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A Norwegian zero emission neighbourhood (ZEN) definition and a ZEN key performance indicator (KPI) tool

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Abstract. Within the Norwegian Research Centre for Zero Emission Neighbourhoods (ZEN) in smart cities, a definition for achieving zero emission neighbourhoods will be developed and tested against nine pilot areas. The ZEN definition considers a series of assessment criteria and key performance indicators (KPI) under seven categories; GHG emissions, energy, power/load, mobility, economy, spatial qualities and innovation. This paper presents the first draft of the ZEN definition, and discusses some of the opportunities and challenges in implementing assessment criteria and KPIs (ZEN metrics) into a ZEN KPI tool. This paper briefly presents the ZEN pilot areas and maps out existing tools used by ZEN stakeholders for the documentation of ZEN metrics. The paper goes further by presenting a ZEN KPI tool conceptual framework for the implementation of the ZEN definition in ZEN pilot areas and outlines a specification for the future development of a ZEN KPI tool. Finally, the paper presents further work for the development of a ZEN KPI tool.

1. Introduction

The United Nation's sustainable development goals (UN SDG) focus on a range of issues to be addressed by society; including healthy living and well-being (SDG 3); affordable, reliable and sustainable energy (SDG 7); sustainable economic growth and productive employment (SDG 8); resilient infrastructure (SDG 9); inclusive, safe, resilient and sustainable cities (SDG 11); suitable consumption and production patterns (SDG 12); combat climate change (SDG 13); protect restore and promote sustainable use of terrestrial ecosystems (SDG 15) and revitalise global partnership for sustainable development (SDG 17) [1]. These are some of the issues addressed in the Norwegian Research Centre for Zero Emission Neighbourhood (ZEN) in smart cities programme [2]. In the ZEN research centre, a definition for zero emission neighbourhoods in smart cities is under development to reduce direct and indirect greenhouse gas (GHG) emissions towards zero [3, 4]. The definition is a working draft that draws on several existing sources and professional expertise to form a comprehensive neighbourhood assessment tool.

The aim of this paper is to outline the background material paramount to the development of a ZEN definition, as well as to outline the development of a key performance indicator (KPI) tool that the ZEN definition will be tested and developed against. This paper briefly presents the ZEN pilot areas and maps out existing tools used by ZEN stakeholders for the documentation and implementation of assessment

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criteria and KPIs (ZEN metrics). The paper presents a ZEN KPI tool conceptual framework for the implementation of the ZEN definition in the ZEN pilot areas and outlines a specification for the future development of a ZEN KPI tool. It also discusses some of the opportunities and challenges in implementing ZEN metrics into a ZEN KPI tool. Finally, the paper presents further work for the development of a ZEN KPI tool.

2. Background

Several existing neighbourhood assessment tools and research projects have informed the development of the first draft of the ZEN definition, as well as professional expertise input from over fifty stakeholders. Such tools and projects include the Research Centre on Zero Emission Buildings methodology for measuring and reporting GHG emissions for the whole life cycle of a building [5-9], the PI-SEC – Planning Instruments for Smart Energy Communities research project which will provide a tool to resolve both municipal planning (top down) and project planning and construction (bottom-up) needs [10], the Horizon 2020 Smart Cities and Communities programme for secure, clean and efficient energy and focuses on efficient and user-friendly technologies and services within energy, transport and ICT [11, 12], the definition of positive energy blocks (PEB) in Horizon 2020 [13], the BREEAM Communities methodology [14], and the CITYKeys research project that supports the development of smart city solutions and services to address societal challenges [15]. More details about these tools and research projects can be found in [3, 4].

In addition, through a series of ZEN partner workshops on design and planning, energy supply, and buildings and materials, over fifty professional experts have given input to the ZEN criteria, and identified national and international standards relevant for the development of a ZEN definition. More specific details on the outcome of these workshops can be found in [4]. The standards identified include NS-EN 15978: 2011 Sustainability of Construction Works – Assessment of Environmental Performance of Buildings – Calculation Method [16], NS 3720: 2018 Method for Greenhouse Gas Calculations for Buildings [17], NS 3457-3: 2013. Classification of Construction Works – Part 3 Building Types [18], NS 3451: 2009: Table of Building Elements [19], ISO 52000: 2017. Energy performance of buildings - Overarching EPB assessment - Part 1: General framework and procedures [20], SN/TS 3031: 2007. Calculation of energy performance of buildings - Method and data [21], NS 3454: 2013. Life cycle costs for construction works - Principles and classification [22], NS-EN 16627: 2015. Sustainability of construction works - Assessment of economic performance of buildings - Calculation methods [23], ISO 15686-5: 2017. Building and construction assets - service life planning. Part 5: Life-cycle costing [24], and NS-EN 16258: 2012. Methodology for calculation and declaration of energy consumption and GHG emissions of transport services (freight and passengers) [25].

