculated and retrieved for both rush and low traffic periods, to capture any queue problems, and should include walking times to and from the stop or parking. The KPI should primarily be based on travel times during morning rush hours. Which mode of transport calculations to be used is dependent on the car distance between the plan area and the destination the travel time will be calculated for. Which modes of transport to be used for the different distance intervals can be found in Table 51. The division of distance intervals is based on travel length of daily journeys in relation to public transport, cycling and walking in NRVU 2018/19 (61).

Table 50. Summary for calculating KPI MOB5.2

MOB5.2	**Travel time ratio**
Objective	To increase the ratio of public and active transport over private motorized transport to reduce GHG emissions relating to *GHG1.5 Operational transport (B8).*
Description	The KPI considers the competition between private cars, cycling, walking and public transport, in an everyday situation with time constraints.
Method	Information on travel times to the nearest local centre by private car, public transport, and active modes respectively, can be retrieved from national or local travel planners, e.g., EnTur and services such as Google Maps. The KPI is calculated using formulae in Table 51 depending on distance by car.
Points available	8 points
ZEN KPI assessment	Points are allocated based on the travel time ratio: 8 points: ≤ 0.5 6 points: ≤ 0.75 4 points: ≤ 1 2 points: ≤ 1.5 1 point: ≤ 2 0 points: > 2
Best practice	– The shorter the overall distance, the more favourable the conditions are expected to be for active modes to compete with travel times by private motorised options. – A combination of short distances to public transport stops, high frequency, and high speed for the public transport service, with no need for change of vehicle on route, provides the most favourable conditions for public transport to be able to compete with private motorized vehicles in terms of travel time. – Locating parking spaces for private motorised vehicles at a distance from dwellings, will add to the door-to-door travel time for private motorized options, and hence affect the travel time ratios in a desired direction from a ZEN perspective.

Table 51. Calculation of travel time ratios

Distance	**Calculation formula**
More than 5km	Travel time $_{\text{public}}$ / travel time $_{\text{private motorized}}$
1.5 – 5km	Travel time $_{\text{bicycle}}$ / travel time $_{\text{private motorized}}$
0 – 1.5km	Travel time $_{\text{walking}}$ / travel time $_{\text{private motorized}}$

6.1.3 MOB5.3 Parking facilities

This KPI considers the physical facilitation of a resident's vehicle ownership or driving a car in, to and from a neighbourhood, in terms of access to a parking space for the vehicle when not in use, see Table 52. The KPI also includes quality of parking facilities for bicycles. The municipality's parking norm specifies local regulations on how many parking spaces should and can be established for residents or workers and may act as a reference value. In areas with low parking capacity, and/or high costs associated with car parking, this may incur restrictions on residents' ability to own a car.

The KPI for parking facilities is specified as the number of car parking spaces available per unit, and design of offered bicycle parking. The goal is to reduce GHG emissions associated with private mobility (by reducing car ownership and use) and to encourage more active mobility (electric bicycles and manual bicycles).

Table 52. Summary for calculating KPI MOB 5.3

MOB5.3	Parking facilities
Objective	To reduce private vehicle ownership, as well as encourage more active forms of mobility (electric/manual bicycles).
Description	Car parking options can be specified as the number of parking spaces available per building unit. Design of high-quality bicycle parking includes access to lockable bicycle stands under a roof with heating and possibility to charge electric bicycles.
Method	Documentation of the parking norm and planned parking facilities for car and bicycles.
Points available	7 points, whereby 5 points are connected to car parking and 2 points are connected to design of bicycle parking
ZEN KPI assessment	Points are calculated based on the percentage reduction in the number of car parking spaces compared to the parking norm (reference), and access to safe parking facilities for bicycle parking. Offered car parking as percentage of parking norm: 5 points: ≤ 60 % 4 points: 60-70 % 3 points: 70-80 % 2 points: 80-90 % 1 point: 90-100 % 0 points: ≥ 100 % Offered high-quality bicycle parking as a percentage of the parking norm for bicycle parking: 2 points: 100 % 1 point: 50-99 % 0 points: < 50 %
Best practice	– Avoid building underground parking facilities for private cars, since underground constructions typically have higher GHG emissions from the materials used in groundworks and foundations. – Reduce the amount of private vehicle parking spaces. Facilitate for *URB4.4 Access to a diversity of amenities, MOB5.1 Access to public transport* and *MOB5.2 Travel time ratio* so that public and active mobility are viable alternatives. – Install electric charging points for cars and bicycles. – Supply safe bicycle parking facilities.

