

Manual for the Standardized KPI Engine

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Abstract

ASCEND aims to accelerate the deployment of Positive Clean Energy Districts (PCEDs), starting with the demonstration of two PCEDs in the Lighthouse Cities (LHCs) Lyon and Munich and the subsequent bootstrapping the implementation of PCEDs in six Multiplier Cities. One of the main goals of ASCEND is to increase information transparency, accessibility and transferability among cities using a common set of Key Performance Indicators (KPIs) in the areas of building, mobility and district energy and emissions, social, governance and economic aspects and ICT processes.

The definition and calculation of KPIs in the mentioned areas are detailed in the Deliverable *D6.2 Monitoring and Evaluation Report & KPIs definition*.

The Deliverable *D6.3 Manual for the Standardized KPI Engine* at hand provides an in-depth description of the KPI Engine, the technical infrastructure that supports the loading and sharing of information on the calculated KPIs in ASCEND. The primary objectives of the KPI Engine are to minimize friction for cities and data providers when uploading data to the dashboard, ensure data quality and transparency, and effectively communicate KPIs to the audience and the relevant stakeholders.

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| PRAZSKA DEVELOPERSKA SPOLECNOST | CZ | PDS |
| BUDAPEST FOVAROS ONKORMANYZATA | HU | BUD |
| BKK BUDAPESTI KOZLEKEDESI KOZPONT ZARTKORUEN MUKODO RESZVENYTARSASAG | HU | BKK |
| ENERGY CITIES | BE | ENC |
| STOCKHOLMS STAD | SE | STK |
| AIT AUSTRIAN INSTITUTE OF TECHNOLOGY GMBH | AT | AIT |
| FUNDACION CARTIF | ES | CAR |
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| UNIVERSITY OF SAINT GALLEN | CH | USG |
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Abbreviations

| Acronym | Description |
|---------------|--|
| AEC | Architects, Engineers, Constructors |
| ASCEND | Accelerate poSitive Clean ENergy Districts |
| BIM | Building Information Modelling |
| CA | Consortium Agreement Data |
| DMP | Data Management Plan |
| DOI | Digital object identifier |
| DH | District Heating |
| DR | Demand response |
| EC | European Commission |
| EPC | Energy performance certificate |
| FAIR | Findable, Accessible, Interoperable and Reusable |
| GA | Grant Agreement |
| GDPR | General Data Protection Regulation |
| GHG | Green House Gas |
| HEU | Horizon Europe |
| ICT | Information and Communication Technology |
| IDs | Identifiers |
| KPI | Key Performance Indicator |
| IMEM | Integrated monitoring and evaluation methodology |
| IPR | Intellectual Property Rights |
| JSON | JavaScript Object Notation (data format) |
| JSON_LD | JSON for Linking Data (data format) |
| KISS | Keep it Simple and Silly |
| KPIs | Key Performance Indicators |
| LHCs | Lighthouse Cities |
| MCs | Multiplier Cities |
| M&E | Monitoring and Evaluation |
| NPV | Net Present Value |
| OpenAIRE | Pan-European open and sustainable scholarly communication infrastructure harvesting research output from connected data providers (https://www.openaire.eu/). |
| OUP | Open Urban Pulse |
| OTC | Open Telekom Cloud |
| ORD | Open Research Data |
| PEDs | Positive Energy Districts |
| PCEDs | Positive Clean Energy Districts |
| PEBs | Positive Energy Buildings |
| PMP | Project Management Plan (D1.1) |
| RES | Renewable energy sources (supply) |
| SCM | Smart Cities Marketplace |
| SPs | Solution packages |
| SRT | Self-Reporting Tool |
| SWOT analysis | Strengths, Weaknesses, Opportunities, and Threats analysis |
| UDP | urban data platforms |
| URI | Uniform Resource Identifier |
| V2H | Vehicle-to-Home |
| WP | Work Package |



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Executive Summary

This Deliverable *D6.3 Manual for the Standardized KPI Engine* provides an overview of the development state and purpose of the ASCEND KPI Engine, which supports the development of Positive Clean Energy Districts (PCEDs) by providing the ICT infrastructure for gathering data to monitor and evaluate the performance of the PCEDs at the demonstration sites of the two Lighthouse Cities (LHCs) of Lyon and Munich. The KPI framework was established in the Deliverable *D6.2 Monitoring and Evaluation Report & KPIs definition*. The KPI Engine integrates diverse data sources and presents in visualizations, making them accessible to stakeholders such as city representatives, PCEDs' administrators, and other stakeholders of the ASCEND Project.

The ASCEND KPI Engine aims at providing evidence on the performance of the various solutions deployed in the demo districts of the LHCs. It is designed to facilitate urban and strategic district planning practices, helping cities address their specific challenges through data collection and analysis. Additionally, it promotes transparency among the cities involved in the project by sharing information and lessons learned.

The report outlines the current state of the ASCEND KPI Engine and highlights the need for further testing of the proposed back end and data flows. The architecture of the KPI Engine will be further developed through close cooperation with cities and project partners. This manual focuses on the functional components and technological approaches of the KPI Engine, leveraging technologies introduced by project partners, particularly the LHCs. It provides initial insights into the data provided by the LHCs and the technical requirements for integrating it into the KPI Engine. As the project is still in an early stage, this document can be considered as a living document that will evolve as the project advances.

Introduction

Following a co-creation process involving key city stakeholders of both LHCs, an integrated monitoring and evaluation methodology (IMEM) has been established as part of Work Package (WP) 6 to monitor and evaluate the performance of the implemented solutions in both PCED demo sites. An essential part of the concept is the monitoring of operational limits and conditions of the implemented solutions to achieve the envisioned PCEDs beside assessing their wider project impact in deploying PCEDs and supporting the long-term goal of LHCs and Multiplier Cities (MCs) towards climate neutrality.

