Introducing the ZEN KPI Tool: A solution for reporting and visualizing performance in zero emission neighbourhoods

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ABSTRACT To tackle sustainability challenges in urban areas, there is a need to shift focus from individual buildings to the broader scale of neighbourhoods. In line with this, the research centre for Zero Emission Neighbourhoods in Smart Cities (FME ZEN) (2017-2024) has expanded on the groundwork laid by its predecessor, the research centre for Zero Emission Buildings (FME ZEB). FME ZEN has developed a definition for zero emission neighbourhoods (ZEN) and assessed ZENs using six categories: greenhouse gas emissions, energy, power, urban form and land use, mobility, and economy. In all, 42 key performance indicators (KPIs) were established to evaluate neighbourhood performance across these categories. However, conducting a comprehensive evaluation of a neighbourhood's performance is challenging, especially when considering conflicting assessment criteria and KPIs. In response, FME ZEN has developed the ZEN KPI tool, which is an automated MS Excel-based tool to track, report, and visualize neighbourhood performance. The ZEN KPI tool determines if a neighbourhood has achieved a net zero emission balance and assigns a ZEN category rating to each of the identified categories in the ZEN definition. Each category is rated on a 20-point scale, except for the GHG emissions category which is assessed based on a net zero emission balance. The ZEN KPI tool users can input calculated KPIs, set ambition levels, and monitor progress through different project phases based on the points achieved for each category. The results for each category rating are considered separately and not summed up to a single point score. The tool has been tested on a pilot project to show the suitability of the tool in offering stakeholders necessary knowledge and insights to make informed decisions.

Keywords: Zero emission neighbourhoods, Key performance indicators, performance evaluation tool, GHG emissions.

INTRODUCTION

The visible consequences of climate change are driving countries to prioritize reducing energy consumption, improving energy efficiency, and mitigating environmental impacts (Renovation wave, 2020; “Fit for 55”, 2021; REPowerEU, 2022). Consequently, the EU and Norway aim to cut greenhouse gas (GHG) emissions by 55% by 2030 and achieve climate neutrality by 2050 (Towards EU climate neutrality, 2024). Urban areas are crucial for transitioning to clean energy and achieving low-carbon goals (Brozovsky, Gustavsen, and Gaitani, 2021). Europe has advanced in energy-efficient and energy-generating buildings, focusing on nearly zero energy buildings (nZEB) under the Energy Performance in Buildings Directive (EPBD) (Energy Performance of Buildings Directive, 2010) and clean energy production under the Renewable Energy Directive (RED) (Renewable Energy Directive, 2009). However, the EPBD lacks a clear nZEB definition, leaving it to individual

nations, resulting in diverse definitions and solutions (Backe and Kvellheim, 2020).

Under the European Economic Area (EEA) agreement, Norway must adopt EU regulations. However, the full incorporation of the EPBD into Norwegian law is incomplete, particularly regarding "nearly zero energy" and the use of "renewable sources produced on-site or nearby." Norway's building sector heavily relies on hydropower, making decarbonizing the power sector less urgent but still highlighting the need for energy diversification and flexibility. Thus, Norway has directed its focus not only towards energy but also towards GHG emission reduction efforts.

In Norway, the Research Centre on Zero Emission Buildings (ZEB) defines a zero emission building as one that generates enough renewable energy to offset its GHG emissions over its lifespan (Fufa et.al, 2016). Various levels of ambition for ZEBs range from ZEB-O, offsetting operational energy emissions, to ZEB-COMPLETE, covering the entire lifecycle. The revised EPBD (Revised Energy Performance of Buildings Directive (EPBD), 2024) adopts the ZEB-O level for new public buildings from 2028 and all new buildings from 2030. The Research Centre on Zero Emission Neighbourhoods in Smart Cities (FME ZEN) extends the ZEB-COMPLETE definition to the neighborhood level by including buildings, infrastructure, and outdoor areas (FME ZEN 2016). This article focuses on the development of a tracking and visualization tool in FME ZEN known as ZEN KPI tool.