7 Economy

Economic sustainability is an important consideration if ZENs are to be mainstreamed. Developing a group of interconnected buildings into a ZEN will likely entail increased investment costs during the implementation phase, but these will most likely be offset by lower operational costs during the operational phase and increased project value. Economy KPIs can be used to highlight the benefits of sustainable project management and promote sustainable solutions, as well as to reduce investment uncertainties and risk and secure cost-effective and economically beneficial zero emission solutions.

In the ZEN definition, the economy (ECO) KPIs are structured according to the three pillars of sustainability to create an affordable, attractive, and viable sustainable zero emission neighbourhood, see Figure 40. The ZEN ECO KPIs are designed to increase openness and information sharing, as well as highlight GHG emission reduction and compensation measures implemented in ZENs. The ZEN ECO KPIs are valid for both the building and neighbourhood assessment boundary level.

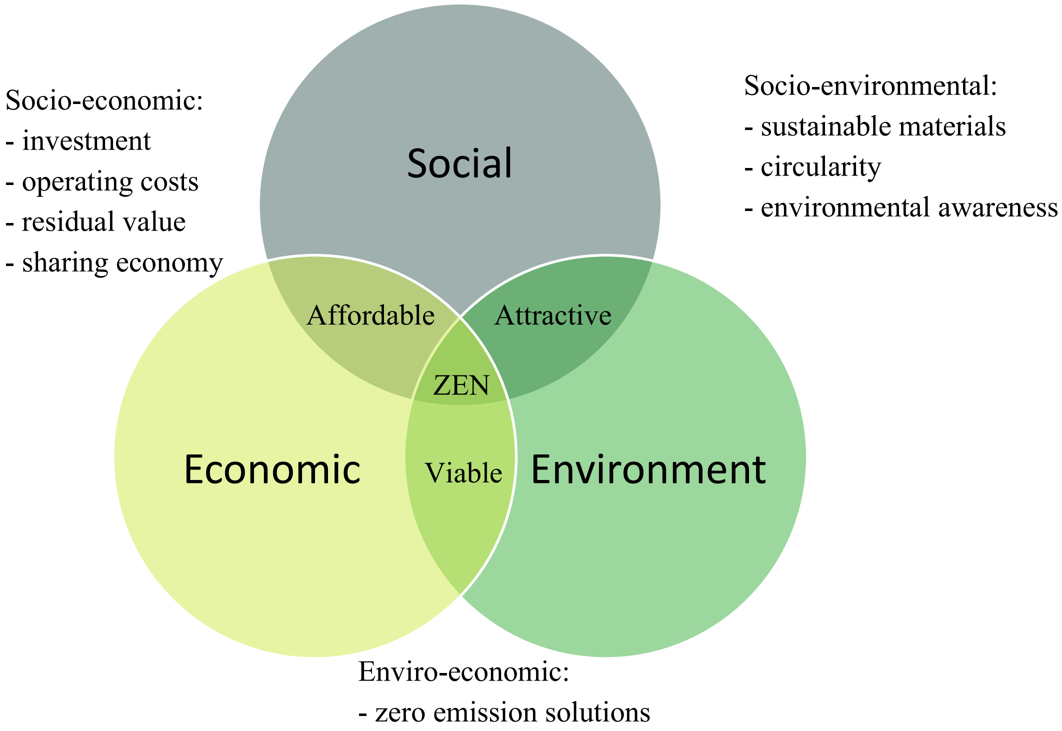


Figure 40. Three pillars of sustainability, adapted from (62).

7.1 Assessment Criteria

The ZEN ECO category comprises of three assessment criteria according to the three pillars of sustainability, namely socio-economic, socio-environmental, and enviro-economic. In terms of ZEN, socio-economic considers the combination of financial decisions with interpersonal dynamics, socio-environmental considers the physical and social setting in which planners and contractors design and develop the area in which people live and interact with their surroundings, whilst enviro-economic appraises the economic effects of zero emission solutions and measures. The socio-economic assessment criteria consists of three KPIs, namely *ECO6.1 Investment costs, ECO6.2 Operating costs* and *ECO6.3 Residual value*. The socio-environmental assessment criteria has four KPIs, namely *ECO6.4 Sharing* *economy, ECO6.5 Sustainably sourced materials, ECO6.6 Circularity* and *ECO6.7 Environmental awareness*, whilst the enviro-economic assessment criteria consists of one KPI, namely *ECO6.8 Cost of emissions saved* .

