D4.4 EVALUATION ACTION PLAN AND REPORTS (UPDATE 2)

Update on the monitoring and evaluation framework for the project

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List of Abbreviations/Glossary

AEF	Activity Evaluation Form
AI	Artificial Intelligence
API	Application Programming Interface
BEF	BIPED Evaluation Forum
BEST	Building Estimate Specification Table
BIPED	Building Intelligent Positive Energy Districts
BMS	Building Management Systems
CAPEX	Capital expenditures
CEA	Cost Effectiveness Analysis
CBA	Cost Benefit Analysis
DMI	Danish Meteorological Institute
DMP	Data Management Plan
DT	Digital Twin
ESG	Economic Social Governance
FAIR	Findable, Accessible, Interoperable and Re-usable
FoA	Field of Action
GA	Grant Agreement
GDPR	General Data Protection Regulation

GHG	Greenhouse Gas
KPI	Key Performance Indicator(s)
LDT	Local Digital Twin
MCA	Multi Criteria Analysis
M&E	Monitoring and Evaluation
NWPs	Numerical Weather Predictions
OD	Origin Destination
OPEX	Operational Costs
PED	Positive Energy District(s)
RES	Renewable Energy Sources
SCIS	Smart Cities Information System
SCBA	Social Cost Benefit Analysis
SCM	Smart Cities Marketplace
SDG	Sustainable Development Goals
SMART	Specific, Measurable, Achievable, Relevant, Time-bound
SRT	Self-Reporting Tool
TRL	Technology Readiness Levels
WP	Work Package

Executive summary

This report presented Deliverable **4.3 Evaluation Action Plan and Reports: Update 2** of Work Package (WP) 4 of the Building Intelligent Positive Energy Districts (BIPED) project. This deliverable reports on Task 4.1, which focuses on the creation of a methodology plan to cover testing cycles and project validation. The framework is expanded upon in this deliverable to included additional KPIs emerging from task 2.6, which engaged model owners to synthesise additional KPIs, which at the time of writing are seen to represent the most feasible and technically meaningful indicators for expanding the scope of the Monitoring and Evaluation (M&E) within the BIPED project.

D4.4 outlines the continued development of the M&E framework tailored for BIPED previously outlined in Deliverables 4.1 and 4.3. The framework integrates both qualitative and quantitative data collection methodologies to ensure a holistic understanding of project performance and impact. Central to the M&E framework will be monthly workshops and forums designed to gather both qualitative and quantitative data by engaging members of the project consortium and Key Performance Indicator (KPI) owners. Quantitative data will be documented using KPI Sheets, offering a structured approach to measuring project metrics and performance indicators. These sheets provide a clear overview of project progress and enable data assessment and evaluation. Additional activities will include engagement with the consortium members to continue to refine data collection and reporting through collaborative conversations regarding roles and responsibilities; and engagement to ensure thematic and methodological clarity, and minimise duplication of effort, in the face of a M&E framework which is subject to further change as task 2.6, and indeed the project overall proceeds, and new KPIs arise.

Following the continued development of the data models, additional KPIs are now possible which were not realistic or achievable when the previous iteration of this report was published. Consequently, additional KPIs have been developed under themes of *“energy”, “mobility”, “climate” and “cross-sectoral”,* in addition to existing themes of *“community engagement”, “energy/mobility”, and “digital solutions*”. These KPIs have been introduced into the M&E framework; and the implications of this are discussed in further detail in Section 2.3 and Annex 1, and throughout the report.

The systematic approach established by the M&E framework aims to continuously assess project effectiveness, identify areas for improvement, and ensure alignment with BIPED's overarching goals and objectives. By leveraging a comprehensive evaluation strategy combining qualitative and quantitative methods, the framework supports informed decision-making and effective project management. This dual approach also facilitates the accurate and consistent collection of KPI data, contributing to the Smart City Information System’s Self Reporting Tool throughout the project’s duration. However, the compatibility between the Self-Reporting Tool dimensions and the BIPED project are explored in further detail in section 2.4. This M&E framework provides the scope and direction for the assessment framework and broadly seeks to support project aims to progress the state of the art in the development and deployment of local digital twins for positive energy districts. Thus, the M&E Framework seeks to support the development of project outcomes which are utilisable beyond the spatial and temporal extent of the Brabrand testbed itself, and indeed the BIPED project’s lifespan.

1. Introduction

This report reviews the need for, and established approach to, monitoring and evaluation within the BIPED project, including key principles of co-creation. The report reviews the convergent parallel approach to evaluation - which leverages both quantitative and qualitative dimensions - and the mechanisms through which this evaluation is conducted.

This deliverable describes the significant advancements in the development of the M&E framework. Key updates included in Deliverable 4.4 are a review of KPIs emerging from task 2.6 and an analysis of their integration within the broader M&E framework. These KPIs have been developed as part of task 2.6, which aims to create an expanded assessment framework for Positive Energy Districts (PEDs). These new KPIs are referred to collectively as *PED* KPIs. This linguistic distinction is used throughout this report to ensure clarity when discussing them distinctly from the KPIs developed through WP4 earlier in the project and laid out in the previous iteration of this deliverable. Pre-existing KPIs are referred to as *Project* KPIs throughout this document for the same purpose, however all KPIs fall within the scope under the M&E framework and thus will be made subject to M&E activities and procedures under WP4.

The report further contains a review of activities with consortium members undertaken throughout year two of the project, and analysis of key findings emerging from said engagements in section 3. Key engagements in this regard include collaborative discussions on the alignment between *PED* KPIs and the WP4 KPIs; KPI workshops undertaken as part of the 2025 General Assembly meeting and towards the end of the year; and engagements with OASC on simplifying data collection processes. An update of progress against PED KPIs as of November 2025 is provided in section 3, which is supported by analysis of each performance in each M&E theme.

These efforts have both expanded the scope of M&E for the project and informed current plans for M&E activities throughout the remainder of the project. These activities will be structured around monthly engagements with KPI owners to ensure clarity and coherence among all KPIs monitored within the framework, and thus areas of M&E overall, on an ongoing basis. Particularly given the framework's foundation in co-creation and noting that technical outputs are still in active development, this ongoing engagement will seek to streamline data collection and reporting until the conclusion of the project. These activities are thus central to the achievement of the broader aims of the M&E framework to support the BIPED project in progressing the state of the art in the development and roll-out of Local Digital Twins for Positive Energy Districts; and delivering final outputs, including datasets, models, the BIPED platform itself, among other key exploitable results. These results will underpin the BIPED project's effectiveness in enabling future utilisation and exploitation of BIPED methodologies and approaches in other Digital Twin projects beyond the spatial and temporal scope of the project.

1.1 Smart Cities, Horizon Europe and Monitoring & Evaluation

As highlighted in the previous iteration of this deliverable, D4.3 section 2, the BIPED M&E framework ensures outcomes remain relevant and impactful for stakeholders and Europe's smart city development. The M&E framework relies on Key Performance Indicators (KPIs) to track progress and achievement, enabling assessment of ongoing performance and impact, resource optimisation, and risk management for the project.

Positive Energy Districts (PEDs) are a crucial part of the transition towards carbon-neutral cities. With advancing technology, PED development increasingly relies on modelling and simulation before real-world deployment, enabled by Local Digital Twin (LDT) technology. LDTs traditionally model energy, traffic, buildings, and the natural environment using diverse data streams. However, excluding social, economic, and cultural factors limits their accuracy, leading to partial representations and suboptimal decisions. These gaps often due to data constraints and siloed design can hinder sustainable urban development.

BIPED aims to enable data-driven decision-making for both short-term city operations and long-term policy planning, supporting AI-based optimisation of PED development. Funded by Horizon Europe (Grant ID: 101139060), the project promotes digital twin models to support evidence-led planning and management of urban areas, towards broader ambitions to enable progress towards climate neutral cities. These models create virtual representations of functional territories using diverse data, helping address PED complexities and optimise existing systems. The project's core focus is to strengthen the role of digital twins in PED development across European cities, guided by an M&E framework as a feedback loop.

1.2 Importance of M&E in BIPED

In the context of the BIPED project, M&E is crucial for the assessment of the initiative's progress towards the project objectives. This includes objectives related to technological developments and higher-level objectives to drive progress in local digital twins for positive energy districts. M&E equips stakeholders with relevant information cultivated through continuous real-time progress monitoring, enabling them to make informed decisions and implement timely interventions. Additionally, M&E works as a vital mechanism in the assessment of risk, ensuring that BIPED is appropriately safeguarded from challenges stemming from the inherently complex nature of urban development. The M&E framework thus supports the resilience of the BIPED project and its associated digital twin models.