The Integrated Monitoring and Evaluation Methodology (IMEM) concept established in ASCEND encompasses local monitoring infrastructure at the PCED demo sites, the automated data collection, transfer and processing and the subsequent calculation of the KPIs. The selected KPIs of the ASCEND project are detailed in the Deliverable *D6.2 Monitoring and Evaluation Report & KPIs definition* and cover eight dimensions around technical performance of the implemented energy solutions at building and district scale, beside mobility, Information & Communication Technology (ICT) infrastructure, social, economic, environmental and governance aspects. The derived KPIs allow to measure the progress, effectiveness, social impact/engagement, and economic feasibility of the 6 Solution Packages intended to achieve the status of a PCED and to allow for comparison among different sites. Further, the derived KPIs and their uniform calculation are suitable for wider replication of the aforementioned Solution Packages and to support the mid-term Europe-wide uptake of the tested solutions and the large-scale deployment of PCEDs for a mainstreamed, long-term sustainable city transformation, taking into account the specific framework conditions of each city.

A core part of the IMEM is the ICT infrastructure established in ASCEND and referred to as the “KPI Engine”, an IT system hosted by DKSR and designed to enable an automated and standardised process of data gathering, processing, analysis, and calculation of related KPIs and the subsequent reporting of the KPIs-based performance metrics results to the key stakeholders to enable informed decision-making.

Before elaborating on the specific features of the KPI Engine being implemented in ASCEND, a general methodology is presented according to which the project specific KPI Engine, and subsequently the required ICT infrastructure is derived.

Amid the ongoing digitalization in various domains, particularly within the realm of smart cities with their integrated physical and digital infrastructures and expected contribution to attain the aspired climate-neutral cities, various ICT infrastructures, such as data platforms, data management platforms and semantic data platform, need to exchange data to generate insights for the planning and replication of solutions. They are designed to handle the vast amounts of data generated across different domains and process them to produce meaningful information for data-driven decision-making. Data platforms are powerful tools providing a comprehensive, integrated digital environment for collecting, storing, managing, and analysing data from various sources including real monitoring data. They are equipped with additional functions for data cleaning, visualisation, and semantic integration to generate tangible information to serve different services and needs like KPIs for monitoring and impact assessment, energy demand forecasting, developing ML and supporting digital twins.

1. Review of existing ICT infrastructure for KPI-based monitoring of PCEDs

PCEDs are considered as key enabler in driving the urban clean energy transition and accelerating the transformation towards smart and climate neutral cities. ICT is pivotal in achieving these goals as it forms the backbone of smart city infrastructure and the effective operation of PCEDs. ICT enables the integration of various systems and services at city and district scales and thus enhances sustainability and optimizes resource usage. ICT penetrates the whole services and activities including among others energy management, smart transportation, monitoring of socio-economic and environmental performance, citizen engagement, etc. Consequently, ICT offers numerous opportunities to improve urban living where leveraging related technologies and data analytics helps cities to become more efficient, sustainable, and responsive to the needs of their residents. As of the White Paper of JPI-UE on “Reference Framework for Positive Energy Districts and Neighbourhoods”, ICT and data management are described as enablers to achieve PEDs’ objectives while stressing the need to follow the guiding principle of inclusiveness, quality of life, and social sustainability [1]. To this end, recent experiences show that not only technological innovation, but also social innovation is crucial for the offtake of PEDs projects [2].

PCEDs represent an innovative urban energy concept achieved by synchronizing multiple domains, including energy, urban planning, socio-economic, technological, financial, and regulatory aspects. In this context, ICT plays a crucial role in integrating various associated systems and infrastructures. It facilitates interactions between buildings, users, and neighbourhood energy systems, all while ensuring social, economic, and environmental sustainability.

Despite the recognized high benefits of ICT -particularly for smart city setting- there is no "silver bullet" ICT solution that fits all the requirements [3]. Several challenges and constraints remain including data privacy, interoperability among different systems and technologies, high initial investment costs and digital divides regarding access and benefits of the ICT between individuals, households, and services due to socio-economic and cultural barriers [4].

On the other hand, in the operational phase, buildings and build environments equipped with ICTs are now producing more data than ever before, resulting in vast amounts of data remaining unused [5]. Additionally, poor information exchange among architects, engineers, and constructors (AEC) leads to siloed data, an issue that Building Information Modelling (BIM) was originally planned to overcome [5], [6].

A key aspect in facilitating the implementation and deployment of integrated solutions for PCEDs is the extracting of solid data-driven information about their performance under real operation conditions, represented in so-called “demo sites of PCEDs.” In these demo sites – such as the planned PCEDs in Munich and Lyon under the ASCEND project – adequate ICT-based monitoring and evaluation infrastructure is established to collect, process, and visualize monitoring data and subsequently extract KPIs to evaluate the overall performance of the implemented solutions. Optimizing the energy performance to achieve a positive energy balance of the PCED is in focus covering efficient energy consumption, optimized utilization of local renewables and the assurance of the needed energy flexibility through demand-response, load shifting, energy storage, to name just a few.

The carefully derived KPIs provide valuable information to support a well-informed decision-making process regarding the implementation, optimized operation, and further deployment of PCEDs.

To enable the above process, a framework of right ICT infrastructure, referred to as the “KPI Engine”, needs to be established to manage the whole process of data gathering/crawling, analysing, and reporting on KPIs in a standardized, automated, and regular basis. Such KPI Engines are empowered with necessary software (back end) to access the data sources of the demo sites, e.g., local urban data platforms, which requires the technical and semantic standardization of KPI Engine communication interfaces. On the other hand, the KPI Engine is empowered with data management capabilities, referred to “dashboard”, to ensure high-quality data collection and the subsequent systematic data preparation covering data exploring, cleansing, blending, profiling and finalization for the KPIs calculation and visualization. Dashboards employ user-friendly visualization layers which is crucial for interpreting the data and guiding the decision-making process [7].

Adding additional features to the established KPI Engine like Linked Data technologies can significantly improve linking and querying data from different sources to help facilitating data integration, interoperability, and enhanced accessibility. This provides further improved decision-making basis and potentially open unexplored areas for applications and research.

Moreover, ontologies are preferred over other representations for their ability to easily grasp relations through logical representation [8]. An ontology-based approach uses ontologies to easily understand relations, with the semantic web providing a potential solution for interoperability [9], [10]. Further, ontologies are referred to as knowledge bases, facilitating the linkage between different data sources [10] and connecting ontologies to metadata [11].

The KPI Engine established in ASCEND focuses on the calculation of KPIs and their visual representation, and therefore does not include such an ontology mapping. However, the advanced integration of linked-data schemas and ontologies in the KPI Engine is recommended and the possibilities of their inclusion will be explored throughout the project. The following section outlines a potential workflow to integrate ontologies into the KPI Engine framework.