Life cycle costs

Life cycle costing (LCC) is an economic evaluation methodology for the assessment of costs relating to building and construction assets, over the entire life cycle of a building, infrastructure, or neighbourhood. LCC calculations provide a snapshot of costs at that given point in time, whereby costs are sensitive to both fluctuating prices and inflation. LCC should be calculated according to *NS-EN 16627: 2015 Sustainability of construction works. Assessment of economic performance of buildings. Calculation methods* (63). *NS-EN 16627* follows the same life cycle modularity principle as defined in the *GHG Emissions* category, namely A1-A5, B1-B7, C1-C4 and D. This allows LCA and LCC calculations to be harmonised.

LCC is useful in all project phases. In the strategic planning phase, LCC forecasting may use 'benchmark costs' based on historical costs of previous projects. LCC in early project stages is used for studying the consequences of the performance requirements before any decisions are made. As the design evolves and more detailed information becomes available, benchmarks should be substituted with project-specific estimated costs. The strategic planning and implementation phases have the greatest potential to influence the operational life cycle costs. Thus, LCC should be completed as early as possible in the design process to maximize the outcome and ensure opportunities to positively influence the project (64). Continual monitoring and optimisation of LCC should continue throughout the project's life cycle.

Using LCC as part of the decision-making process requires good accessibility to reliable input data, starting with generic information (i.e., statistics and historical costs) and going on to more specific information. Cost information can be obtained from manufacturers and suppliers, contractors, testing and research organisations, publications, commercial databases, feedback from operational assets, and organisations' internal data. Data from the Norwegian Price book (Norsk prisbok (65)) can also be used as reference values.

The reporting units for LCC are aligned with the reporting units in the chapter on *GHG Emissions* and are as follows; Total Norwegian kroner and Norwegian kroner per square meter gross floor area (GFA) per year ($NOK/m^2_{GFA}/yr$) whereby the analysis period is 50 years and the calculation interest rate is 4%. The time period in which LCC calculations are carried out shall be stated.

Socio-economic

7.1.1 ECO6.1 Investment costs

This KPI captures investment costs calculated according to *NS-EN 16627* (63), see Table 53. Investment costs refer to building construction costs and the cost of assets or items that are purchased or implemented with the aim of improving the GHG emissions of the ZEN and should as a minimum include life cycle modules A1-A5. Investment costs are seen from the developer's perspective, and shall be calculated according to *NS 3453: 2016 Specification of costs in building projects*, see Table 54 (66). *NS 3453: 2016* is aligned with *NS 3451: 2022 Table of building elements used* in the LCA calculations for ZEN GHG KPIs. It is expected that there will be a higher investment in more energy-efficient and zero emission buildings and infrastructure. This KPI will be assessed at both the building and neighbourhood level. Discount agreements between contractors and suppliers are not included.

Table 53. Summary for calculating KPI ECO6.1

ECO6.1	**Investment costs**
Objective	Economic sustainability will be important for the mainstreaming of ZENs, where project owners and investors need to articulate a business case in developing a group of interconnected buildings into a ZEN, which will likely entail higher upfront costs with investments in energy, heating and storage systems, and material costs. This KPI captures those investment costs.
Description	Investment costs refer to building construction costs (A1 – A5) and the cost of assets or items that are purchased or implemented with the aim of improving the GHG emissions of the ZEN.
Method	Investment costs are calculated according to *NS-EN 16627* and *NS 3453:2016 Specification of costs in building projects* for the ZEN and a reference case (R), see Table 54. Results are reported in terms of NOK and NOK/m^{2GFA}/yr. As a minimum, all buildings and energy systems within the neighbourhood should be included. The reference project energy system can be based on the reference project developed in the Energy category. Existing areas will have no investment costs, unless changes are being made to the existing area, then the costs associated with the changes being made are to be included.
Points available	1 point
ZEN KPI assessment	1 point for calculating investment costs (A1-A5) for the whole ZEN neighbourhood (ZEN) and a reference case (R)
Best practice	– Identify low-cost materials and technologies with low-embodied GHG emissions