M&E activities – and dissemination of related findings - likewise support awareness and replicability of BIPED throughout and beyond the project lifetime. Monitoring and evaluation of data in BIPED is thus vital to the achievement of broader aims to support innovation in local digital twins, and the planning and management of sustainable urban areas. By continually monitoring data, the BIPED consortium can identify trends,

patterns and potential challenges allowing for timely adaptation through collaborative decision-making processes. Beyond insights into project performance, continuous monitoring and evaluation is crucial to generate insights into the interplay between the monitoring activities themselves, action in response, and project outcomes. Thus, the framework supports the synthesis of exploitable results and deepens understandings of their implications for future digital twin projects.

The BIPED Project presents a prime opportunity to progress the state-of-the-art in the development and roll-out of digital twin models across European cities. The M&E framework supports a continuous iterative process, which aims to maximise the impact of the project during and beyond the project lifetime. The outputs of this process will enable stakeholders in other digital cities and districts to easily access, understand and replicate, BIPED approaches, or adapt them based on lessons learned in the creation of smart and sustainable urban areas.

1.3 The BIPED M&E Framework

As highlighted in D4.3, BIPEDs M&E activities are structured around a data-driven M&E framework. This framework serves as the backbone for effective decision-making, performance assessment, and optimisation of consortium efforts and outputs. The framework defines the systematic process of collecting, analysing, and interpreting data generated by various tools embedded within the city of Aarhus' infrastructure. It encompasses a structured approach to monitoring the project's performance across different domains such as transportation, energy, buildings, and environment. BIPED's M&E framework can thus be seen as a plan for M&E activities throughout the project and guides consortium members (and equivalent stakeholders in future projects) on the roles, responsibilities, and methodologies for monitoring and evaluating their own actions and impact.

A full overview of the development process of the Framework can be found in D4.3

1.3.1 Co-Creation and Data Collection

In the landscape of smart city and digital twin development, collaborative innovation and stakeholder engagement act as pillars supporting the principle of co-creation. The development of the M&E framework was conducted as part of WP4, in conversation with WP2 and WP3. This process culminated in documents and methodologies which formalised M&E principles and processes, including regarding KPIs and stakeholder engagement. To maintain consistency across iterations of this deliverable, this report was developed following said methodologies and procedures.

Co-creation in BIPED initially manifested as periodic meetings where stakeholders analysed qualitative and quantitative data from project activities. These sessions fostered dialogue, reflection, and joint decision-making, ensuring transparency and accountability. By combining data-driven insights with participatory processes, project activities and outputs were made technologically robust and socially and environmentally sustainable. Partners provided feedback on project activities, assessing performance and lessons learnt. Reports were aligned with quantitative and qualitative data from collection sheets to validate outcomes. This

process will continue throughout the remainder of the project. Through structured engagement and long-term monitoring, partners enable the observation of the impact of BIPED and related projects.

2. Continued Development of the M&E Framework

2.1 Quantitative and qualitative methodology

The capacity of the M&E framework to enable robust monitoring throughout is underpinned by the convergent parallel approach. This approach seeks to simultaneously collect quantitative and qualitative data, which are then aligned and integrated. Following this approach, qualitative and quantitative dimensions are seen as a single resource for monitoring and evaluation, rather than one explaining or proving the other.

Qualitative evaluation involves a comprehensive review of all engagement with partners and stakeholders regarding the evaluation of project activities and interventions. This encompasses the evaluation of activities and interventions as reported by partners and synthesised through analysis of feedback forms, and records of interviews, informal discussions, and group workshops. The quantitative dimension utilises a group of measurable interventions, described as KPIs, to compare the performance and progress of the project consortium's interventions in achieving project goals over the lifespan of the project. This methodology and relevant processes are described in further detail in the preceding deliverables in this series, D4.1, and D4.3 (section 3)

2.2 Monitoring and Evaluation Themes

KPIs within BIPED represent the quantitative dimension of the monitoring and evaluation framework and were designed to thematically align with the stated aims of the BIPED consortium, and support the development of accessible, replicable, and exploitable results for the Brabrand testbed and beyond. At that time, M&E activities and consequently the Project KPIs were grouped into three themes*: Community Engagement, Energy/Mobility, and Digital Solutions.* All KPIs were developed and refined through iterative participatory design activities, i.e. workshops, and collaborative discussions. However, it is crucial to note that the *Energy & Mobility*, and *Digital Solutions* KPIs were designed in conversation with WP2 and WP3 leads, pending the development of additional KPIs as part of Task 2.6, which intends to create an expanded PED assessment framework. Table 1 provides an overview of these themes.

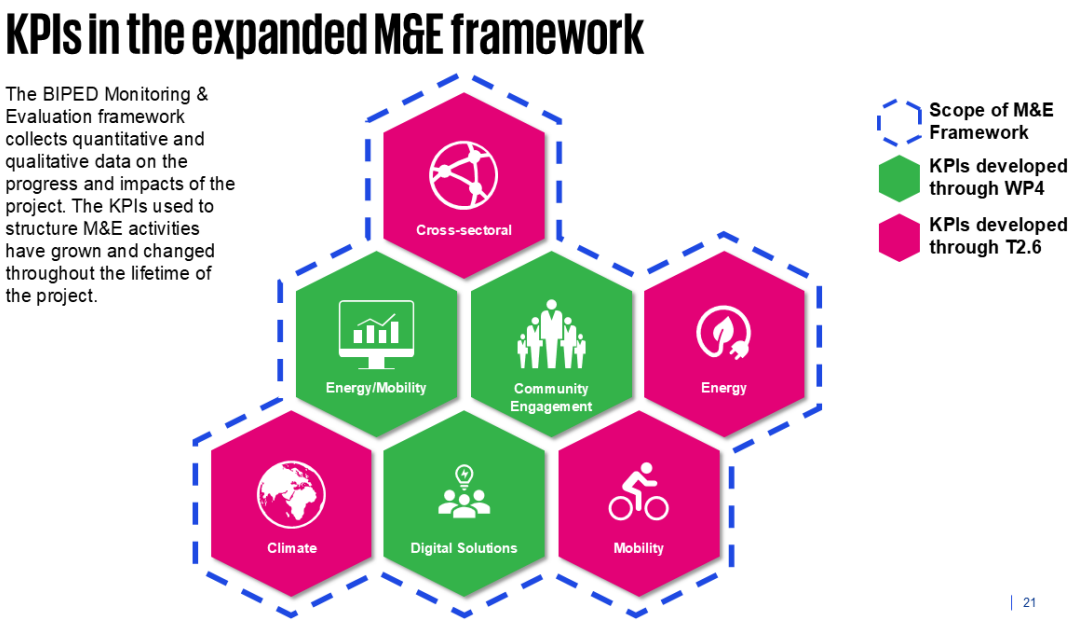
Table 1. BIPED M&E themes

Community Engagement
The KPIs which fall under the community engagement theme are focused on the long-term impact of the interventions and the extent to which key stakeholders and citizens are made aware of the activities within the BIPED project and the wider potential of Digital Twin technologies being utilised on a micro and macro scale within their cities and day to day lives.
Energy & Mobility
Energy & Mobility KPIs will provide insights into the contribution of project interventions to energy efficiency and sustainability goals. These KPIs serve as benchmarks to make informed decisions to optimise energy usage within Aarhus.
Digital Solutions
Digital Solutions KPIs for a project will offer essential insights into the effectiveness and impact of digital technologies deployed. Analysing KPIs such as user engagement metrics, system uptime, response times, and adoption rates provides a comprehensive view of the project's digital performance.

2.3 Expansion of KPIs in the M&E Framework

A key aim of task 2.6 is the integration of additional KPIs within the Monitoring & Evaluation framework. As noted in the introduction, for clarity in this report, the KPIs emerging from task 2.6 activities are referred to as *PED KPIs* in this document. This is merely a linguistic distinction used to support streamlined discussion of their development and status. All KPIs fall within the boundaries of the broader M&E framework (figure 1) and will be monitored and evaluated through WP4 activities throughout the remainder of the project.

Figure 1. KPIs in the M&E framework



The intention guiding the development to the *PED* KPIs is to expand the M&E framework's capacity to monitor and evaluate energy, mobility, climate, and cross-cutting urban sustainability dimensions. These indicators do not merely seek to expand the elements being monitored under the M&E framework, but to deepen understandings of the state and interplay of said elements, and implications thereof, for the Braband testbed and positive energy districts in general. In alignment with principles of co-creation, these KPIs were developed through collaborative discussions across Tasks 2.2–2.5 and inputs from the various BIPED model owners. All KPIs remain subject to change as part of the process of iterative refinement. As of December 2025, the *PED* KPIs outlined below (table 2) constitute the most technically meaningful and feasible performance indicators for the WP2 modelling activities from the perspective of the relevant model owners and technical leads. As the project progresses and associated digital solutions mature, this perspective may change and provide impetus for co-creation activities to amend any of the KPIs within the framework or include additional KPIs within the framework as part of its continued refinement. These KPIs are described in further detail in Annex 1.