2.1. The ZEN definition

In the ZEN research centre, a neighbourhood is defined as a group of interconnected buildings with associated infrastructure, located within a confined geographical area. A zero emission neighbourhood aims to reduce its direct and indirect greenhouse gas (GHG) emissions towards zero over the analysis period, in line with a chosen ambition level with respect to which life cycle modules and building and infrastructure elements to include. The neighbourhood should focus on the following, whereby the first four points have direct consequences for energy and emissions:

a) Plan, design and operate buildings and associated infrastructure components towards zero life cycle GHG emissions.
b) Become highly energy efficient and powered by a high share of new renewable energy in the neighbourhood energy supply system.
c) Manage energy flows (within and between buildings) and exchanges with the surrounding energy system in a smart and flexible way. Flexibility should 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.
f) Plan and locate amenities in the neighbourhood to provide good spatial qualities and stimulate sustainable behaviour.
g) Development of the area is characterised by innovative processes based on new forms of cooperation between the involved partners leading to innovative solutions.

In addition, seven categories and accompanying assessment criteria and key performance indicators (KPI) have been identified by expert stakeholders as important for a Norwegian zero emission neighbourhood in smart cities definition (i.e. GHG emissions, energy, power/load, mobility, economy, spatial qualities and innovation). A full overview of the ZEN assessment criteria and KPIs can be found in [13] and are summarised in Table 1. These assessment criteria and KPIs utilise existing policies, frameworks, standards and references that architect, engineer and constructor (AEC) professionals are already familiar with. KPI results will be used to track, understand and validate the progress and performance of the ZEN pilot areas. Some assessment criteria and KPIs are valid for a building (B) system boundary, neighbourhood (N) system boundary or both (BN). In addition, the assessment criteria and KPIs are to be reported across a range of project phases, namely; the strategic planning phase, the implementation phase and the operational phase. KPIs for the spatial qualities and innovation categories still need to be developed.

Table 1. ZEN assessment criteria and key performance indicators [3, 4].

Category and Assessment Criteria	KPIs	Unit	System boundary	References
GHG Emissions				
Lifecycle GHG emissions				[16-19]
	- per building	$kgCO_{2eq}/m^2$ heated floor area (BRA)/yr	B	
	- per infrastructure	$kgCO_{2eq}/m^2$ outdoor space (BAU)/yr	N	
	- per user	$kgCO_{2eq}$/capita	BN	
	- total life cycle GHG emissions	tCO_{2eq}	BN	
GHG emission reduction				
	- reduction compared to a base case	%	BN	
Energy				
Energy efficiency in buildings				[2, 20, 21, 26]
	- net energy need	kWh/m^2 heated floor area (BRA)/yr	B	
	- gross energy need	kWh/m^2 heated floor area (BRA)/yr	B	
	- total energy need	kWh/m^2 heated floor area (BRA)/yr	B	
Energy carriers	- energy use	kWh/yr	BN	
	- energy generation	kWh/yr	BN	
	- delivered energy	kWh/yr	BN	
	- exported energy	kWh/yr	BN	
	- self consumption	%	BN	
	- self generation	%	BN	
	- colour coded carpet plot	kWh/yr	BN	
Power / Load				
Power/load performance				[2, 27]
	- yearly net load profile	kW	BN	
	- net load duration curve	kW	BN	
	- peak load	kW	BN	
	- peak export	kW	BN	
	- utilisation factor	%	BN	
Power load flexibility				
	- daily net load profile	kW	BN	
Mobility				

Mode of transport	- per mode of transport	%	N	[14, 15, 17, 25]
Access	- to public transport	Metres and frequency	N	
Economy				
Life cycle costs (LCC)	- per building - per infrastructure - per user - total LCC	NOK/m² heated floor area (BRA)/yr NOK/m² outdoor space (BAU)/yr NOK/capita NOK	B N BN BN	[19, 22-24, 28]
Spatial Qualities				
Demographic needs and consultation plan	- to be developed	- to be developed	BN	[14]
Public space	- to be developed	- to be developed	N	

2.2. The ZEN pilot areas

Altogether, the ZEN pilot areas encompass one million square meters of development for more than 30,000 inhabitants. The pilot areas include Campus Evenstad, Ydalir in Elverum, Furuset in Oslo, Fornebu in Bærum, Zero Village Bergen, NTNU Campus and Sluppen in Trondheim, the NRK site in Steinkjer and NyBy in Bodø. A mapping of the ZEN pilot area's characteristics regarding location, stakeholders, goals, measures, status and challenges can be found in [29].