Table 54. Specification of construction costs (A1 – A5) NS 3453:2016 (66)

	Type of cost	**Reference (R)**	**ZEN**
01	Shared costs		
02	Building		
03	Heat, ventilation, and sanitation		
04	Electric power		
05	Telecommunications and automation		
06	Other installations		
01 – 06	Building cost		
07	Outdoors		
01 – 07	Contractor cost		
08	General costs		
01 – 08	Construction cost		
09	Special costs		
10	Value added tax (VAT)		
01 – 10	Base cost		
11	Expected addition (incl. VAT)		
01 – 11	Project cost		
12	Uncertainty provision (incl. VAT)		
01 – 12	Cost framework		

	Type of cost	**Reference (R)**	**ZEN**
13	Price regulation (incl. VAT)		
01 – 13	TOTAL		

7.1.2 ECO6.2 Operating costs

This KPI captures annual operating costs, relating to energy use, see Table 55. Operating costs are seen from the building owner's perspective. Operational costs should include life cycle modules B1 to B6. This KPI will be assessed at both the building and neighbourhood level.

Table 55. Summary for calculating KPI ECO6.2

ECO 6.2	Operating costs
Objective	Economic sustainability will be important for the mainstreaming of ZENs, where building owners need to articulate a business case in developing a group of interconnected buildings into a ZEN, which will likely entail higher upfront costs with investments in energy, heating and storage systems, and material costs, but offset this investment by lower operational costs during the operational phase. This KPI captures these operational costs.
Description	Operating costs refer to investment-related annual costs for those assets or items purchased or implemented for improving GHG emissions of the neighbourhood.
Method	Operating costs are calculated according to *NS-EN 16627* for B1-B6 for the ZEN neighbourhood (ZEN) and a reference case (R). Results are reported in terms of NOK and NOK/m^{2GFA}/yr. The reference project energy system can be based on the reference project developed in the Energy category. Existing areas can use current operating costs as a reference. Planned changes to the existing area shall be included in the ZEN project.
Points available	1 point
ZEN KPI assessment	1 point for calculating operational costs for the whole ZEN neighbourhood (ZEN) including buildings and infrastructure and a reference case (R)
Best practice	- Energy-efficient buildings with low operational energy use - Robust materials with long service lifetimes that require fewer replacements - Fulfil EU taxonomy requirements

7.1.3 ECO6.3 Residual value

This KPI focuses on the end-of-life residual value of the area, including its buildings and infrastructure, see Table 56. This KPI highlights circular economic value of the area by documenting the residual value therefore reducing end-of-life GHG emissions.

Table 56. Summary for calculating KPI ECO6.3

ECO 6.3	**Residual value**
Objective	To document end-of-life residual value of the neighbourhood, its buildings and infrastructure with an aim to reduced end-of-life GHG emissions.
Description	Residual value refers to the value of assets or items within the neighbourhood that can be reused or recycled at end-of-life.
Method	Residual value is calculated according to *NS-EN 16627* for the ZEN and a reference case for C1-C4 and D. Results are reported in terms of NOK and NOK/m^{2GFA}/yr. The reference project can be based on business as usual.
Points available	1 point
ZEN KPI assessment	1 point for calculating C1-C4, D residual value for the whole ZEN neighbourhood (ZEN) and a reference case (R)
Best practice	– Choose materials and components that are easily demounted – Choose materials and components that can be reused – Choose materials and components that can be recycled – Digital twin of the ZEN that includes material passports

Socio-environmental

7.1.4 ECO6.4 Sharing economy

This KPI facilitates for a sharing economy within the ZEN through proactive measures, see Table 57. Investments are made to facilitate for a sharing economy. Joint use will reduce GHG emissions in terms of area use, will improve on area efficiency, whilst sharing resources and services may reduce GHG emissions from the users during the operational phase. Benefits of a sharing economy include:

- accessibility to economic opportunities for everyone involved,
- building trust among participants and communities,
- lower ownership and maintenance costs,
- easier access to capital and resources,
- increased choice and variety of goods and services,
- income generation potential for providers,
- sustainable alternative that reduces waste and environmental impact,
- shared resources and knowledge.