Table 2. Summary overview of current PED KPIs as of December 2025

Theme	Name	Description	Unit
Energy	Peak electricity demand / district heating demand	This KPI expresses overall peak energy demand in the PED. The KPI can be provided for electricity demand, district heating demand, space heating demand and domestic hot water demand separately, based on data availability. Derivatives of this KPI can be defined by relating the final energy demand to building square meters (sqm) and occupants / building users.	[kW], [kW/m2*a], [kW/occupant]

Energy	District Heating system energy flexibility	Quantify available energy flexibility: The validated (data-to-physics) grey-box model coupled with advanced control strategy (MPC or RL) can be used to characterize how much energy flexibility (in terms of time, power and energy) the DH system can provide.	kW, kWh or dkk, euro (depending on the indicator itself)
Energy	Load forecasting: explained variation	The fraction of variation of district heating loads, explained by the model point forecast. This may be computed for a number of time horizons (ranging from e.g. 15 minutes to 48 hours).	%
Energy	Load forecasting: forecast improvements	The relative reduction in the root-mean-squared-error (RMSE) of reconciled forecasts vs base forecasts. This indicator measures the extent of performance gain from using hierarchies to reconcile (improve) base forecasts.	%
Energy	District heating supply temperature reduction	The reduction in supply temperature enabled by models, e.g. accurate load forecasts and/or improved control algorithms.	°C
Cross-sector	Availability of Green Space	The amount of green area in a city per 100 000 population. The amount of green space availability by population densities.	[m²] per 100,000 inhabitants. [m²] of green space / person.
Cross-sector	Distance to Green Space	Distance to green spaces (e.g., parks) by grid cell population density & demographic categories. for now: accessibility without demographics	m
Cross-sector	Renewable Land Use	Share of the public area that is also used for renewable energy production, e.g., use of shallow geothermal energy, PV parklet, wind, etc.	[m²], [%]
Cross-sector	Plot Density	Relationship between energy demand and Plot Density	[m²], [KWh/m²], [kW/m²], [%/%], [(Energy Imports /

			Energy Demand)/Plot Density]
Climate	Climate-Driven Roadway Degradation	Percentage of the roadway network that has experienced damage due to climatic effects (e.g., precipitation, flooding, freeze-thaw cycles) and requires maintenance, as identified within a common monitoring timeframe.	%
Climate	Cost savings - Critical Infrastructure	Cost savings realized from preventive maintenance on roadway infrastructure informed by digital twin insights and climate projections, as compared to traditional reactive maintenance models. Reflects avoided repair costs minus maintenance expenses, aligned with predefined budgets and segments.	EUR
Climate	Thermal Comfort	Assess individual comfort levels based on monitoring data and feedback if available. I.e., monitor temp and humidity and have a survey as to what situations were still perceived comfortable. This could yield information to calibrate the optimization of heat supply.	[%rh], [°C], Accompanied Survey (Likert Scale)
Climate	Model Coverage of Road Network in digital twin	Percentage of the roadway network (urban streets, highways, or other defined segments) that is actively monitored by the digital twin system for climate-related risks.	[%]
Climate	Pedestrian Wind Comfort	Annual Pedestrian Wind Comfort indicator represents a comprehensive year-round assessment of how wind patterns affect human experience throughout the site, using established standards like the Lawson Criteria. For this project the most suitable criteria is General Lawson.	Wind Speed Threshold (m/s)
Mobility	Energy consumed by traffic	The sum of energy consumed by fossil-fuelled cars compared to the energy consumed by electric cars.	[kWh]
Mobility	Motorised GHG (CO_2) emissions	A percentage difference in greenhouse gas emissions from the operation of cars and trucks based on a simulated scenario.	[%]
Mobility	Traffic Flow and Congestion - Aarhus	This indicator measures the volume and movement of vehicles along transportation networks over a specific period.	Vehicles per hour (veh/h)
Mobility	Traffic Flow and Congestion - Brabrand District	This indicator measures the volume and movement of vehicles along transportation networks over a specific period, combined with the duration and severity of traffic congestion.	Vehicles per hour (veh/h)

The *PED* KPIs, in conjunction with the *Project KPIs*, have thus converged within the overall M&E framework. This convergence expands the capacity of the framework to quantify the impact of the BIPED project based on the actions taken by the consortium to develop and the impact of the digital twin on the test district over time. As a result, the outcomes of monitoring and evaluation activities undertaken for the remainder of the project will lead to the development of more robust findings which can be more widely applied beyond the spatial and temporal boundaries of the project.

Following this expansion, consortium members have identified a need for further clarity and full integration of all KPIs within the M&E framework, to support streamlined reporting and transparency regarding related roles and responsibility. This has been discussed in further detail in section 3.3 below. While D4.3 section 3.2 noted that the three themes of M&E would remain unchanged throughout the remainder of the project to ensure consistency, additional work may be needed to better illustrate the individual and collective function and thematic relevance of all KPIs. This will ensure robust and streamlined monitoring and evaluation, in support of project objectives for dissemination, re-use, and exploitation of project findings. This will support the objective of Task 4.5 that aims to provide KPI-driven recommendations on replicating and scaling up PEDs on the way to a climate-neutral city.

2.4 Self-Reporting Tool (SRT) submission and BEST Tables

As noted in D4.3 section 3.7, The Self-Reporting Tool (SRT), developed by the Smart City Information System and now part of the Smart Cities Marketplace (SCM), enables project coordinators to report outputs and populate the SCM database. It serves as the link between project data and stakeholders, allowing users to upload details of interventions. Reported information is monitored in real time to support replication. The European Commission requires data submission at PED level using BEST Tables, ensuring consistency across EU projects and reducing reporting complexity. This approach makes projects comparable, as individual KPI-based reporting would lead to inconsistencies. The SRT's primary role is to act as a comparison tool. The SRT and BEST tables provide a standardised, quantitative record of BIPED data, ensuring comparability with other EU projects and supporting long-term replication. While BIPED maintains its own framework for specialised reporting and lessons learned, data submission to the SRT was planned to commence in Year Two. In support of that aim, WP4 engaged with SCM, leading to BIPED being listed on the SCM-SRT. However, it should be noted that reporting under the SRT has not commenced at the time of writing. The dimensions of the self-reporting tool are generally focused on physical interventions in the built environment. BIPED is primarily concerned with the development of digital interventions to support evidence-led decision-making in the planning and management of sustainable urban areas. As such it is difficult to quantify the impact of the project on the PED dimensions within the SRT. Similar challenges are present when attempting to attribute changes in PED performance to the BIPED project, particularly given the nascent nature of technical outputs. While the consortium will continue to consider alignment with the SRT as the digital twin

matures throughout the final year of the project; additional engagement may be required to assess the compatibility between the project and the dimensions of the SRT going forward.

3. KPI Update

3.1 KPI Data Management

The BIPED consortium remains committed to the development of findable, accessible, interoperable, and re-usable (FAIR) data, emphasising open access, peer-reviewed data sources in line with Horizon Europe Guidelines and best practice. FAIR data management practices aim to improve the dissemination of results, access and reuse of research data, and exploitation of data and results. The consortium continues to adhere to the highest standards of research ethics and integrity, and conducts all work in compliance with applicable national, EU, and international law. This includes strict compliance with GDPR principles such as data minimisation and privacy by design. This ensures effective mitigation of ethical risks, particularly those posed by aggregation and anonymisation of personal data. KPI data collection and ownership is governed by the ***Data Collection Methodology Creation & Execution*** section of the M&E framework. This section outlines data collection strategies, ensuring the use of high-quality, appropriately sourced data, and supporting transparency, replicability, and continuous improvement of collection procedures. KPMG will continue to engage with KPI owners and technical experts to gather qualitative and quantitative data on performance against KPIs, and on the framework and KPIs themselves. This aligns with the framework's principles of co-creation and enables continuous improvements in monitoring and evaluation. Further details on Data Management and Privacy, Ethical LDT Implementation, and KPI collection, ownership, and reporting can be found in D1.3, D1.4, and D4.3 respectively

3.2 KPI Activities

3.2.1 General Assembly KPI workshop and further discussion of KPI 11.

As noted in section 1.3.2 of the technical report, KPI 11 is identified as needing additional refinement. Initially developed through Work Package 4 to track market uptake of the digital twin solution, this KPI was noted as being of primary relevance to the end-stages of the project during discussion at the 2025 general assembly, as market uptake necessarily requires prior technical development of the digital twin solution. In later conversations, consortium stakeholders noted that a revision of the KPI may better help illustrate utilisation of the digital twin throughout the Brabrand test district, by expanding to include more diverse user-platform interactions, i.e through independent utilisation of the digital twin by individual citizens or stakeholders, rather than technical integration of the digital twin into buildings or assets. Implications and planned engagement on this matter is discussed further in sections 3.3 and 4.3.