BACKGROUND

To accelerate progress towards a low-emission society, implementing zero emission technologies at the neighborhood level is effective. However, this broader scope increases complexity and requires assessment frameworks, guidelines, and standards to evaluate neighborhood-level performance effectively. As a result, various concepts such as zero energy districts (Polly et al, 2016.), zero carbon neighbourhoods (Nematchoua, 2020), net-zero energy communities (Carlisle, Van Geet, and Pless 2009), Positive Energy Districts (PEDs) (Gohari et al., 2024), Sustainable Plus Energy Neighbourhoods (SPENs) (Salom et al. 2021), and Climate Positive Circular Communities (CPCC) (ARV, 2022), have emerged to address environmental impacts at larger scales. In Norway, efforts have expanded from individual buildings to neighbourhoods, exemplified by FME ZEN (FME ZEN 2016), building upon lessons learned from previous research on Zero Emission Buildings (ZEB) (FME ZEB, 2016.). Other popular Norwegian building sustainability schemes include FutureBuilt (Resch et al. 2022), BREEAM-NOR (Grønn byggallianse 2022), and Powerhouse (Asplan Viak 2020; M. K. Wiik, et al. 2023a) which can also be applied at the neighbourhood level. Each have a varying focus on either energy or emissions, on achieving a (net) zero/positive/plus balance for various definitions of area (district /community /neighbourhood). Brozovsky et al. (Brozovsky, Gustavsen, and Gaitani 2021) uses the term Climate Friendly Neighbourhood (CFN) as a comprehensive designation for these various expressions, and identifies 35 distinct terminologies associated with CFNs, underscoring the absence of clear definitions and the arbitrary application of terminology.

In the context of FME ZEN, a net zero emission neighbourhood aims to reduce and compensate its direct and indirect GHG emissions towards zero over an analysis period of 50 years, in line with a chosen ambition level (Wiik et al. 2024a). This can be obtained by first reducing and then compensating for GHG emissions through implementing different measures such as energy efficient systems, increased resource efficiency through the implementation of circular economy principles, as well as through the export of local, renewable energy production. To facilitate this process, FME ZEN has developed a ZEN definition framework (Wiik et al. 2024b) including a ZEN definition guideline (Wiik et al. 2024a) a ZEN process guideline (Rokseth et al. 2024), a ZEN toolbox (Houlihan and Bar.2019), a ZEN dashboard (Dashboards- Grafana, 2024), and a ZEN KPI tool and accompanying ZEN KPI tool user guide (Homaei and Wiik, 2024). The ZEN definition framework outlines six different categories and 42 key performance indicators (KPIs). These categories include: GHG emissions (GHG), energy (ENE), power (POW), urban form and land use (URB), mobility (MOB), and economy (ECO). Examples of KPIs include: GHG1.1 Materials, ENE2.2 Delivered Energy, POW3.2 Peak export, URB4.2 Block density, MOB5.1 Access to public

transport and ECO6.4 Shared economy. All KPIs contribute either directly or indirectly to the overarching goal of a zero emission neighbourhood. They serve to evaluate the overall performance of a neighbourhood, which is defined as a group of interconnected buildings with associated infrastructure, located within a confined geographical area (Wiik et al. 2024b). More information on the ZEN definition framework and individual KPIs can be found in (Wiik et al. 2024b) (Wiik et al. 2024a). The scope of this article is limited to the validation of the ZEN KPI tool. Previous work by Wiik et al. outlines that the ZEN KPI tool should be flexible, transparent, easy to understand, facilitate for comparisons, and clearly communicate results (Wiik et al. 2019). In addition, the ZEN KPI tool needs to handle a range of quantitative and qualitative ZEN KPI results (ZEN indicators), as well as be robust enough to withstand future developments (Wiik et al. 2019).

THE ZEN KPI TOOL

The ZEN KPI tool is an MS Excel-based multicriteria decision analysis (MCDA) tool and consists of nine worksheets with colour-coded tabs, see Figure1 (Homaei and Wiik 2024). The initial worksheet provides background information, while the second worksheet focuses on ambition levels across various categories and general input data (Figure 1). Following these are six worksheets dedicated to each category, with the last worksheet dedicated to visualizing and presenting the results. The ZEN KPI tool has been developed as a decision support tool to facilitate the tracking, reporting, and visualization of these KPI results for aspiring ZENs. A ZEN KPI tool user guide has been developed to aid stakeholders in using the tool (Homaei and Wiik, 2024).

Th users need to insert the calculated ZEN KPIs in the excel sheet. White cells are allocated for data entry and the coloured cells are for automatic calculations. Figure 2 shows an example of data entry for Energy category.