A high-level representation is provided in [10], illustrating the processes employed in a KPI engine. The process begins with defining the desired KPIs, which then inform the development of the ontology. To prepare for this development, however, it is essential to analyse the information demand, which includes identifying, localizing, and characterizing the necessary data. The ontology is then utilized to represent the relationships between this information. For developing the ontology, it is advantageous to use existing ontologies and adapt them as necessary.

The prepared data and the calculated KPIs are then used for the graphical representation of the KPIs. Depending on the specific KPI, the formula is identified using the ontology, according to which the relevant data is also identified and the KPI calculated and returned to the relevant stakeholder.

Urban data platforms store a multitude of data, and in the operational phase, buildings are generating more data than ever before [5], necessitating the extraction of only relevant data [9]. The Semantic Energy Information Framework aids in data retrieval from diverse sources with different structures, ensuring interoperability and structuring data through categorization and scale identification [5]. (Corrado et al., 2015).

Showcasing these interdependencies and relationships among stakeholders is crucial [11], and data should be shared to ensure effective collaboration [9] and data exploitation. Additionally, providing

relevant stakeholders with focused and relevant information is vital [6]. Dashboards are valuable tools for graphically presenting data and supporting decision-making, facilitated by a KPI Engine with the described functionalities [5].

2. KPI Engine requirements

2.1. KPI Engine Definition

The KPI Engine includes the infrastructure to receive and process the monitoring data from the LHCs (covering both dynamic and static data), assess data validity, make any necessary transformations in order to compute the project-level KPIs, and visualize them in dashboard(s) as illustrated in Figure 1. It constitutes the central ICT infrastructure for crawling data from the local urban data platforms deployed in the LHCs, and act as the focal point for monitoring the performance of both demo districts towards PCED throughout the lifespan of ASCEND.

At an early stage in the ASCEND project, it was envisioned that the KPI Engine would connect to the raw data sources. However, based on talks held with the lighthouse cities, this will not be the case due to domestic data privacy regulations in some cases. It has been agreed that the data will instead be accessed and processed by Lighthouse Cities in their local platforms and made accessible to the KPI Engine via an API. The diagram below shows the (high-level) scheme of the KPI Engine. For more details, see the sections below.

The 38 core KPIs included in the KPI Engine cover building, mobility, district energy and emissions, as well as economic and financial aspect, social engagement, governance, and technical implementation of the project. These 38 indicators follow the KPI framework of the ASCEND project established in the Deliverable *D6.2 Monitoring and Evaluation Report & KPIs definition*.

The development of the KPI Engine is happening in parallel to the set-up of city-APIs. It is important that at the time of preparation of this manual, information is yet to be made available on the specific APIs; however, it has been agreed that the building scale KPIs will be used to test data workflows. The automated ingestion of data via the city-API is only expected to start in the beginning of 2025. Until then, data ingestion will temporarily occur via manual file transfer.