3.2.2 Task 2.6 & Task 4.1 KPI alignment Meetings

In support of principles of stakeholder engagement and collaborative innovation, KPMG engaged with Work Package 2 leads AIT to ensure alignment and coherence between KPIs emerging from task 2.6 and the initial KPIs developed as part of Work Package 4. These meetings were crucial to support the enablement of task 2.6 in contributing to robust M&E of consortium activities and project impacts. During these sessions it was agreed that AIT would lead the development of additional KPIs through consultation with the relevant model owners within the consortium as part of task 2.6. These KPIs are to be treated collectively, i.e. KPIs emerging from task 2.6 fall within the broader M&E framework and will be monitored and evaluations through activities and procedures under Work Package 4.

3.2.3 KPI feedback forms & BIPED Technical Team Meeting

In alignment with the convergent parallel approach underpinning BIPED M&E, KPMG circulated a quantitative KPI update form, and qualitative feedback forms to all KPI owners to provide updates on the 25 *Project* KPIs. Following circulation, KPI owners raised the issues of administrative burden and duplication of effort presented by lack of clarity surrounding roles and responsibilities in collating updates and quantifying actions since the month 18 technical report, particularly following the development of the *PED* KPIs as part of Task 2.6. It was decided that additional work was needed between KPMG and AIT to agree on approaches for reporting on all KPIs as part of this deliverable and consolidate relevant updates.

3.2.4 BIPED KPI Consolidation Meeting

A meeting was held between KPMG and members of Work Package 2 lead AIT, to discuss approaches for reporting on the KPIs for this period and going forward until the conclusion of the project. At that meeting it was decided that an additional session was needed to improve clarity regarding M&E activities and the roles of the consortium members in collating updates for this and future reporting periods.

3.2.5 BIPED KPI Workshop

Following the KPI consolidation meeting, a BIPED KPI workshop was held to discuss the functions of both the Project and PED KPIs within the overall M&E framework, and the roles and responsibilities of consortium members in collating information for this report and future reports throughout the remaining lifetime of the project. During this workshop, consortium members identified several challenges in collating and describing actions taken and suggested several actions which could be undertaken to support improved understanding of roles and responsibilities, minimise administrative burden, and support streamlined Monitoring and Evaluation until month 36. Further detail of these challenges and their implications for monitoring and evaluation can be found in section 3.3.

Table 3. KPI workshop agenda

Section Name	Description
Introduction and Workshop Objectives/Agenda	Led by KPMG, this segment outlined the objectives of the workshop and its importance in the broader context of the project. It emphasised the goal of supporting improved understandings of the role of both Project and PED KPIs, and responsibilities for consortium members in providing progress updates for the purposes of this report and future reports.
Review of the monitoring and Evaluation Framework	KPMG delivered this section, which acted as a reminder of the scope and role of the overall monitoring and evaluation framework in tracking progress and supporting analysis of Key Exploitable Results at the conclusion of the project.
KPI groups and their relationship to the M&E framework.	This segment provided further analysis on the development and inter-relationship between both Project and PED KPIs, highlighting the importance of monitoring and evaluating both actions taken by the consortium and the impact of those actions on the Brabrand test district.
Project KPI discussion	This collaborative segment involved a discussion between KPMG and the identified leads on all 25 Project KPIs; including the opportunity to provide an updated progress report and identify any challenges in achieving targets and/or in quantifying progress under the KPI's established description or scale.

3.2.6 Per – Unit Definition Meeting

This meeting between KPMG and the WP4 lead was held to develop simplified "per-unit" descriptions in the context of reporting under the KPIs. Feedback during the KPI workshop identified that while some descriptions were self-explanatory, others required confirmation as to what exactly was being quantified by the KPI. This discussion focused on the *Project* KPIs, rather than the *PED* KPIs. Task 2.6 is still ongoing, and at the time of this meeting the *PED* KPIs actively undergoing refinement and consolidation. Due to their nascent status, no attempts had been made to complete the associated calculations, and thus no challenges or opportunities relating to data collection had been identified. These KPIs are still subject to change and ongoing M&E activities throughout the remainder of the project will seek to reveal challenges or opportunities for further refinement of all KPIs. Section 4.1 includes an overview

of draft "per-unit" descriptions of all KPIs discussed during this session. KPMG will seek to further refine these descriptions with the relevant KPI owners and wider consortium prior to the commencement of M&E activities in the final year of the project, and on an ongoing basis thereafter.

3.2.7 Community engagement KPIs meeting

KPMG, AAKS, and OASC engaged to discuss draft "per-unit" definitions of relevant community engagement KPIs, and the implications of the workshop on progressing these KPIs. While the target for community workshops has been exceeded, the target for co-creation and training workshops has yet to be achieved. The workshop was identified as a suitable setting for the surveying of participants to support reporting under KPIs 7 and 9, which draw on stakeholder responses to understanding citizen awareness and understanding of the potential of the digital twin, and perceptions of usability of the digital twin. In alignment with the parallel convergent approach to M&E collection, it was agreed that feedback collected during the workshop could leverage qualitative and quantitative elements, which can be used to inform improvements to the digital twin solution. Co-creation of feedback forms and mechanisms will continue as the planned workshops develop.

3.3 Findings of KPI activities

Throughout KPI activities since the previous iteration of this deliverable, consortium members identified several challenges and opportunities for further refinement of the M&E framework, KPIs, and related reporting procedures. The following is a summary of key outcomes regarding these challenges, and possible approaches to mitigate these challenges and streamline the process going forward. Planned actions relating to these points are described in section 4.3.

Roles and responsibilities in M&E
Many of the *Project* KPIs have two or more named leads. While all leads are responsible for contributing to the work quantified by the KPI, ambiguity regarding ultimate responsibility for providing updates was seen as possibly creating administrative burden and duplication of effort. As a result, the main outcome was to distinguish between primary KPI owners/lead organisations and support organisations.

- ***Lead organisations*** would be responsible helping to progress the actions, and for collating and submitting updates to relevant KPIs,
- ***Support organisations*** would be responsible for helping to progress actions but would not be responsible for submitting updates.

Consortium members felt that these 'lead' and 'support' dynamics has emerged naturally over the course of the project, and that formalising these roles could support a more streamlined monitoring and evaluation process throughout the remainder of the project. While at present all *PED* KPIs have a single assigned lead, engagement on this matter will seek to provide similar clarity for their respective owners of the *PED* KPIs, noting that due to their nascence they have yet to be calculated. This is of particular relevance as KPIs requiring collective input may emerge throughout the remainder of the project.

Coherence of KPI groups and categories

Members noted that a review of KPI names and categories ahead of 2026 M&E activities could support clarity and understanding. As noted above, the *Project* KPIs were initially developed pending the development of additional KPIs during task 2.6. However, the KPIs developed during task 2.6 are categorised as “Energy”, “Mobility”, “Climate” and “Cross-sectoral”, in addition to the existing KPI themes of “Community engagement”, “Energy/Mobility” and “Digital Solutions”. Thus, KPIs fall into 7 categories. At the time of this meeting, consortium members noted overlap in the specific elements being monitored following the addition of new KPIs. Continued refinement and consolidation of the PED KPIs in the interim has reduced this, illustrating the importance of stakeholder-engagement in supporting co-creation, and the value of iterative refinement in enabling robust M&E without duplication of effort. Conversely, as these KPIs are subject to change following further technical development, continued engagement will ensure the continued avoidance of challenges in this regard.

Clarity regarding “per-unit” definitions

Members noted that additional work may be needed to clarify “per-unit” definitions for certain KPIs, particularly ‘Community Engagement’ Project KPIs, which aim to quantify certain types of events and feed into other KPIs such as the total number of participants engaged during said events. KPMG and OASC have worked to develop draft “per-unit” definitions to, with a view to simplifying collation and reporting going forward.