Why was the ZEN KPI tool developed? The primary objective of the ZEN KPI tool is to operationalize the ZEN definition (Wiik et al. 2024a) and aid ZEN stakeholders through the planning, and implementation of ZENs. The ZEN KPI tool is a tracking, reporting, and visualization tool, meaning that the tool does not serve as a stand-

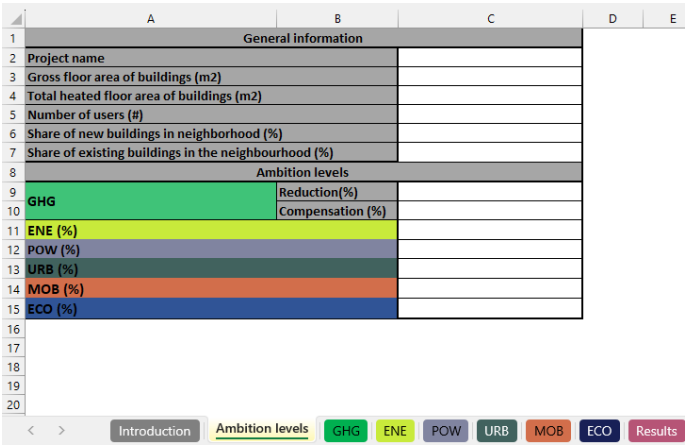

Figure 1. Screenshot of the ZEN KPI tool Ambition levels worksheet.

ENE2.2 Delivered energy	Scenario	Implementation phase
Electricity (kWh/yr)	ZEN (Z)	
	REFERENCE (R)	
District heating (kWh/yr)	ZEN (Z)	
	REFERENCE (R)	
Bio heat (kWh/yr)	ZEN (Z)	
	REFERENCE (R)	
Total (kWh/yr)	ZEN (Z)	0
	REFERENCE (R)	0
	Difference	
Points		

ENE2.2 Points	From	To
1	0 %	6 %
2	7 %	13 %
3	14 %	19 %
4	20 %	25 %
5	26 %	31 %
6	32 %	38 %
7	39 %	44 %
8	45 %	50 %

ENE2.3 Self-consumption		
Self-consumption (%)		51 %
Points		2

ENE2.3 Points	From	To
0	0 %	25 %
1	26 %	50 %
2	51 %	100 %

Figure 2.Screenshot of Energy category (example for data entry in white cells).

alone calculation tool, but is a multicriteria decision support tool, that provides stakeholders with the necessary knowledge and insights to make informed decisions towards achieving the goal of ZEN.

Who can use the ZEN KPI tool? The ZEN KPI tool offers advantages to all ZEN stakeholders involved in the development of a ZEN (see Figure 3). First, ambition owners who want to establish a zero emission neighbourhood can use this tool to track, monitor and visualize their ambition levels and targets at a neighbourhood level. Second, when it comes to subdevelopments inside a neighbourhood, project owners, public and private property developers can use the tool to input data and track, monitor and visualize KPI results for their projects.

Third, architects, consultants, engineers, and suppliers involved in the neighbourhood or subdevelopments can

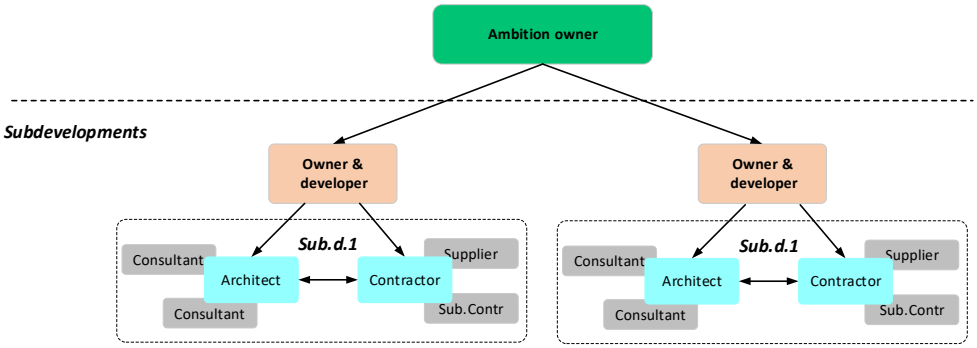

Figure 3. Stakeholders in ZEN developments. (Vergerio and knotten, 2024).