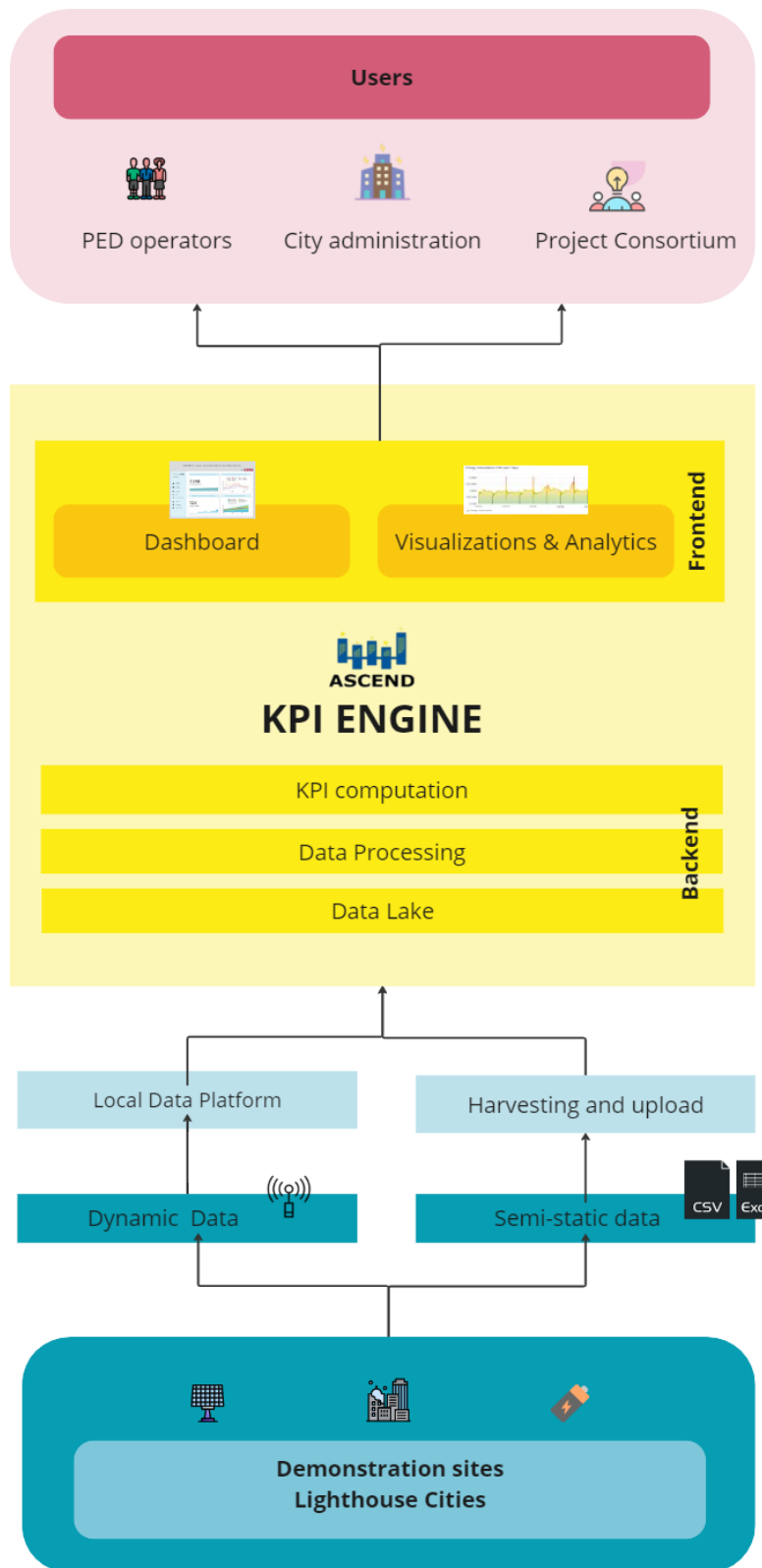


Figure 1: KPI Engine Scheme

2.2. The KPI Logic

There is a logical order by which the ASCEND KPIs feed into each other as depicted in Figure 2 below. At the lowest level (building and mobility), collected technical and social monitoring data are incorporated to calculate the energy demand of building and mobility. Monitoring data of energy supply (including local renewable energy generation) is evaluated to establish the building energy balance. Social monitoring data are integrated in the calculation of building and mobility energy demand and supply. Aggregating the energy demand and supply of all buildings and mobility solutions provides the district energy demand and supply, as well as the related energy balance for different time periods, considering monitoring data related to existing flexibilization options at the district scale.

The energy-related emission of the district is then calculated based on the district annual energy balance. The economic KPIs are calculated using economic data on the implemented solutions at the district scale, annual energy saving, CO₂ reduction, and additional supplementary information from the technology providers.

The generated KPIs across social, economic, and environmental dimensions are used to evaluate the sustainability of the implemented demo PCEDs in both LHCs, where assessing cost-effectiveness of the achieved energy and emission reduction measures is essential.

The social and governance KPIs are calculated based on data provided by the cities, and the ICT KPIs are monitored at a project level.

In practice, chaining the calculations is challenging, since downstream KPIs require complete inputs from upstream KPIs. In cases such as district energy demand, where it is possible to directly obtain data from energy providers, this will be directly used as the input to the KPI. In such cases, the directly obtained district energy demand can be used to validate the sum of building energy demand within the district.

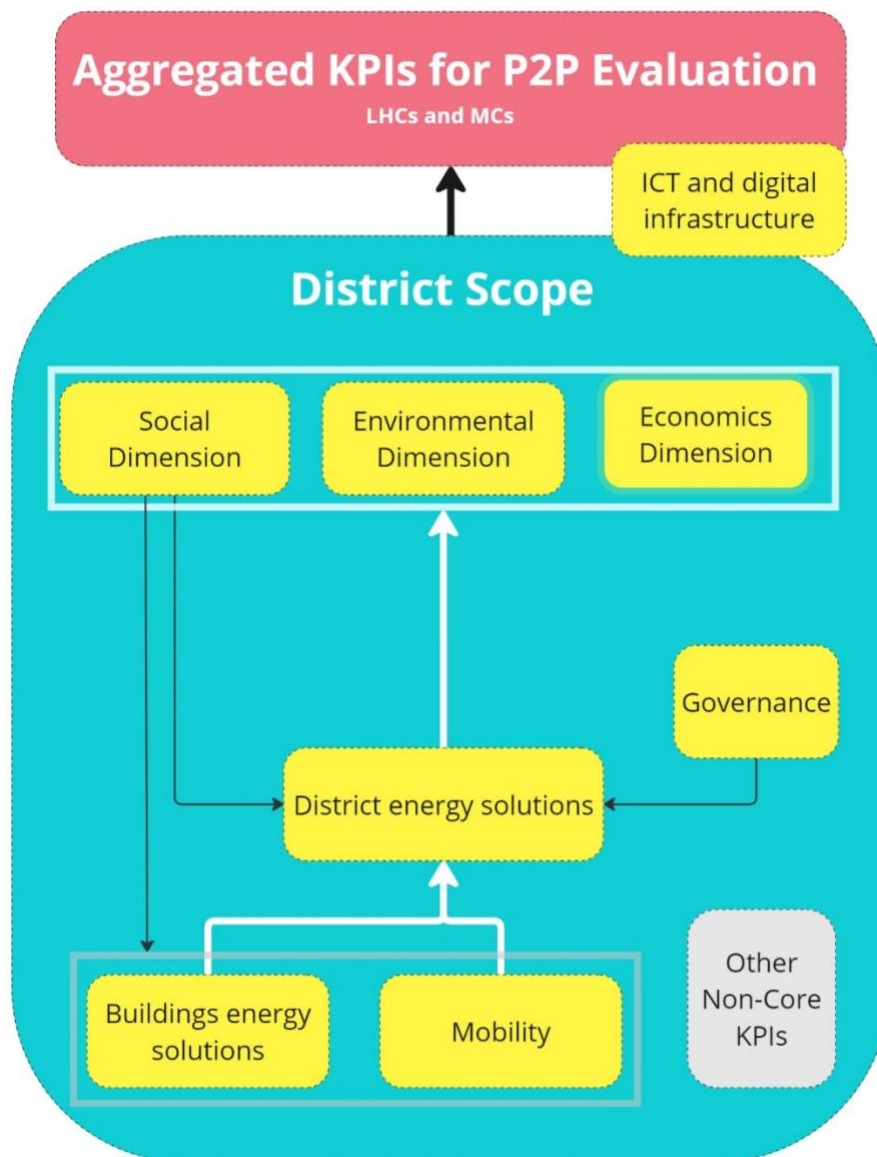


Figure 2: Workflow of KPIs calculation and interaction between the different groups of KPIs.

The data sources required for KPIs calculation can be functionally distinguished as follows:

- ❖ **City Data** is the data collected and available from the different cities. They may be related to core or optional KPIs. They are characterized by different formats and styles, collection methods, and periods. They can have different characteristics that are not present in other cities' data sets. They also may be ingested or collected into the KPI Engine in different ways.
- ❖ **Solution Provider Data** are data created and used by the procured solutions. They can be used to measure some KPIs and then evaluate and assess the impact of these solutions on the city. Since this is handled by the Cities, no handling or storage of these data by the KPI Engine is foreseen.
- ❖ **Additional (Open) Data Sources:** Typically, these data show some level of similarity between cities, but they need to be aligned and harmonized to be comparable and compatible. Another additional data source can be climate-related sources such as Copernicus.