3. Methodology

First steps involve mapping existing tools used by ZEN stakeholders to measure ZEN metrics. This is followed by discussing the purpose and user needs of a ZEN KPI tool. This information is used to develop a ZEN KPI conceptual framework that can then be used to theoretically test the ZEN definition with real data from the ZEN pilot areas. The testing will be a continuous, iterative process that goes beyond the scope of this paper. Part of this process will involve ascertaining suitable minimum requirements, ambition levels, reference values, threshold values, weighting and benchmarking for the successful implementation of a ZEN KPI tool.

4. Results and Discussion

4.1. Existing tools

The ZEN research centre stakeholders use a plethora of tools to document the assessment criteria and KPIs as outlined in Table 1. A mapping exercise has been carried out, and the following tools have been documented for each category: GHG emissions (e.g. ZEB emission tool, OneClick LCA, bLCAd-tool, områdeLCA, EFFEKT, PI-SEC indicator tool, Simapro Arda, vegLCA), energy (e.g. IDA-ICE, ZEB energy tool, PI-SEC indicator tool, Energyplus, SIMIEN), power/load (e.g. eTransport), mobility (e.g. PI-SEC), economy (e.g. Bygganalyse), spatial qualities (e.g. BREEAM Communities, PI-SEC planning wheel, Urbanetic Fabric, GIS, CITYBES, SSB data) and innovation (to be mapped). The list of tools that may be used in ZEN is by no means exhaustive. However, there is a distinct lack of harmonisation between these tools, which leads to difficulties in harmonising the inputs and outputs of a potential ZEN KPI tool. Some of the main issues include differences in system boundaries, methodology and data(bases) used, as well as differences in data resolution used dependent on the phase of the project (i.e. typically a low data resolution is used in the early planning phases and a high data resolution in the latter project phases). In addition, there is an increase in data complexity when one shifts the focus from an individual building or infrastructure to the whole neighbourhood level. The various tools identified in the mapping exercise use a range of different computing formats. A ZEN KPI tool would need to be flexible and compatible with these different formats (e.g. csv, xml, json, sql and html) [30].

4.2. The ZEN definition and ZEN KPI tool specification

The main purpose of the ZEN KPI tool is to operationalise the ZEN definition, and aid ZEN stakeholders through the planning, design, construction and operation of zero emission buildings, infrastructure and neighbourhoods. As a result, the ZEN KPI tool should be flexible for a range of conditions, easy to understand and clearly communicate the output of results. In addition, the ZEN KPI tool should be transparent and facilitate for comparisons between components, buildings, infrastructure and neighbourhoods. The ZEN KPI tool will need to process large amounts of data, as well as harmonise various standards, methods, data(bases), tools, system boundaries and interpret quantitative and qualitative measures. The ZEN KPI tool should be made available in Norwegian and English since a range of stakeholders will be using it. The ZEN KPI tool will also need to be robust and withstand future developments and changes, for example the future development of CO_2 emission requirements and tightening of energy requirements in Norwegian building codes [31].

Some of the challenges identified by stakeholders in the ZEN pilot areas include project organisation and management, lack of knowledge, legislation, goal conflicts, time and cost pressures, new energy technologies, system boundaries, risks and uncertainties, flexibility, transferability, complexity and scale [29]. A guideline for the implementation of the ZEN definition has identified a range of contextual parameters that affect the assessment of a pilot area [4]. These include the various project phases a pilot area progresses through (i.e. strategic planning phase, implementation phase and operational phase), the scope of assessment (i.e. material/component, building/infrastructure, neighbourhood and city) and which stakeholders are involved during the various project phases (i.e. planners, developers, architects, engineers, utility companies and citizens etc.).