Table 57. Summary for calculating KPI ECO6.4

ECO6.4	**Sharing economy**
Objective	To facilitate for a sharing economy within the ZEN.
Description	Investments are made to facilitate for a sharing economy. Joint use will reduce GHG emissions in terms of area use, whilst sharing resources and services will reduce GHG emissions from the users during the operational phase.
Method	Documentation that a shared resource or service have been implemented in the neighbourhood. The resource or service should be dimensioned according to the number of users and calculate the GHG emissions saved by implementing the measure. See Best practice for examples.
Points available	3 points

ECO6.4	Sharing economy
ZEN KPI assessment	1 point for mobility share implemented 1 point for common spaces implemented 1 point for collective services and shared equipment implemented
Best practice	– Mobility share: electric cars, electric bikes, ride shares – Collective services: canteen, vehicle charging, renewable energy – Common spaces: wash/utility room, offices, gym or training facilities, workshop, function rooms, guest apartment – shared equipment: gardening tools, kitchen appliances, power tools, sports equipment, ski shed – Community garden – - Digital app that enables sharing

Figure 41. Examples of a sharing economy from the ZEN pilots (photos from Bærum municipality and NTNU).

Figure 41 shows examples of sharing economy from the ZEN pilot areas including a community garden at Flytårnet in Bærum and common workshops at NTNU. In addition, the school at Ydalir is used as a community centre and Ydalir Torg will have shared guest apartments and a shared PV system on the shared garage space for charging of electric vehicles.

7.1.5 ECO6.5 Sustainably sourced materials

This KPI is focused on sourcing materials sustainably to reduce environmental impacts from procurement, see Table 58. It also assures that impacts from materials are not problem shifted to other environmental impact categories than GHG emissions. Requirements on material procurement can for example be written into contracts. The scope shall correspond to the material inventory lists included in GHG emission calculations in the GHG category.

Table 58. Summary for calculating KPI ECO6.5

ECO 6.5	**Sustainably sourced materials**
Objective	To source materials sustainably and reduce environmental impacts from procurement.
Description	This KPI focuses on how main construction materials (wood, concrete, steel, aluminium, chemicals, plastic, and rubber) are sourced to reduce environmental impacts, reduce waste, and avoid problem shifting to other environmental impact categories that GHG emissions.
Method	– Wood and wood-based products originate from forests managed according to sustainable forest management principles as certified by FSC or PEF. – Minimum 70% of concrete used shall be low carbon concrete A or better. – Minimum 75% recycled steel/aluminium content. – No dangerous substances from the Substances of Very High Concern (SVHC) included on the EU's REACH Candidate list or on the Norwegian priority list. – No synthetic plastic and rubber surfaces on playgrounds and outdoor areas e.g. artificial turf, mats, tiles, fibres, chips and granules. – Amount of waste and treatment of waste achieves minimum a green level from Figure 42.
Points available	2 points
ZEN KPI assessment	1 point if all material requirements listed above are met 1 point if waste requirement is met
Best practice	– Use pre-assessed Svanemerket, EU-blomsten, SINTEF Technical Approval, SINTEF Environmental Certificate products – Use ECOproduct to identify 'green' indicator for health and environmentally dagerous products – Follow BREEAM-NOR MAT03 Responsible procurement of materials – Source wood and wood-based products from sustainably managed forests – Use low carbon concrete A or better where possible – Choose metals with high recycled content – Reuse or recycle construction and demolition waste – Do not use dangerous substances on the EU's REACH candidate list – Do not use synthetic plastic or rubber surfaces