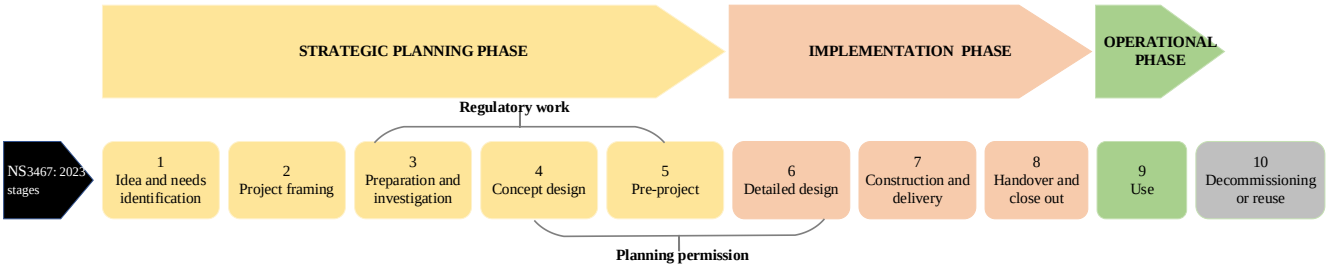

Figure 4. Different project phases in a ZEN project (Rokseth et al. 2024).

also track and report their progress. Additionally, researchers can use the ZEN KPI tool to evaluate neighbourhood performance and further develop the ZEN definition framework and ZEN KPIs.

When should the ZEN KPI tool be used? The ZEN definition framework outlines three project phases: the strategic planning phase, the implementation phase, and the operational phase (Wiik et al. 2024a). These phases are depicted in Figure 4, which illustrates their alignment with the Norwegian Standard NS 3467: 2023 Stages and deliverables in the life cycle of construction works (NS3467:2023, 2023). During both the strategic planning and implementation phases, various stakeholders can utilise the ZEN KPI tool. However, it's important to note that the ZEN KPI tool does not include the neighbourhood's performance during the operational phase. Instead, this aspect is managed by the ZEN Dashboard (Dashboards- Grafana, 2024), which enables users to monitor, amongst other factors, operational energy use, mobility patterns, and operational GHG emissions throughout the operational phase.

What information does the ZEN KPI tool provide? The ZEN KPI tool evaluates the net zero GHG emission balance (nZEN balance) for a whole neighbourhood. This tool also evaluates the other categories (ENE, POW, URB, MOB, and ECO) based on a 20-point system for each category and rates each category based on a defined set of rating threshold values, see Figure 5. The rationale behind this system is that GHG is the most significant category in the ZEN definition. Therefore, it will be measured in absolute values and does not require a point allocation system. The other categories will each be given equal weight (20 points each) and will be evaluated individually, rather than being combined into a single score for the neighbourhood. ZEN KPI tool users can proceed to input ZEN indicators from the ZEN KPI toolbox into the ZEN KPI tool once they have familiarized themselves with the various ZEN KPIs. During this process:

- The ZEN KPI tool utilizes input data from the tool user to allocate points to each category (except the GHG category) based on the predefined point allocation systems given in the ZEN definition guideline (Wiik et al. 2024a).
- The ZEN KPI tool presents the neighbourhood's performance across the predefined assessment criteria and KPIs through a spider diagram, offering

a comprehensive perspective on the neighbourhood's strengths and areas for improvement.

- The ZEN KPI tool evaluates the net zero GHG emission balance (nZEN balance) for the whole neighbourhood in terms of a bar chart.

It is important to recognize that the rationale behind the point allocation system and benchmark values in the ZEN KPI tool is given in the ZEN definition guideline (Wiik et al. 2024a) and may in the future require periodic review and adjustment.

Colour code	Ranges	ENE rating	POW rating	URB rating	MOB rating	ECO rating
Dark green	80-100%					
Green	60-80%					
Light green	40-60%					
None	< 40%	No rating	No rating	No rating	No rating	No rating

Figure 5. Colour codes and rating threshold values for visualization of a neighbourhood's performance.

APPLICATION ON A CASE

Ydalir is one of nine pilot areas within FME ZEN, which is used as a case study to demonstrate the functionality and operability of the ZEN KPI tool in this article. The pilot is situated approximately 1.5–2 km northeast of Elverum's centre in Innlandet county and it includes a land area spanning around 311 400 m^2. Ydalir consists of 14 subdevelopments with 10 different developers, and it is expected to be completed in 2040. Ydalir encompasses various types of buildings, including a school, a nursery, care homes, apartment blocks, single-family houses, and terraced houses. Additionally, Ydalir's infrastructure includes roads, pedestrian walkways, cycle paths, as well as green spaces.