Data frequency can either be real-time or historic:

- ❖ **Real-time data** are collected for real time measures of entities or events in the city (e.g., building or district energy consumption, live traffic counts, and so on). In most cases, real-time data is provided by sensor systems or IoT devices. They are characterized by different formats and specifications, different time availability, and different ownership. While real-time capabilities may be built into the KPI Engine, no use case has been identified so far within the current set of KPIs with this requirement. Most real-time data will be processed by the cities and provided to the KPI Engine in an aggregated form.
- ❖ **Historic data** are static data, which will be collected only once or in long intervals. This type of data may come from various sources. It can be statistical data, geographical information, plans or maps. It is expected that a large amount of the data ingested by the KPI Engine will be historical. It will be provided by solution providers, cities and additional data sources.

2.3. Frontend Requirements

The Frontend of the KPI Engine will be developed based on the outcomes and requirements listed in the Table 1 below.

Table 1: Specification of the requirements considered in the development of the frontend of the KPI Engine.

| Feature/Outcome | Visual Requirements |
|---|---|
| <p>Show the impact of various investments against Core KPIs throughout the project</p> | <ul style="list-style-type: none"> ❖ Provide appealing and clear visual reporting of the core and where applicable optional KPIs. ❖ Use appropriate maps and graphs to break down district energy demand, emissions, return on investment and social impact as specified in the KPIs. ❖ Include adequate descriptions and project timelines to complement the graphics. |
| <p>Be transparent about data completeness and quality</p> | <ul style="list-style-type: none"> ❖ Differentiate between different data streams flowing into the same KPI. For example, for the building-energy-related KPIs, data from simulations, smart meters or energy performance certificates are accepted as sources. These should be clearly distinguishable if plotted on the same graph. ❖ Show blank data, create room for comments and descriptions of the challenges. ❖ Include sufficient explanation to the different data streams. This needs to be provided as metadata with each data stream. |

| | |
|---|--|
| Balance elements of competition and collaboration | <ul style="list-style-type: none"> ❖ Enable direct comparison between cities. ❖ Show ASCEND-level KPIs which aggregate the performance of the various cities, designed to encourage collaboration and onboarding of more cities. |
| Allow lighthouse cities to share their journey towards achieving a PCED. | <ul style="list-style-type: none"> ❖ City-specific dashboards pages, showing progress on all or individual KPIs for the selected city. ❖ Differentiate between Lighthouse Cities and Multiplier Cities in the visualizations. |

2.4. Backend Requirements

Table 2 below depicts an extensive list of requirements needed to cover two cases listed below on the backend development of the KPI Engine. Some of the processes are elaborated further in section 6.

- ❖ Case 1: Cities manage negotiation with service providers, data collection, aggregation, modelling and KPI calculation in-house. The results and metadata are made available via API to the KPI Engine. This is the case for both LHCs.
- ❖ Case 2: Cities negotiate with data providers but do not handle the data. In this case, the processing and KPIs calculation is also done by the KPI Engine. These additional steps are marked with a * and may be developed for MCs as needed.
- ❖ Case 3: PCEDs are still in planning stage during most of the ASCEND monitoring period. The only information that can be displayed in this case would be simulation results based on modelling the energy performance of the planned PCED. The details of how this is executed will need to be discussed with the planning team.

Table 2: Specification of the requirements considered in the development of the backend of KPI Engine.

| Outcome | Requirement |
|---|---|
| Connect to smart meters in buildings* | Set up Open Urban Pulse (OUP) Connector to the data sources. The data gets stored in a data lake. |
| Clean, resample and aggregate data* | Collect data from OUP data lake, build and run the necessary pipelines for cleaning, resampling, aggregating, etc. |
| Ingest structured data (e.g., csv files)* | Establish which data types will be used, how they will be uploaded, and the frequency at which they will be uploaded. |
| Ingest semi/unstructured data (eg. Images, Pdf files)* | In addition to the above, identify which libraries or additional steps are necessary to process each filetype. |
| Recalculate KPIs according to the ASCEND Framework at regular intervals* | Translate the KPI calculation logic into code, orchestrate regular calculations. |
| Load district characteristics (building IDs, location, map, etc.) | This is done once per district/City, so initially there will be no need to automate this step. |

| | |
|--|---|
| Fetch processed data from city-APIs at regular intervals | Schedule regular API Calls with Apache Airflow. Run data validation checks as part of the retrieval process. |
| Merge with existing data | Check the fetched data, check the timestamps against existing data and merge. |
| Calculate any remaining District-Scope KPIs* | This may be the case for social, governance or financial KPIs which fall out of scope of the city analytics platforms. In these cases, we need to provide means of ingesting the data, build pipelines to clean and process the data and calculate the KPIs on a regular basis. |
| Calculate Ascend-scope KPIs | Combine a relevant subset of ASCEND KPIs from all cities in a way that shows the total impact of ASCEND while allowing direct comparison between cities for each KPI. |
| Store structured data in a database which is accessible by Superset | Data to be stored in Postgres databases in an Apache Superset-ingestible format. |

3. KPI Engine Architecture

The KPI Engine includes a data processing back end and a front end. The latter will be built in Apache Superset, an open-source software application for data exploration and data visualization, which is not described in detail in this document. The back end is described in further detail in this section.

The core function of the back end is to regularly fetch data (KPIs, metadata, calculation values) from cities via API calls, ensure quality and consistency, make additional calculations such as project-level KPIs and publish to a database which is accessed by the front end.

3.1. KPI Engine Communication Interfaces

The technical and semantic specifications of the KPI Engine architecture is illustrated in Figure 3. The core coordination and orchestration tasks will be performed using Apache Airflow, an open-source workflow management platform. This ensures reliability and consistency in the different KPI computations, which may require data from various sources (City-APIs, data lake or if needed also third-party sources directly) to compute the KPIs.

The KPIs will be stored based on the logic of the FIWARE data scheme, but no technological model like the FIWARE data broker will be used. Finally, the calculated KPIs will be saved to a Postgres database which will be accessed by Apache Superset for dashboard creation.

The KPI data, computations and front-end will be hosted by DKSR. However, details such as domain name or whether this will be embedded inside an official ASCEND page still need to be defined at time of writing.