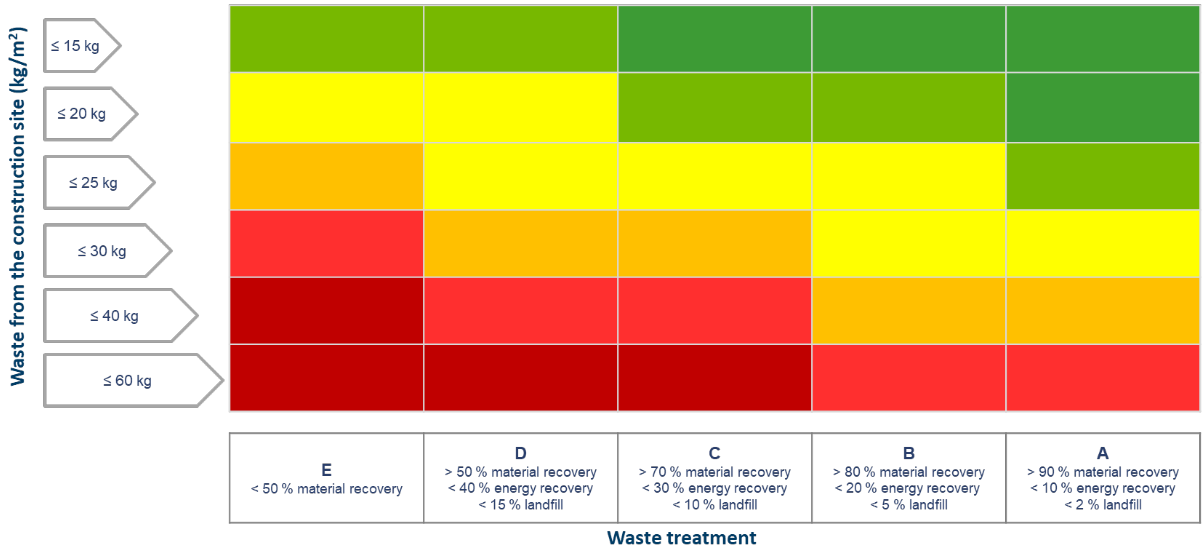


Figure 42. Stepwise approach to waste reduction and waste handling (67)

7.1.6 ECO6.6 Circularity

This KPI refers to what extent circular actions are taken to ensure reduction and compensation of GHG emissions from preserving existing buildings and infrastructure (e.g. conservation and renovation) as well as materials (e.g. reuse and recycle), see Table 59. There is also an added social-environmental value to conserving historical buildings and cultural heritage. Conservation of green qualities is dealt with under the urban form and land use category. The scope shall correspond to all existing buildings, infrastructure, and materials within the area and the material inventory lists included in GHG emission calculations in the GHG category can be used.

Table 59. Summary for calculating KPI ECO6.6

ECO 6.6	**Circularity**
Objective	To ensure that circular actions are taken to ensure reduction and compensation of GHG emissions from preserving existing buildings, infrastructure, and materials within the ZEN.
Description	GHG emission reductions and compensations can be achieved by conserving existing buildings, infrastructure and materials.
Method	Pre-demolition analysis (PDA) to map and identify existing features suitable for conservation and rehabilitation e.g. buildings, infrastructure, and materials. Follow Grønn Byggallianses 'tenk deg om før du river' principles (68). Document the reuse and recycling potential of materials and components within the area e.g. by following FutureBuilts Circularity Index.
Points available	2 points
ZEN KPI assessment	1 point for carrying out a pre-demolition analysis (PDA) of the ZEN and identifying existing features for conservation and renovation. 1 point for documenting potential reuse and recycling of materials and components within the area e.g. by following FutureBuilts Circularity Index.