Ongoing relevance and applicability of KPIs

Members noted that the names and descriptions of certain KPIs may need to be further clarified or otherwise refined to ensure relevance, particularly considering the ongoing technical development of the data models. Particularly the ‘*energy/mobility’* KPIs were noted as requiring additional consideration and potential review. Feedback suggests it may be worth exploring refocusing these KPIs to address the TRL of the related *Modules* available on the platform, as the TRL of each *module* is reflective of work done to develop and refine several data models. The KPI “*Number of buildings/assets utilising the Digital Twin Solution”* is an example of a KPI which at this stage of the project has not shown significant change. As noted in section 3.2.1, this KPI is a key item for which further discussion is needed as part of M&E activities in 2026. These discussions will seek to refine the scope and methodology for this KPI, to support its relevance to the project. “*Interoperability of the Digital Twin Solution*”, was likewise noted as an example of a KPI which, while relevant, has seen limited progress due to the cadence of the project. While interoperability is a key consideration of the project in line with FAIR data management principles, there is no dedicated workstream for interoperability. Considerations of future evaluation of interoperability are discussed in further detail in section 4.3

4 M&E Progress Update

4.1 Project KPIs – November 2025 Update

Table 4. Status update of Project KPIs as of December 2025

Group	No.	Name	Description	Data Collection and Data reporting Owner	Data collection methodology	Measurement Type	DRAFT "Per-unit" definition	Target	Current (November 2025)
Community Engagement	1	Number of community participation events organised/coordinated	The role of community participation events is to enable local communities to have a greater understanding of the Digital Twin solution. Community participation events refer to events such as learning workshops, joint exhibitions or event participation and other events promoting the project and its outcomes. By tracking the community participation events and evaluating their outcomes, you can gauge the level of community engagement within the project and make informed decisions to enhance participation and collaboration.	AAKS	Excel Tracker	Number	Number of events hosted	10	61
Community Engagement	2	Number of Co-Creation & Training Workshops	BIPED will conduct a number of co-creation & training workshops which will involve key stakeholders identified by AAKS. The co-creation workshops Co-will focus on collaborating with key stakeholders to guide the design process of the Digital Twin solution and other BIPED interventions. The training workshops will be commenced upon completion of the Digital Twin solution and will involve the same key stakeholders and train them in the use of the Digital Twin solution.	AAKS, DTU	Excel Tracker	Number	Number of workshops hosted.	10	6
Community Engagement	3	Workshop Participants	By systematically measuring stakeholder engagement through workshops and evaluating participation levels, engagement, and outcomes, you can assess the effectiveness of your engagement efforts and ensure that stakeholder perspectives are considered in project decision-making and implementation.	AAKS, DTU	Registration Form	Number	Number of workshop attendees. (Number of unique attendees where possible)	400	492
Community Engagement	4	Networks/Associations Targeted	Through engagement with smart city networks such as SCC1 Monitoring & Evaluation Task Group, BIPED can engage with networks and associations focusing on smart city and digital twin projects which share common goals and objectives. Engaging with these networks/associations will give BIPED expertise into digital twin/smart city experiences which will help the project navigate potential challenges	AAKS, DTU, OASC	Excel Tracker	Number	Number of associations	30	6
Community Engagement	5	EU Cities Engaged	BIPED will showcase the digital solution and engage with 100 cities via the Net Zero Cities project supporting the EU's Mission of "100 Climate-Neutral and Smart Cities by 2030" newly launched as part of the Horizon Europe programme. The project works as a service-oriented platform supported by world-class practitioners. It helps European cities by providing them with the support and solutions they need to achieve their Net Zero goals. BIPED will also broaden this to general engagement with EU cities, which does not necessarily have to go through the NZC mission network.	AAKS, DTU, OASC	Excel Tracker	Number	Number of cities engaged with.	100	24
Community Engagement	6	Joint Actions with 'Sister Projects'	Through participation in smart city networks, BIPED can engage with 'sister projects' and 'PED projects' in the digital twin/smart city sphere. Through this network, BIPED can carry out joint actions with 'sister projects' for the digital twin solution By	All (Leads AAKS, DTU,	Horizon Results Booster, OASC/All	Number	Number of actions	3	7

			systematically measuring joint actions with other projects, BIPED can evaluate collaboration in terms of alignment, impact, benefits, challenges, and lessons learned when implementing a digital twin solution across different environments/settings.	KPMG, OASC, DRI,AIT)	Partners Engagement				
Community Engagement	7	Increased Citizen Understanding and Awareness of the potential of Digital Twin projects	This KPI aims to measure the initial citizen awareness of digital twins and the nature of how they operate. Through the lifecycle of the project, BIPED will aim to raise this awareness through bi-annual workshops, focus groups and questionnaires with citizens and track the potential increase in awareness via BIPED's efforts and the wider digital twin landscape and awareness of the potential socio-economic impacts of the digital twin solution.	AAKS (With assistance from KPMG)	Stakeholder Survey(s)	Five-point Likert scale / Questionnaire	Average score emerging from focus groups, workshops, and surveys regarding awareness of the BIPED digital twin and its potential socio-economic impacts.	3 (On Likert Scale 1-5)	3
Community Engagement	8	Media Coverage (News articles, videos, mentions) of BIPED Project	This KPI assesses the frequency and breadth of media attention, reflecting the project's visibility and public awareness, vital for garnering support and replicability of the Digital Twin solution.	DRI	Excel Tracker	Number	Total number of media posts	10	15
Community Engagement	9	Usability of the Digital Twin Solution for End Users	The extent to which the solution is perceived as difficult to understand and use for potential end-users. It is presumed that a smart city solution that is easy to use and understand will be more likely adopted than a difficult solution. Usability of the digital twin will refer to how effectively, efficiently, and satisfactorily a user can interact with and achieve specific goals using a digital twin system. The definition will include the following components: **Ease of Use:** The system's interface should be intuitive, allowing users to navigate and interact with the twin without extensive training or prior experience. **Efficiency:** Users should be able to complete tasks quickly and accurately. This often means that the digital twin should allow users to find and manipulate data seamlessly, optimizing workflows. **Accessibility:** The digital twin should be accessible to all intended users, considering factors like cross-platform functionality, compatibility, and adaptive design for varied user needs. **Reliability and Responsiveness:** The system should reliably represent real-time or near-real-time data of the physical asset, with minimal delay or disruption. This is especially critical in environments where digital twins monitor ongoing operations, like industrial machinery or transportation networks. **Interpretability:** Users should find it easy to interpret the visual and data representations within the digital twin. Effective data visualization and relevant, clear metrics help make complex information understandable, which enhances decision-making. **Feedback and Error Tolerance:** The system should provide feedback to users, helping them understand the consequences of their actions and recover from errors if they occur.	DKSR, AAKS	Stakeholder Survey(s)	Likert Scale	Average score emerging from stakeholder usability surveys.	3 On Likert Scale 1-5)	

Community Engagement	10	Peer Reviewed Publications	This KPI measures the number and of research papers or articles published by BIPED partners in journals, conference proceedings, magazines, or other outlets. Peer-reviewed publications refer to scholarly work that has undergone review by subject matter experts before being accepted for publication. These publications are typically considered credible and authoritative in the academic and research community.	All	Excel Tracker	Number	Number of unique articles published by BIPED partners in peer reviewed academic publications.	10	3
Energy/Mobility	11	Number of buildings/assets utilising the Digital Twin Solution	This KPI tracks the uptake of the market by the number of buildings/assets which are able and technically equipped to adopt the digital twin solution.	DTU, AAKS, DKSR, VCS	Registration Form/Excel Tracker	Number	Number of buildings able and technically equipped to uptake the digital twin solution	20	0
Energy/Mobility	12	Energy Model TRL Development	We will describe a new energy systems modelling tool that will be able to take advantage of short-term flexibility in long-term energy planning. This tool will take advantage of the additional flexibility unlocked by sector coupling and data-driven methods on all relevant scales, but here with a focus on PEDs to smart cities.	DTU	Excel Tracker	TRL Level	TRL	8	4
Energy/Mobility	13	Mobility Model TRL Development	Creates a traffic model of selected area. Portrays hourly changes in traffic flows in the area. Allows recalculating traffic flows in reaction on added events or changes in the road network topology and/or traffic demand	RT	Excel Tracker	TRL Level	TRL	9	8
Energy/Mobility	14	Traffic Enviro Impact Analyst TRL Development	Traffic Enviro Impact Analyst is software designed to help assess traffic's environmental impact on air and noise pollution. The software uses traffic flows as input and applies emission factors and dispersion models to calculate the level of air pollution generated by vehicles, as well as a noise model to estimate the amount of noise pollution.	UWB	Excel Tracker	TRL Level	TRL	7	4
Energy/Mobility	15	DKSR Open Urban Platform TRL Development	Open-Source real-time platform for cross-domain data integration and matchmaking. Real-time sensor data platform that follows the vision of Open Urban Platforms [OUP] as expressed by the European Innovation Partnership Smart Cities and Communities and defined in DIN SPEC 91357. The OUP enables small and large cities and businesses to efficiently integrate new and existing data sources, process and analyse data in near real-time, and ultimately share the data with various stakeholders. Unlike many other platforms, it is cloud agnostic and can run in the cloud, in container environments Kubernetes or in the local data centre. Depending on the requirements, cloud-based services or open-source technologies can be used for these purposes.	DKSR	Excel Tracker	TRL Level	TRL	9	8
Digital Solutions	16	Demonstrations of the Digital Twin Solution/Platform	By systematically measuring demonstrations held of the Digital Twin and evaluating feedback and impact, you can assess the effectiveness of the solution and refine the solution to ensure an interoperable solution.	All (Leads: AIT, DTU, AAKS, DRI)	Excel Tracker	Number	Number of demonstrations	10	16
Digital Solutions	17	Datasets Published	Publication of open datasets for use by third parties	All (Leads: AIT, DTU, UWB, RT)	Excel Tracker	Number	Number of datasets	5	25