As a first step, it is necessary to gather information on ambition levels from the Ydalir Masterplan (Elverum Vekst 2017, 2019, 2021) and data on the individual ZEN KPI results (Krekling Lien and Venås 2020; Wiik et al. 2022; Wiik et al. 2023b; Wiik et al. 2023c; Winsvold 2021). Since Ydalir is still under development, the authors used results from the subdevelopment Ydalir Torg for the GHG and ECO categories to highlight the ZEN KPI tool's decision support aspect. ENE, POW, URB, and MOB KPIs apply to the whole neighborhood. Due to ongoing development and varying project phases, the data is incomplete and cannot provide a ZEN performance rating for whole neighborhood. The collected data offers a snapshot of the status at Ydalir, reflecting a patchwork of different ZEN KPI results.

The Ydalir master plan's system boundary for GHG reduction includes life cycle stages A1-A4, B6, and D, targeting a 50% GHG emissions reduction compared to reference values. In addition, the neighborhood aims to generate 10-15 kWh/m^2 annually using solar panels, resulting in a 28% compensation target for the subdevelopment. Ambition levels were also set for ENE (70%), POW (0%), MOB (25%), URB (40%), and ECO (20%), indicating a primary focus on GHG and ENE. ENE, POW, and ECO ambition levels are based on the Ydalir master plan (Elverum Vekst, 2019), while MOB and URB ambition levels are based on regulation plans due to limited influence of ambition owner over regional or national decisions on development location and public transport facilities.

The developer of Ydalir Torg needed a decision support on two issues in Ydalir Masterplan: 1) building to Passivhus standards instead of Norwegian building code (TEK) (Direktoratet for byggkvalitet, 2017), and 2) reducing GHG emissions by 50% compared to reference values (Winsvold, 2021). Due to market conditions and inflation, using Passivhus standards became challenging. The developer asked to drop this requirement if they could still achieve a 50% GHG reduction using low embodied carbon materials and TEK's energy requirements. The ZEN KPI tool compared these alternatives, using GHG emission reference values for the strategic planning phase and the developer's GHG emission calculations for the low embodied carbon TEK alternative in the implementation phase. The calculation of energy and emission for these alternatives are explained in (Wiik, et al., 2023c; Wiik et al., 2022). Cost calculations for the Passivhus and TEK scenarios were used for the strategic planning and implementation phases in the ECO category, respectively. Conflicting assessment criteria and KPIs included increased embodied GHG emissions and investment costs due to more insulation and energy-efficient solutions versus reduced operational GHG emissions and operational

costs in the Passivhus scenario. Other categories were evaluated at the neighborhood level.

RESULTS

To follow is a series of figures that show the results from the testing of Ydalir in the ZEN KPI tool. Figure 6 shows the GHG emission results for the strategic planning and implementation phases for Ydalir Torg. Here, we can see that the subdevelopment has achieved a -52% reduction in GHG emissions between project phases, which is higher that the ambition level for GHG reduction (50%). This feedback secures the developers the build the buildings based on TEK standard. A 10% compensation is achieved for remaining GHG emissions in the implementation phase, which is lower than the ambition of 28% for compensation.

Figure 7 shows the neighbourhood performance in a spider diagram for the other categories, and in relation to the ambition levels. It should be noted that the ECO indicators are only calculated for the Ydalir Torg subdevelopment and not for the whole neighbouhood. The results indicate that the development exceeds the set ambition levels for POW, URB, MOB, and ECO. However, its performance in ENE falls short of the ambition level. The lowest performance is in mobility (25%). This performance may be due to the limited influence developers have on MOB and URB once the neighborhood's location is determined. The results also reveal that meeting the ambition levels for categories the owners have prioritized, such as GHG and ENE, is more challenging. Conversely, some categories outside the owners' primary focus, like POW have become more ambitious than the ambition levels set in Ydlair's master plan. This may be related to the new national requirements and other developments. This suggests that in long-term projects, ambition levels should be revised periodically, to align goals with developments.
The ZEN KPI tool user can then check results in "Result worksheet" to see which individual KPIs they are scoring low on, and plan changes in the development accordingly. Figure 8 shows a visualisation of the results in terms of ZEN category ratings. As shown, Ydalir receives a light green mark for ENE and URB, ECO, a green mark for POW, and no mark for MOB. In addition, the figure shows that the nZEN balance has not been achieved for the considered subdevelopment.