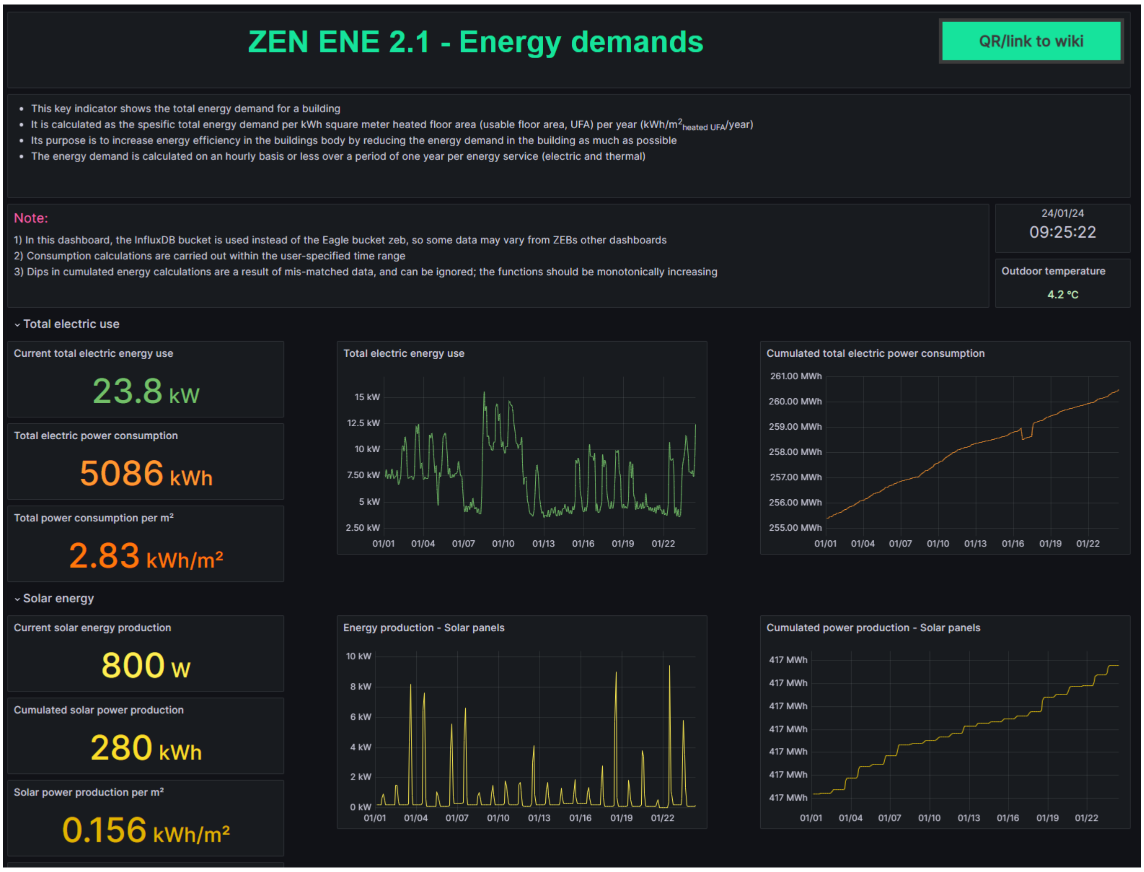
ECO 6.6	**Circularity**
Best practice	– Follow Grønn Byggallianses principle of 'think before you demolish' – Carry out a PDA of the ZEN – Map reuse and recycling potential of materials and components

7.1.7 ECO6.7 Environmental awareness

This KPI captures the degree of environmental awareness, transferred from the project owners, planners, and developers to the users (facility manager and occupants) in terms of GHG emission reduction and compensation, see Table 60. Environmental awareness ensures zero emission knowledge transfer at handover. This KPI is relevant for the implementation phase and operational phase.

Table 60. Summary for calculating KPI ECO6.7

ECO 6.7	**Environmental awareness**
Objective	To make sure that material and energy measures implemented in the neighbourhood are used in an appropriate manner so that the intended effect of GHG emission reduction and compensation measures are achieved.
Description	Environmental awareness refers to environmental consciousness, knowledge interest, and willingness that the user has when it comes to sustainability. This environmental consciousness will reflect the user's attitude and behaviour and lead the user to engage in activities to reduce consumption and compensate for GHG emissions in the neighbourhood.
Method	Handbook on how to use the ZEN at handover including information on management, operation, and maintenance. Neighbourhood dashboard where users can track their energy use, see Figure 43.
Points available	2 points
ZEN KPI assessment	1 point for preparing and providing a ZEN handbook to users at handover with useful information on management, operation, and maintenance on ZEN features e.g. PV-system, material passports, smart energy management systems etc. 1 point for establishing and implementing a ZEN dashboard for tracking and monitoring GHG emissions from energy use
Best practice	– Local sustainability skill development – Handbook on ZEN neighbourhood- Dashboard for tracking and monitoring GHG emissions from energy use



ZEN ENE 2.1 - Energy demands

- This key indicator shows the total energy demand for a building
- It is calculated as the spesific total energy demand per kWh square meter heated floor area (usable floor area, UFA) per year (kWh/$m^2_{\text{heated UFA}}$/year)
- Its purpose is to increase energy efficiency in the buildings body by reducing the energy demand in the building as much as possible
- The energy demand is calculated on an hourly basis or less over a period of one year per energy service (electric and thermal)

Note:
1) In this dashboard, the InfluxDB bucket is used instead of the Eagle bucket zeb, so some data may vary from ZEBs other dashboards
2) Consumption calculations are carried out within the user-specified time range
3) Dips in cumulated energy calculations are a result of mis-matched data, and can be ignored; the functions should be monotonically increasing