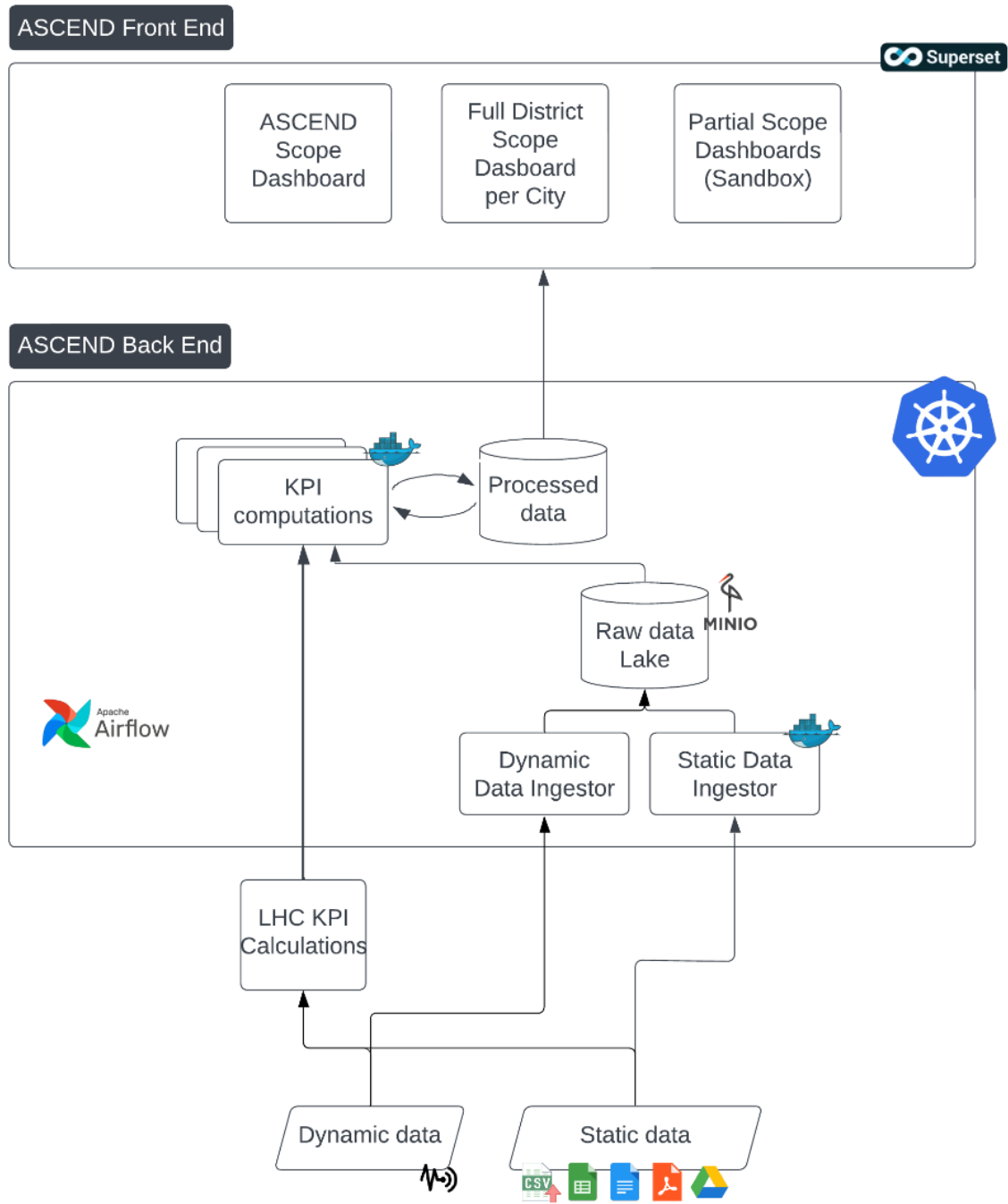


Figure 3: A schematic of the KPI Engine architecture.

3.3. Data Standardization

Each KPI involves several intermediate calculation steps and tens of variables which need to be consistent across all cities. This is being done in close collaboration with the LHCs who are developing their calculation pipelines concurrent to the KPI Engine development. A set of variable IDs proposed by Munich will be tested during the first phase of implementation, which will focus on D1 (Building Energy), D2 (PCED Energy) and D5 (District Emissions). In total, these three topics include 14 KPIs and 102 variables. The following section offers a more detailed description of the D1 (Building Energy) KPI group. This group has been selected to illustrate and demonstrate the functionality of the KPI Engine, as building energy data will be the first data sets that cities submit to the KPI system.

The definition of a building within the context of D1 varies depending on whether the thermal envelope, ownership or address is considered the defining factor. This decision is left to the discretion of the cities, who will provide the building ID and corresponding geometry.

D1 – Sustainable and Smart Solutions at Building Scale

The data required for the building scale KPIs are heterogenous and incomplete due to limited availability of locally installed meters (e.g., smart meters), third party data contractors, multiple ownership models, privacy concerns, and different data suppliers. A minority of municipality-owned buildings in each district with smart meters will have the richest information and real monitoring data, while most will be privately owned and have little to no information. Similarly, the local renewable energy production -like installed PV systems- can be calculated based on the known capacity and average operation parameters, but in most cases, it will not be possible to monitor the live production. Cities cannot release occupancy data if it can be reverse engineered to reveal household size. At district scale, grid operators will most likely provide the total aggregated district energy consumption from substations. The reporting interval is country-specific and subject to negotiations.

The above are just examples of the challenges which complicate data collection for the Building level KPI dimension. Building scale energy demand and consumption will be collected or calculated based on the data available for each building. In the case of Munich, the energy demand for buildings where no meter data is available will be simulated using an **urban city model**. Nine variables have been created to represent possible sources of energy demand/consumption information at building scale.

4. KPI Engine processes

The KPI Engine applied in ASCEND involves a series of steps designed to manage the entire process of monitoring and evaluation and KPI-based impact assessment of the solutions implemented in both LHCs.

As detailed below, the KPI Engine is equipped with robust data management capabilities to ensure high-quality data collection and systematic data preparation, including data exploration, cleansing, blending, and profiling. The final step deals with KPIs' calculation, visualization, and subsequent analysis to gain insights into performance trends and patterns as a basis for KPI-based impact assessment. Additionally, the KPI Engine is enabled with automatic alerts and notifications to report errors, diagnostics, and debugging actions throughout the entire chain of data collection and transmission. This ensures effective tracking and facilitates the development of plans to mitigate faults and failures.