Digital Solutions	18	Models Linked to PED Published	Publication of models for use by third parties.	AIT, DTU, UWB, RT	Excel Tracker	Number	Number of models	3	5
Digital Solutions	19	Usage of Open-Source Software and Solutions	The use of open-source software and solutions means less possibilities of vendor lock-in and more space for communities to develop smart city solutions. It also lowers the software costs	AIT, DKSR, DTU	Excel Tracker	Percentage	Percentage of software and solutions utilised by the digital twin which is open source.	75%	30%
Digital Solutions	20	Quality of Open Data	Percentage of data that uses DCAT standards. The quality of open data is better if standardized. Processes get easier when data standards are applied. The DCAT standard allows municipal employees to produce data in a standardized way.	CDK, DKSR, INNO, DTU	Stakeholder Survey(s)	Percentage	Percentage of all BIPED data which uses DCAT standards	75%	50%
Digital Solutions	21	Soft Datasets Integrated	Capture and integrate soft (intangible) data into the BIPED Digital Twin platform which goes beyond tangible energy and mobility sources to better understand how spaces and policies affect people's behaviours etc.	AIT, DKSR, DTU	Excel Tracker	Number	Number of soft datasets	20	2
Digital Solutions	22	Website Visits	Number of visits to the BIPED website.	DRI	Matomo	Number	Number of visits to the BIPED website	10,000	6,027
Digital Solutions	23	Social media followers	Across different channels e.g. LinkedIn, Twitter, YouTube, SlideShare.	DRI	Social Media Analytics	Number	Number of followers across all social media channel	1,000	650
Digital Solutions	24	Number of Aarhus City Council Staff Trained to use the Digital Twin	This KPI tracks the training of the developed digital twin through the number of city council staff that have received training for the tool. The staff trained will be able to operate the digital twin and its functions to assist with analysis of and reporting on project implementation, baseline development feasibility studies and general use.	DTU, AAKS	Registration Form/Excel Tracker	Number	Number of training session attendees.	20	5
Digital Solutions	25	Interoperability of the Digital Twin Solution	Interoperability is the ability of a system (or product) to work with other systems by providing services to and accepting services from other systems and to use the services so exchanged to enable them to operate together (ISO/TS 37151). The indicator assesses the improvement in interoperability in a qualitative manner. Levels of Interoperability: IMTs define five levels of interoperability maturity: Ad hoc (level 1): Poor interoperability – the digital public service cannot be considered interoperable Opportunistic (level 2): Fair interoperability – the digital public service implements some elements of interoperability best practices Essential (level 3): Essential interoperability – the digital public service implements the essential best practices for interoperability Sustainable (level 4): Good interoperability – all relevant interoperability best practices are implemented by the digital public service Seamless (level 5): Interoperability leading practice – the digital public service is a leading interoperability practice example for others Source: https://interoperable-europe.ec.europa.eu/collection/interoperability-	OASC, AAKS, DTU, AIT, DKSR	Stakeholder Survey(s) & Interoperability Maturity Model	Interoperability Maturity Model (https://ec.europa.eu/isa2/sites/isa/files/interoperability_maturity_model.pdf)	Performance based on IMT.	Level 3	0

			maturity-tools-imts-digital-public-services#:~:text=IMTs%20define%20five%20levels%20of,elements%20of%20interoperability%20best%20practices						

4.2 Progress Update based on KPIs

The findings of the most recent KPI update indicate strong performance against the project KPIs overall. Of the 25 KPIs, 32% (n=8) have been achieved, with most of those (n=7) having been exceeded as of December 2025. This section reviews progress across each M&E theme.

4.2.1 Community Engagement

Community Engagement KPIs are the most advanced at present, with 50% exceeded and a further 10% achieved as of December 2025. It should be noted that two of these which have been achieved – "*Increased Citizen Understanding and Awareness of the potential of Digital Twin projects*" and "*Usability of the Digital Twin Solution for End Users" are* derived from survey findings and thus subject to change throughout the remainder of the project. While the target for community events and number of stakeholders engaged have both been exceeded, there is still need for additional co-creation sessions, engagement with smart city networks, and engagement with other EU cities, positioning these KPIs and related activities as the key focus under the theme of community engagement for the remainder of the project. The high level of achievement under this theme indicates that the KPIs are broadly aligned with the objectives and tasks associated with community engagement.

4.2.2 Energy & Mobility

As of November 2025, none of the energy & mobility targets have been achieved, although healthy progress is ongoing, as can be seen in the month 18 technical report. This validates the challenges identified in the previous iteration of this deliverable, which at that time noted the complexity associated with developing KPIs for such nascent outputs of the project. The integration of additional KPIs into the framework further expands the scope of monitoring and evaluation related to the models and their impacts, enabling future activities to more holistically evaluated the performance of the PED and the impacts of the digital twin. A key consideration for future collaborative refinement of the framework will be to ensure ongoing thematic, linguistic, and methodological coherence of the energy & mobility KPIs following expansion of the M&E framework, which now contains additional KPIs relevant to energy, mobility, climate, and cross-cutting urban sustainability dimensions emerging from task 2.6.

As noted in section 3, *"Number of buildings/assets utilising the Digital Twin Solution"* has been identified as primarily relevant to the end stages of the project. The KPI was initially aimed at monitoring market uptake of the digital twin solution within buildings technically equipped and capable of doing so. Thus, robust understandings of technical requirements needed to adopt the model are a crucial prerequisite in establishing the number of buildings within the Brabrand testbed capable of doing so. As the digital twin is still in active development, further engagement will be needed to refine this KPI and related data collection methodologies. This engagement is described in further detail in section 4.3.

4.2.3 Digital Solutions

Digital Solutions KPIs are proceeding well, with 30% exceeded, and the remainder not yet achieved. Targets related to demonstrations of the digital twin, and publishing of datasets and models have been exceeded. These achievements align with FAIR data management principles, and consortium ambitions to support dissemination, re-use, and exploitation of project results. As of November 2025, the consortium has reached 60% and 65% of their target for website visits and social media followers respectively. Only five Aarhus city council members have been trained on the digital twin at this stage (25% of target), however this work is ongoing to progress this figure as the digital twin continues to mature throughout the remainder of the project. "*Interoperability of the digital twin solution"* has not progressed to date, and "*Soft datasets integrated*" has also shown limited progress at this stage. Similarly to the challenges identified in section 4.2.2 above, this stems primarily from their end-stage relevance. The groundwork for interoperability has been laid, including the implementation of Minimum Interoperability Mechanisms. MIM0 and MIM2, addressing data accessibility and data models respectively, have been identified as the most fundamental and necessary interoperability mechanisms, which enable development of more advanced interoperability frameworks. While interoperability principles have thus been implemented throughout relevant workstreams, as noted in section 1.3.3 of the technical report; meaningful assessment of interoperability becomes more feasible as the system itself matures. The integration of soft datasets is a key component of the consortium's work to progress local digital twins beyond technical data models and towards more holistic representations of urban environments. Work to capture, scale, and integrate soft datasets is ongoing, and discussed in further detail in deliverable 2.3. However, similarly to the above, integration of soft data is inherently contingent on the prior development of the technical models. Thus, while these KPIs are still seen as effective indicators, progress in this area has been constrained by lower technical maturity earlier in the project timeline and these KPIs are likely to display more rapid progress throughout the end stages of the project.