However, one of the main challenges with the ZEN definition is that it is an early, first version that has not yet been tested against ZEN pilot areas or through the proposed ZEN KPI tool. As a result, it will be necessary to revise parts of the ZEN definition to take into consideration the practicalities of implementing various KPIs. For example, the access to public transport KPI under the mobility category is likely to be expanded to include access to other amenities, green spaces, city centres and local shopping centres. Similarly, the scope of the spatial qualities' category will be expanded to cover user qualities and contain more KPIs to reflect this. For example, the demographic needs and consultation plan assessment criteria may be expanded to include KPIs that consider gender, age, minority background, disabilities, population and resident density, occupation, total number of users and ZEN residents. These are useful indicators for other assessment criteria within the ZEN definition. For example, the total number of users can be used in calculating life cycle GHG emissions per user and life cycle costs per user. This shows that a future ZEN KPI tool will need to be dynamic and take into consideration these interconnections.

4.3. The ZEN KPI tool conceptual framework

A conceptual framework has been developed for the ZEN KPI tool from the information and experiences gathered on the ZEN definition, ZEN pilot areas, ZEN stakeholders and existing tools used to measure ZEN metrics, see Figure 1. It builds upon the initial ZEN toolbox framework developed by Houlihan Wiberg and Baer in [32]. The framework takes into consideration the various contextual parameters that will affect input data (grey boxes on the left-hand side of the figure), such as project phase, scope and stakeholders. It also maps out the various existing tools used by ZEN stakeholders (red box) to assess the various ZEN metrics outlined in the ZEN definition (yellow box) and shows how the results from these tools will feed into the ZEN KPI tool, structured according to the seven ZEN definition categories. Once the input data has been gathered an iterative process will take place within the ZEN KPI tool (green box) which involves obtaining and setting reference values, threshold values, weighting and benchmarking. Reference values will be set according to current standard practice (e.g. net energy need values set according to requirements in the Norwegian building regulations (TEK17) for new buildings), whilst the threshold, weighting and benchmarking values will be decided upon through a series of expert workshops with ZEN stakeholders, and by testing proxy data gathered from the ZEN pilot areas in the ZEN KPI tool. Ambition levels and goals can then be set according to the benchmark values. Finally, the results can be visualised in a range of ways, for example, in terms of a spider diagram, traffic light system, or mapped onto a city information model (CIM) of the neighbourhood. The results from the ZEN KPI tool can also be used in a series of visualisation tools (blue box) developed by the ZEN research centre, such as a dashboard of results, GIS, virtual reality and augmented reality.