4.1. Data Management capabilities

To exemplify how the KPI Engine handles data coming in different formats from various sources, the following sections describe the technical process for data collection, ingestion, and processing, up to the KPI computation. Some likely and less likely scenarios are described as follow.

Most Likely Scenario:

- ❖ **Fetch Precomputed KPIs from the City API Endpoint**
Solution providers directly compute KPIs/PIs/indicators and interact with the Analytics-Engine ingestion to upload the values via REST-API. The Analytics-Engine validates and persists this data. The values, along with relevant metadata, are then accurately reflected in the front end.
- ❖ **Manual Upload: Upload by City**
City Managers manually update the KPIs/PIs/indicators. For example, “number of citizens involved in the project” every two months using an online interface. This data is collected through a Google Sheet or Form. Upon each update, the file is uploaded to the Data Lake, and the Analytics-Engine is notified. The KPI Engine then processes the new data, computes the defined KPIs/PIs/indicators, and sends the result to Apache Superset for visualization via Postgres, along with relevant metadata (e.g., city, project).
- ❖ **Manual Upload: Upload of Geodata by City**
City Managers manually update contextual information such as building geometry in geojson format. The file is uploaded to the Data Lake via a web interface (this could initially be implemented as a Google Drive folder). The Analytics-Engine validates the geojson format and ingests the data. The engine then computes the relevant KPIs and sends the results, along with metadata (e.g., city, neighbourhood), to the front end.
- ❖ **Automatic Consumption from Third Party System**
The KPI Engine ingestion module automatically consumes data from a solution provider's app servers via an API monthly. The KPI Engine processes this data as needed (e.g., “Heating Degree Days per month”). The results, including relevant metadata (e.g., city, app version), are passed on to subsequent calculation stages and saved in a database which is accessed by the front end.

Less Likely Scenarios:

- ❖ **Automatic Consumption & Complex Computation of Third-Party Data**
The Analytics-Engine is configured to run a data pipeline that ingests and processes the data monthly (this could be implemented using Apache Airflow). If required, the raw data (e.g., from Sentinel and/or Copernicus) is stored in the Data Lake. The Analytics-Engine uses ML/AI tools to analyse the satellite images and compute the defined KPIs/PIs/indicators. The computed KPIs/PIs/indicators, along with metadata (e.g., city), is then sent to the front end.
- ❖ **High-Frequent Consumption of Third-Party Data**
A connector of the DKSR OUP is provided to the Third party to upload the data at the defined intervals. The DKSR OUP stores this data and makes it available to the Analytics-Engine. It is configured to run a data pipeline when new data is made available (again, here Apache Airflow could be used). The data is consumed from the DKSR OUP Outbound module and processed by the Analytics-Engine to compute the relevant KPIs, and the results, along with metadata (e.g., city, sensor location), are sent to the front end for real-time visualization.

4.2. Data collection

Based on the established monitoring infrastructure at the demo PCEDs, data will be collected beside additional data sources. Data will be fetched from the Lighthouse Cities via an API endpoint, although manual file transfer will be used as an interim solution until the API is set up. Additional ingestion methods (forms, manual transfer, email, etc.) will be explored on a case-by-case basis, particularly for the Multiplier Cities that will work in a special testing setting called “Sandbox” to pilot the KPI Engine functionalities and learn about data-driven monitoring and planning for PCED.

4.3. Data Preparation

Every data fetched from City APIs will be checked, transformed, and merged into the database feeding the frontend. Examples of these checks are listed below. This list will be updated as the project evolves.

- ❖ Check that the variable names received match the expected variable names.
- ❖ Check for new or missing buildings.
- ❖ Check that the date/time matches what is expected.
- ❖ Check for missing critical values.
- ❖ Check that values are within a valid range.
- ❖ If the input variables are provided, run the KPI calculation and check against the provided values.

Following the cleaning, the project-level KPIs and any other datasets (e.g., Comparison of single KPI across cities) will be computed and exposed to the front end.

4.4. Operations

The update frequency for most D1 (Building Energy), D2 (PCED Energy) and D5 (District Emissions) KPIs is expected to be monthly. Initially this will also be the rate at which it is fetched by the KPI engine. Event-driven updates can be implemented if necessary. In most cases, sensitive data will be handled by Cities and will not be available to the KPI Engine. Exceptions will be handled on a case-by-case basis.

4.5. Alerts and Notifications

Appropriate warnings will be set up to notify the relevant people about any issues that may arise, such as incorrect data entry, missing data, anomalies, or unusual values. Frequent issues will be tracked and used to drive updates to the design or processes involved.

5. Conclusion

D6.3 provides the manual of the KPI Engine that will serve as the central tool in the integrated monitoring and evaluation process established in ASCEND. D6.3 is a living document that will be updated throughout the project's duration. This approach allows for the necessary flexibility to adapt and evolve as Cities navigate the challenges of data collection and privacy constraints, while providing rapid feedback loops and enabling them to meet their reporting commitments effectively.

The KPI Engine is being developed within ASCEND in cooperation with both LHCs. This manual has been written at an intermediate stage of the project, where LHCs are still assessing data availability and collection strategies. The documentation presented in this report reflects regular ongoing discussions with LHCs and within the Community of Practice.

Given the broad scope of the KPIs, the first implementation of the KPI Engine will focus on D1, D2 and D5 (Building, District and Environmental dimensions, respectively), with the other dimensions to follow. The development of the KPI Engine is synchronized with the information and infrastructure rollout timeline provided by the LHCs to ensure optimal process alignment while meeting project requirements.

The processes described in this manual reflect the realities of data collection: negotiations with utilities and property owners are ongoing to acquire data in the required resolution. Sensitive data owned by the Cities are handled, processed and made available to the KPI Engine at regular intervals. In the case of Munich, missing data will also be replaced with simulation results from a digital energy twin. The information sources will be transparently documented in the dashboard.

ASCEND has established the KPI calculation and monitoring workflow to evaluate and visualize the performance of the implemented solutions. This will facilitate further reporting and provide actionable insights for future urban decarbonization projects.