4.3 Monitoring and Evaluation for the remainder of the project

The two pillars of co-creation in the context of M&E for BIPED – collaborative innovation and stakeholder engagement, will continue to shape M&E activities for the duration of the project. Likewise, they will inform KPMG's approach to collaboration with consortium stakeholders to address the identified challenges. This approach will be structured around monthly engagements with KPI owners, which will include specific actions in the following areas:

Engagement on the ongoing relevance, applicability, and coherence of KPIs: As part of the continued iterative refinement of the M&E framework, the consortium will engage on all KPIs within the framework on an ongoing basis, to ensure effective M&E in the face of continued development of the BIPED digital twin throughout the remainder of the project. This

includes engagement on KPIs most relevant to the later stages of the project, which have seen limited progress up to this point. This engagement will thus also work to support continued progress of consortium actions towards goals such as interoperability and soft data integration, until such time as the relevant KPIs can be appropriately reported on.

Engagement on alignment with the SRT: As noted in section 2.4, the current dimensions of the SRT are not fully compatible with the nature of the BIPED project, which aims to support evidence-based decision making, rather than delivering direct interventions in the Brabrand test district**.** As such, the consortium will continue to explore options to improve the alignment between the BIPED project and the SRT dimensions as the technical outputs of the project progress.

Engagement on roles and responsibilities: KPMG will seek to support formalised assignment of singular leads for *Project* KPI data collection and reporting. While consortium members note that in many instances these roles have emerged as natural outputs of working dynamics over the course of the project thus far, actions undertaken to formalise these roles must consider the viewpoints and broader role of all stakeholders to identify the most appropriate designation of 'lead' and 'support' roles. It should be noted that at the time of writing all *PED* KPIs emerging from task 2.6 have been assigned a single "owner/responsible partner", which is likely to streamline engagement on this matter. However, these KPIs are subject to change as task 2.6 progresses, and the consortium will continue to engage on roles and responsibilities where necessary to maximise coherence and alignment, particularly noting the possibility for new KPIs to emerge which require collective input from multiple model owner in the future.

Engagement on per-unit definitions of KPIs: A key determinant of accurate progress reporting in BIPED is alignment with established descriptions and methodologies for KPI data collection and reporting laid out in the M&E framework. KPMG and OASC engaged to develop draft "per-unit" descriptions to support clarity in reporting. These descriptions aim to support robust monitoring and evaluation by defining the minimum unit which can be captured through the KPIs. Having developed these draft descriptions, additional work will be undertaken to validate and adopt them through engagement with relevant consortium members in preparation for M&E activities in 2026.

The actions taken to address these challenges, which may include interviews, group meetings, or participatory workshops, will support a high level of collective understanding regarding roles, responsibilities, and functions within the M&E framework. These iterative and participatory actions ultimately seek to improve the effectiveness and impact of ongoing monitoring and evaluation activities. These ongoing activities will consist of regular touchpoints with KPI reporting leads, across the consortium. Thus, the actions noted above, among others which may become necessary in the future, will work to improve the effectiveness and impact of monitoring and evaluation, supporting alignment of consortium activity as the project progresses through its final phases.

5. Conclusion

Significant progress has been made in the Monitoring & Evaluation (M&E) framework development for the BIPED project since the previous iteration of this deliverable. The systematic approach established by the M&E framework, and related engagement with consortium stakeholders has continued to enable ongoing assessment of project effectiveness. This has revealed opportunities for further refinement in support of continued alignment of project activities with the overarching goals and objectives of BIPED. This comprehensive evaluation strategy can thus be seen to leverage both qualitative and quantitative dimensions to support informed decision-making and effective project management.

Key developments include the expansion of the M&E framework following development of additional KPIs during Task 2.6. This expansion to the scope and depth of monitoring and evaluation for BIPED is of crucial significance for the framework's capacity to enable achievement of project outcomes. Continued utilisation and refinement of KPIs in BIPED are key to the future exploitation of BIPED project outcomes, by providing additional metrics which can be used to inform future replication, adaptation, and exploitation of BIPED approaches in new contexts.

This approach lays the groundwork for reporting through the Smart City Information System's Self-Reporting Tool, by ensuring accurate and consistent collection of KPI data throughout the project's duration. However, work is ongoing to explore options to improve alignment between the BIPED project and the dimensions of the SRT and mitigate any challenges which may arise from current misalignment thereof.

The insights emerging from KPI activities confirm the importance of the pillars of co-creation in supporting clarity, alignment, and effectiveness of M&E in enabling the BIPED project to progress the state of the art in developing and deploying local digital twins for positive energy districts. Monthly engagements with the consortium members throughout the final year of the project will be used to support aligned action and robust M&E, towards end-stage aims to produce final outputs which are exploitable, beyond the conclusion of the project. This will ensure that the monitoring and evaluation framework will continue to centre innovative collaboration and stakeholder engagement as mechanisms to promote synergy across the consortium and improve project outcomes.

6. Annex

Annex 1 PED KPIs (as of December 2025)

This Annex presents the Extended set of PED KPIs, developed within Work Package 2 (WP2), to support the Monitoring and Evaluation (M&E) process of the BIPED Positive Energy District (PED). The purpose of the WP2 KPI set is to explore an enriched PED framework that spans energy, mobility, and a wider range of cross-sectoral urban sustainability dimensions. The indicators included here reflect the outcome of extensive consolidation and collaborative discussions across Tasks 2.2–2.4, together with methodological inputs from the relevant model owners. As such, the set represents a coherent view of what is currently technically meaningful and feasible for WP2 modelling activities at this stage of the project.

The KPIs presented here are therefore provided as a structured input into the BIPED M&E Framework under WP4. This KPI list is not final and may be further refined as the overall M&E framework, is consolidated.

Table 5. PED KPIs as of December 2025

Sector	Name	Definition	WP2 Task Connection	Unit	Model Connection	KPI Owner/ Responsible Partner	Calculation	Required input data.	Data format	Potential Soft data (Y/N)	Expected Impact
Energy	Peak electricity demand / district heating demand	This KPI expresses overall peak energy demand in the PED. The KPI can be provided for electricity demand, district heating demand, space heating demand and domestic hot water demand separately, based on data availability. Derivatives of this KPI can be defined by relating the final energy demand to building square meters (sqm) and occupants / building users.	T2.2	[kW], [kW/m2*a], [kW/occupant]	Load Forecasting/ MPC - Model Predictive Control/ reinforcement learning (black box model). Kreslob to provide information on what the grid can handle. AIT Occupancy Model.	DTU		Hourly monitoring data of district heating network substation or electricity substation.	Time series data, tabular, CSV		Peak electricity demand / district heating demand
Energy	District Heating system energy flexibility	Quantify available energy flexibility: The validated (data-to-physics) grey-box model coupled with advanced control strategy (MPC or RL) can be used to characterize how much energy flexibility (in terms of time, power and energy) the DH system can provide.	T2.2	kW, kWh or dkk, euro (depending on the indicator itself)	DTU Grey Box Model	DTU	Different calculations (indicators) for different case studies	Real measurement obtained from CDK portal; Weather data (DMI), price data (Energinet), etc.	Time series data, tabular, CSV		District Heating system energy flexibility
Energy	Load forecasting: explained variation	The fraction of variation of district heating loads, explained by the model point forecast. This may be computed for a number of time horizons (ranging from e.g. 15 minutes to 48 hours).	T2.2	%	Load Forecasting	DTU	100*(1-RSS/SS), (Or equivalent multivariate form.) RSS = Residual Sum of Squares SS = Sum of Squares.	Actual values and forecasts of district heating loads.	Time series data, tabular, CSV/JSON or binary formats.		Load forecasting: explained variation
Energy	Load forecasting: forecast improvements	The relative reduction in the root-mean-squared-error (RMSE) of reconciled forecasts vs base forecasts. This indicator measures the extent of performance gain from using hierarchies to reconcile (improve) base forecasts.	T2.2	%	Load Forecasting	DTU	100*(RMSE/(RMSE_B)-1) RMSE = Root Mean Squared Error RMSE_B = Root Mean Squared Error (Base forecasts)	Actual values, base forecasts and reconciled forecasts of district heating loads.	Time series data, tabular, CSV/JSON or binary formats.		Load forecasting: forecast improvements
Energy	District heating supply temperature reduction	The reduction in supply temperature enabled by models, e.g. accurate load forecasts and/or improved control algorithms.	T2.2	°C	Load Forecasting	DTU/ potential connection to other partners	T_b-T_a T_b = supply temperature before change T_b = supply temperature after change	Typical/average (or distribution of) temperatures before and after change.			District heating supply temperature reduction
Cross-Sector	Availability of Green Space	The amount of green area in a city per 100 000 population. The amount of green space availability by population densities.	T2.4	[m²] per 100,000 inhabitants. [m²] of green space / person.	Digital Twin	AIT (DSS)	Total amount of green space in m2* 100000) / Total inhabitants. 1. total population/gridcell (&demographic categories) 2. size of closest green space polygon: total sqm of green space polygon at closest green space cell -> formula: m2 of green space polygon / total population by grid cell (&demographic categories) Steps: Step 1: prepare pop density / grid cell. then get the demographic data Step 2: green space polygon sqm	Local census and population data; green space measured in m2	GeoJSON, Json, csv, for GIS Systems		Availability of Green Space
Cross-Sector	Distance to Green Space	Distance to green spaces (e.g., parks) by grid cell population density & demographic categories. for now: accessibility without demographics	T2.4	m	Digital Twin	AIT (DSS)	Within a defined circle radius (as the crow flies). 2models: 1.radius (as the crow flies) 2.road network classification: A: 0m B: 0-100m C: 100-250m D: >250m	road network grid (100x100m) demographic data Green area locations (coordinates).	GeoJSON, Json, csv, for GIS Systems		Distance to Green Space
Cross-Sector	Renewable Land Use	Share of the public area that is also used for renewable energy production, e.g., use of shallow geothermal energy, PV parklet, wind, etc.	T2.4	[m²], [%]	Digital Twin	AIT (DSS)	Total amount of public space in m2/ total GFA of study area * 100/1	Area in m2 of study area; area of public space designated to renewable energy production. Copernicus Land Cover (sparse resolution) VHR satellite imagery	GeoJSON, csv for GIS systems		Renewable Land Use
Cross-Sector	Plot Density	Relationship between energy demand and Plot Density	T2.4	[m²], [KWh/m²], [kW/m²], [%/%], [(Energy Imports / Energy Demand)/Plot Density]	Digital Twin	AIT (DSS)					Plot Density
Climate	Climate-Driven Roadway Degradation	Percentage of the roadway network that has experienced damage due to climatic effects (e.g., precipitation, flooding, freeze-thaw cycles) and requires maintenance, as	T2.4	[%]	Climate Risk	DTU	Degradation (%)=(AreaLength of Road Damaged by Climate/Total Road Length in Study)×100 Identify damaged segments within a	Road condition monitoring data, climate stress indicators(precipitation, rainfall, freeze-	Numeric, time-series		Climate-Driven Roadway Degradation