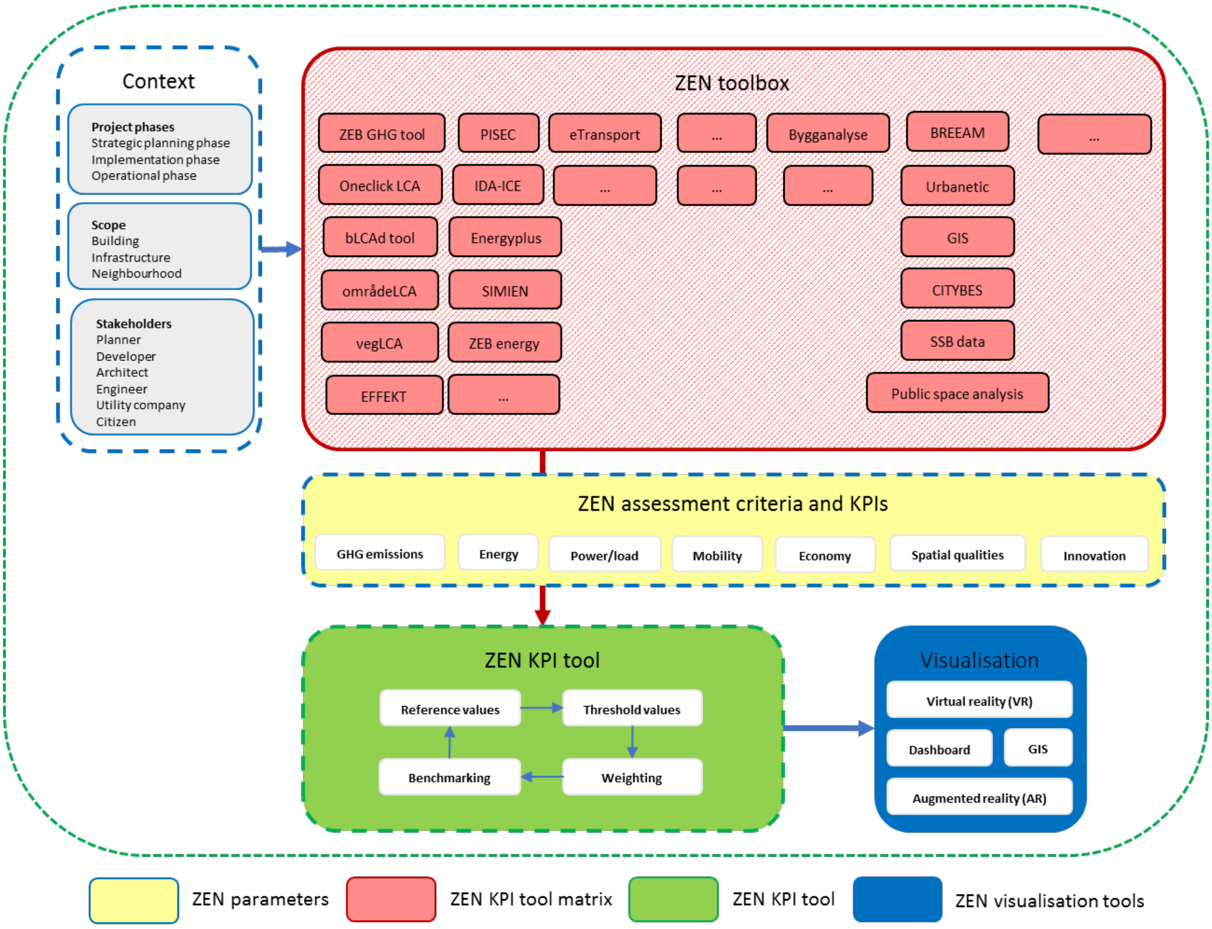

Figure 1. ZEN KPI tool conceptual framework developed from [32].

It is acknowledged that not every KPI is suitable for weighting or benchmarking in the ZEN KPI tool, but are useful information to document and use in some of the other KPIs. For example, it may be difficult to weight and benchmark a net load duration curve in the power/load category but is useful information for weighting and benchmarking the utilisation factor. The authors acknowledge that it may also be difficult to implement ambition levels and goals in accordance with the ZEN definition when many of the ZEN pilot areas are already underway and have already set their own goals for reaching a ZEN. Efforts will need to be made to harmonise existing goals and ambitions with that of the ZEN research centre's definition. In other cases, some KPIs are important to document in order to identify areas for improvement within the neighbourhood. For example, the GHG emission result and net energy need per building indicators help identify which buildings lead to higher GHG emissions or higher energy use in an early planning phase and can then be used to target areas for improvement in the implementation and operational phases.

Different types of multicriteria decision management (MCDM) and multicriteria decision analysis (MCDA) will be considered. It is important to find a method that makes it possible to assess and range design alternatives so that they can be compared to quickly ascertain the best course of action. When it comes to weighting, the aggregation model defines how weights and value functions for each attribute are synthesised in order to find an overall value for each category. The simplest one, and by far the most frequently used, is the simple additive weighting (SAW) model, whereby:

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

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

Another issue that needs to be resolved within the ZEN KPI tool is the requirements for data resolution. For example, is a detailed life cycle GHG emission assessment at the material component level required at an early strategic planning phase? Or is it enough to simplify the process and calculate GHG emissions based on rules of thumb for the whole neighbourhood? For example, one could multiply empirical data from previous projects with building quantities in the new project (e.g. X $kgCO_{2eq}/m^2/yr$ per m^2 of floor, wall and roof etc. for each building within the development) and then carry out more detailed calculations during the implementation and operational phases when more project specific data is available.

Finally, the authors have identified three ZEN pilot areas for the further development and testing of the ZEN KPI tool, namely; Fornebu which is in the strategic planning phase, Ydalir which is in the implementation phase and Campus Evenstad which is in the operational phase. Future work will involve gathering data from these pilot areas to help test and simulate a first version of the ZEN KPI tool based on the proposed ZEN KPI tool conceptual framework and ZEN definition.

5. Conclusion

This paper has presented the current working draft of a Norwegian definition for zero emission neighbourhoods, briefly outlined the ZEN pilot areas and mapped out existing tools used by ZEN stakeholders to document ZEN metrics. This paper has used this information together with experiences and feedback from stakeholders to present a ZEN KPI tool conceptual framework for the implementation of the ZEN definition into ZEN pilot areas and has outlined a specification for the future development of a ZEN KPI tool. It has also discussed some of the opportunities and challenges in implementing ZEN metrics into a ZEN KPI tool. Finally, this paper has presented further work for the development of a ZEN KPI tool.

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