24/01/24
09:25:22

Outdoor temperature
4.2 °C

Total electric use

Current total electric energy use
23.8 kW

Total electric power consumption
5086 kWh

Total power consumption per m²
2.83 kWh/m²

Total electric energy use

Cumulated total electric power consumption

Solar energy

Current solar energy production
800 W

Cumulated solar power production
280 kWh

Solar power production per m²
0.156 kWh/m²

Energy production - Solar panels

Cumulated power production - Solar panels

Figure 43. Example of a dashboard for tracking and monitoring GHG emissions from energy use from ZEB LAB (69)

Enviro-economic

The enviro-economic assessment criterion should be performed for a reference (R) and ZEN (Z) scenario. The reference scenario should be based on business as usual and reflect today's current practice. The ZEN scenario can include various measures, such as choice of energy system, construction method, or materials. Results from this assessment criteria can be used in communication and marketing of the ZEN with examples of best practice.

7.1.8 ECO6.8 Cost of emissions saved

This KPI assesses the economic efficiency of different GHG emission reduction measures in a ZEN by calculating the expenses associated with the emission reduction measures, see Table 61.

The cost of emissions saved KPI shows the cost or benefit for implementing different zero emission strategies. A lower or negative value shows greater cost-effectiveness, meaning that fewer financial resources are required to achieve a given reduction in GHG emissions. This KPI can help decision makers to reduce risk and make informed decisions about which zero emission strategies to implement, considering both environmental and economic considerations. Point allocation for this KPI is based on the following:

- **Net present value (NPV)** summarises the *ECO 6.1 Investments*, *ECO6.2 Operating costs and ECO6.3 Residual value.* NPV is the sum of the discounted future cash flow used for comparing alternatives over the same period of analysis. NPV should be calculated by discounting future cash flows to present value. LCC is typically presented in real cost figures to ensure accuracy regardless of the point in time at which the costs are incurred. A predefined real discount rate of 4% is considered in DIGDIR's guide for public buildings (70).

- **Annual cost (AC)** is a uniform annual amount equivalent to the project net costs, considering the time value of money throughout the period of analysis. The annual costs are calculated as an annuity, which means the costs are averaged to be the same amount every year. The annual equivalent value is the regular annual cost that when discounted equals NPV of the investment.
- **Payback period (PP)** is the time it takes to cover investment costs and is considered as an additional criterion used to assess the period during which an investment is at risk. It is calculated as the number of years elapsed before the NPV of the cumulative returns exceeds the initial investment. Simple payback takes real (non-discounted) values, while discounted payback uses present (discounted) value. The costs and savings occurred after payback has been reached, are not considered.

Table 61. Summary for calculating KPI ECO6.8

ECO 6.8	**Cost of emissions saved**
Objective	To provide an overview of economic efficiency of different ZEN measures.
Description	Cost of emission saved is defined as the expenses associated with the emission reduction measures. The following indicators are a prerequisite for calculating the of cost of emission saved for the ZEN compared to a reference (R). • Net present value (NPV) • Annual cost (AC) • Payback period (PP) • Cost of emissions saved See Table 62 for an example.
Method	Calculate NPV (NOK), AC (NOK), PP (years), and cost of emission saved (NOK/tCO$_2$e) for different ZEN investments compared to the reference.
Points available	8 points
ZEN KPI assessment	1 point per calculated indicators for a material-related measure in ZEN 1 point per calculated indicators for an energy-related measure in ZEN 1 point per calculated indicators for a mobility-related measure in ZEN 1 point per calculated indicators for an area efficiency-related measure in ZEN 4 points for other documented ZEN measures (1 point per measure)
Best practice	– See examples of best practice in the other KPI categories.

Table 62. Example reporting of ECO6.8 Cost of GHG emissions saved

Project	**Ydalir Torg, Elverum**
Year	2022
Project phase	Implementation
ZEN measure	Passive house
Description	Fulfilling passive house requirements for two timber-framed terraced houses instead of building to Norwegian building code (TEK17). Cost and GHG emission calculations include additional investment cost and emissions during construction due to increased levels of insulation and energy cost and emission savings from less heat loss in the operational phase. See ZEN report no.43 and Wiik et al.(71,72)

Project	**Ydalir Torg, Elverum**
Image	
Net present value	TEK scenario: 4.5 - 4.7 million kr/house Passivhus scenario: 4.8 million kr/house
Annual cost	TEK scenario: 202 - 207 thousand kr/house Passivhus scenario: 213 - 215 thousand kr/house
Cost of GHG emissions saved	Savings: - 46 019 NOK/ t CO_2e
Payback period	8 years

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