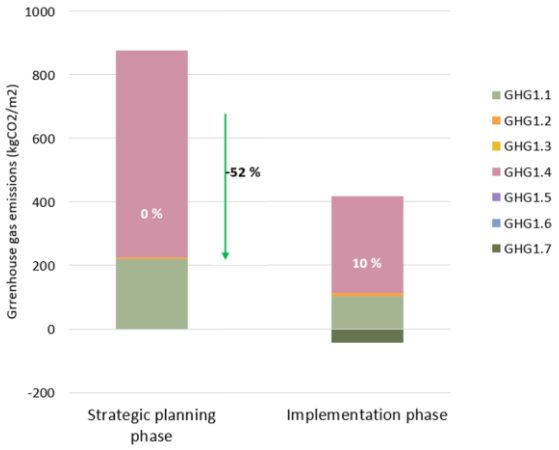

Figure 6. GHG emission results for the strategic planning and implementation phases for Ydalir Torg.

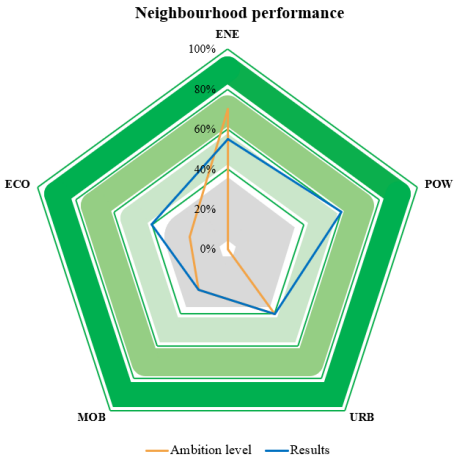

Figure 7. The neighbourhood performance in a spider diagram for all categories except GHG emission.

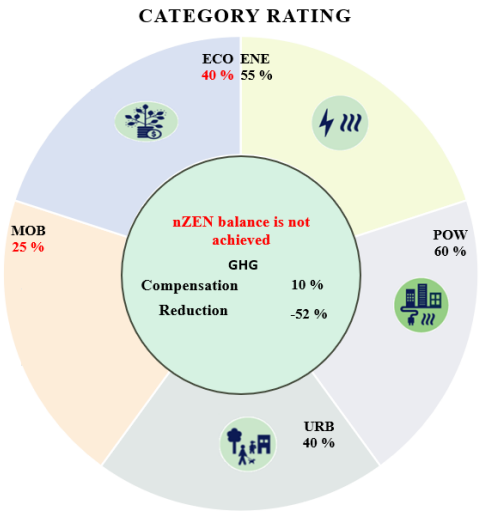

Figure 8. Visualization of results in terms of category rating.

DISCUSSION

Opportunities: The results demonstrate that the ZEN KPI can be input into the ZEN KPI tool to generate a visual representation of a ZEN's performance, and to track and monitor progress. For Ydalir, the tool served as a decision support system for Ydalir Torg, aiding the contractor in choosing between TEK or Passivhus building solutions. The findings helped local authorities revise the Ydalir masterplan, allowing property developers to use TEK as long as they achieve a 50% reduction in GHG emissions compared to reference values. Additionally, the results indicate that current compensation measures are insufficient to reach the 28% target, suggesting the need for more PV panels in the garage areas of the buildings. The tool also facilitates communication of ZEN KPI results with stakeholders.

Limitations**:** The ZEN KPI tool currently focuses solely on the criteria defined within ZEN definitions and KPIs, ignoring factors outside this scope. Expanding the tool's scope could include factors like biodiversity, land use change, and other environmental indicators beyond global warming potential. Additionally, there is potential to integrate the ZEN KPI tool with other KPI calculation tools, such as those for energy or emissions.

Challenges**:** The tool requires detailed input data and KPIs, which are challening to obtain during early planning phases. ZEN developments often have various sub-developments, each managed by different developers on different timelines, requiring diverse skills for KPI calculation. Collecting and reporting KPIs at the neighborhood level is difficult and demands effective coordination by the ambition owner. Additional obstacles include variations in data formats and units, and the time-consuming nature of calculating results across multiple stakeholders.

CONCLUSIONS

This article introduces the ZEN KPI tool, a tracking and visualization tool developed in FME ZEN. The results demonstrate the tool's suitability and functionality in aiding decision-makers to make informed choices.

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