		identified within a common monitoring timeframe.					defined timeframe. Measure the total length of these damaged sections, divide by the total road length in the study area, and multiply by 100 to calculate the percentage affected. **Goal:** quantify the extent of climate-related damage to the road network Calculating this KPI per year, helps to understand how much the road can get worse over the period without using model. Likewise, the KPI can be calculated when the model is in place, and used for representing the model effectiveness.	thaw cycles),GIS data,			
Climate	Cost savings - Critical Infrastructure	Cost savings realized from preventive maintenance on roadway infrastructure informed by digital twin insights and climate projections, as compared to traditional reactive maintenance models. Reflects avoided repair costs minus maintenance expenses, aligned with predefined budgets and segments.	T2.4	[€]	Climate Risk	DTU	Cost Savings (€)=∑(Expected Repair Cost−Preventive Maintenance Cost) First identify the road segments included in the Digital Twin model and maintenance plan. Then, estimate the expected repair costs without intervention using historical damage data, budget planning and climate projections. Record the actual costs of preventive maintenance and subtract these from the projected repair costs to determine the net savings. **Goal:** Economic advantages of preventive maintenance. It measures the cost savings made possible by utilizing the Digital Twin system. Encourages proactive responses to climate-related risks, supports more effective budget planning and supports investments in predictive infrastructure tools.	Historical maintenance records, projected repair costs (could be nice to be based on climate), actual maintenance cost logs and road segment inventory with predefined maintenance budgets.	Numeric, financial (CSV/XLS)		Cost savings - Critical Infrastructure
Climate	Thermal Comfort	Assess individual comfort levels based on monitoring data and feedback if available. I.e., monitor temp and humidity and have a survey as to what situations were still perceived comfortable. This could yield information to calibrate the optimization of heat supply.	T2.4	[%rh], [°C], Accompanied Survey (Likert Scale)	CLIMIFY Indoor Climate Model	DTU	1. Response Distribution (RD) = Standard deviation of weighted comfort responses Weights: +2 (Much warmer), +1 (Warmer), 0 (As is), -1 (Colder), -2 (Much colder) Goal: Lower RD over time indicates model is aligning better with user comfort. 2. UCS = ("As is" responses / total responses) × 100% Optional: Weekly UCS = 7-day rolling average Probability of complaint 3. Probability of complaint Probability that a user will want the environment adjusted ("warmer"/"much warmer" or "colder"/"much colder") at a given measured or predicted indoor temperature. Overall PoC = (non-"as is" responses / total responses) Directional PoC = split into want warmer / want colder	Time-series data: temperature (°C), setpoint (°C), relative humidity (%), CO_2 (ppm), user feedback (Likert scale) per building.	Time-series JSON/CSV; numerical (float) for sensors, categorical (integer) for Likert scale.		Thermal Comfort
Climate	Model Coverage of Road Network in digital twin	Percentage of the roadway network (urban streets, highways, or other defined segments) that is actively monitored by the digital twin system for climate-related risks.	T2.4	[%]	Climate Risk	DTU	Coverage (%)=(Area Monitored Length/Total Road Length in Study)×100 First define the total road length within the study area. Next, identify the specific road segments that are actively monitored by the Digital Twin system(red or yellow colour). Finally, divide the total length of monitored segments by the total road length and multiply by 100 to obtain the coverage percentage. **Goal:** measure the extent to which the road network is digitally monitored for climate-related risks to improve climate resilience planning.	Road condition monitoring data, climate stress indicators(precipitation, rainfall, freeze-thaw cycles),GIS data,Digital Twin platform outputs	Numeric, time-series		Model Coverage of Road Network in digital twin
Climate	Pedestrian Wind Comfort	Annual Pedestrian Wind Comfort indicator represents a comprehensive year-round assessment of how wind patterns affect human experience throughout the site, using established standards like the Lawson Criteria. For this project the most suitable criteria is General Lawson.	T2.4	Wind Speed Threshold (m/s)	AIT Wind Comfort Model	AIT (DRC)	The results presented in 5 step scale by Frequency Threshold in percentage terms (%). The scale and ultimate out is as follows: comfort levels (A - sitting long, B - sitting short, C- walking leisurely, D - walking fast, E - uncomfortable). The calculation is as follows: (wind speed event) / (frequency of occurrence throughout the year).	Building geometry is sourced through open street map. Required input for the simulation is the location of the project (project site). For more detailed analysis position and size of trees can be added.	Currently output as GeoTIFF and imported into the digital twin platform of Aarhus		Pedestrian Wind Comfort
Mobility	Energy consumed by traffic	The sum of energy consumed by fossil-fuelled cars compared to the energy consumed by electric cars.	T2.3	[kWh]	Traffic Enviro Analyst/University of West Bohemia	UWB	distance travelled, combined with vehicle type, and a normalized energy consumption of the vehicle type	Energy consumed / Traffic flows on road segments, share of different propulsion types	JSON		Energy consumed by traffic
Mobility	Motorised GHG(CO2) emissions	A percentage difference in greenhouse gas emissions from the operation of cars and trucks based on a simulated scenario.	T2.3	[%]	Traffic Enviro Analyst/University of West Bohemia	UWB	CO2 emission estimated based on the energy consumed by traffic and the propulsion type (diesel/petrol/electric/other)	CO2 emissions / Traffic flows on road segments , share of different propulsion types	JSON, raster		Motorised GHG(CO2) emissions
Mobility	Traffic Flow and Congestion - Aarhus	This indicator measures the volume and movement of vehicles along transportation networks over a specific period.	T2.3	Vehicles per hour (veh/h)	RoadTwin SW/ Road Twin	RoadTwin	traffic flow (vehicle-based) on street segments/ intersection legs … aggregated to hourly volumes	Traffic flows on road segments, share of different propulsion types under a	JSON		Traffic Flow and Congestion - Aarhus

								defined scenario / Basic traffic model.			
Mobility	Traffic Flow and Congestion - Brabrand District	This indicator measures the volume and movement of vehicles along transportation networks over a specific period, combined with the duration and severity of traffic congestion.	T2.3	Vehicles per hour (veh/h)	microscopic traffic model	AIT	real time simulated traffic flow (vehicle-based) on street segments/ intersection legs … aggregated to hourly volumes	Traffic flows on road segments, share of different propulsion types, Origin-Destination Matrices from macroscopic model.	Traffic flows on road segments, share of different propulsion types		Traffic Flow and Congestion - Brabrand District