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7. Annexes

Variable IDs

The 31 core KPIs detailed in the Deliverable *D6.2 Monitoring and Evaluation Report & KPIs definition* have been assigned unique IDs¹ as highlighted below with coloured background below. The same applies for the variables used in their calculation that also are assigned unique IDs as listed in the table below, which should be adhered to by all cities using the KPI framework, ensuring data consistency across the different cities.

This table will be updated in the course of the project.

| ID | Name |
|------------|---|
| D1EBC1 | Building Energy Demand and Consumption |
| D1EBC1_01 | Floor area of the building |
| D1EBC1_02 | Heating degree days (NFwt) |
| D1EBC1_03 | Cooling degree Days (NFwt) |
| D1EBC1_04 | Average residents number (Durchschnittliche Bewohner:innen (NFoc) |
| D1EBC1_05 | Number of residents (Bewohner:innen) |
| D1EBC1_06 | Heat Consumption (monitored) |
| D1EBC1_07 | Heat Consumption (Jahresabrechnung MW) |
| D1EBC1_08 | Heat Consumption (SWM/Modell München) |
| D1EBC1_09 | Heat Demand (energy performance certificate/ Energieausweis) |
| D1EBC1_10a | Heat Demand (KPI Engine TUM) - DIN |
| D1EBC1_10b | Heat Demand (KPI Engine TUM) - mit Lastprofil (wetterbeding/Heizperioden?) |
| D1EBC1_11 | Heat Demand (berechnet ENP/MünchenModell) |
| D1EBC1_12 | Electricity Consumption (SWM) |
| D1EBC1_13 | Electricity Demand (load curves/Standardlastprofile) |
| D1EBC1_15 | Household number (Anzahl der Haushalte) |
| D1EBC2 | On-site installed RE capacity for building power and heat supply |
| D1EBC2_01 | Installed power PV |
| D1EBC3 | On-site renewable power and heat production (measured) |
| D1EBC3_00 | Production of electricity |
| D1EBC3_01 | Production of electricity (own consumption) |
| D1EBC3_03 | Production of electricity PV (grid feed-in) |
| D1EBC4 | Annual building energy balance (demand-supply balance) |
| D1EBC4_01 | Production (district heating) |
| D1EBC4_02 | Energy consumption gas, oil, dh |
| D1EBC4_03c | Electricity demand-supply balance (15 min Intervals = Difference of Production and Consumption (based on load curves) |
| D1EBC4_03a | Production of electricity (own consumption) = D1EBC1_13 from load curves |

¹ IDs are defined according to the following Naming convention: Dimension, Number, Name, Core/OPTional, sequential numbering! e.g. D1EBC1: Dimension1, Energy of building, Core, first. Additional first letter of LHCs might be added later, i.e. L or M

| | |
|---------------|--|
| D1EBC4_03b | Production of electricity (von oben!) see D1EBC3_00 |
| D1EBC4_04 | Final energy consumption electricity (grid-related) |
| D1EBC4_05 | Production of electricity PV (grid feed-in) |
| D2EDC1 | PCED annual final energy demand/consumption (measured) |
| D2EDC1_01 | Sum heat consumption (monitored) |
| D2EDC1_02 | Sum heat consumption (Jahresabrechnung MW) |
| D2EDC1_03 | Sum heat Consumption (SWM/Modell München) |
| D2EDC1_04 | Sum heat Demand (Energieausweise) |
| D2EDC1_05 | Sum heat Demand (KPI Engine TUM) |
| D2EDC1_06 | Sum heat Demand (berechnet ENP) |
| D2EDC1_07 | Sum Electricity Consumption (SWM) |
| D2EDC1_08 | Sum Electricity Demand (load curves, Standardlastprofile) |
| D2EDC1_09 | Number of buildings |
| D2EDC1_11 | Sum Energy consumption Mobility (Gas, Diesel) |
| D2EDC1_11_01 | Traffic volume for cars and SV |
| D2EDC1_11_02 | Road length |
| D2EDC1_11_03 | Energy content for cars and SV (heavy goods vehicles) |
| D2EDC2 | Total final energy savings of the PED |
| D2EDC2_01 | Sum of monitored energy consumption in energy consumption in building sector across all energy carriers in the baseline situation (reference). |
| D2EDC2_02 | Sum of modelled energy consumption in energy consumption in building sector across all energy carriers in the baseline situation (reference). |
| D2EDC2_03 | Sum of monitored energy consumption in building sector after the interventions |
| D2EDC2_04 | Sum of modelled energy consumption in building sector after the interventions |
| D2EDC3 | Total installed RE capacity for the district power and heat supply |
| D2EDC3_02 | Installed power PV |
| D2EDC4 | Total RE production of the district (for power and heat supply) |
| D1EBC3_01 | Production of electricity (own consumption) |
| D1EBC3_03 | Production of electricity PV (grid feed-in) |
| D2EDC5 | Smart energy storage capacity |
| D2EDC5_01 | Cumulative added stationary electric battery energy storage capacity in the district |
| D2EDC5_02 | Cumulative battery electric vehicle (BEV) capacity with V2G capability in the district (estimation) |
| D2EDC5_03 | Cumulative added thermal storage capacities |
| D2EDC6 | Annual energy demand-supply balance of the PED |
| D2EDC6_01 | Sum Production (district heating) |
| D2EDC6_02 | Sum Energy consumption gas, oil, dh |
| D2EDC6_03 | Sum Production of electricity (own consumption) |
| D2EDC6_04 | Sum Production of electricity PV (grid feed-in) |
| D2EDC6_05 | Sum Final energy consumption electricity (grid-related) |
| D2EDC6_06 | Sum Energy consumption Mobility (gas, Diesel) |
| D1EDC7 | Self-supply-ratio (SSR) |
| D1EDC7_01 | Sum Production (district heating) |
| D1EDC7_02 | Sum Energy consumption gas, oil, dh |
| D1EDC7_03 | Sum Production of electricity (own consumption) |
| D1EDC7_04 | Sum Production of electricity PV (grid feed-in) |
| D1EDC7_05 | Sum Final energy consumption electricity (grid-related) |
| D1EDC7_06 | Sum Energy consumption Mobility (gas, Diesel) |
| D3MBC1 | Change towards sustainable and clean modal split |

| | |
|----------------|--|
| D3MBC1_01 | Person kilometres (pkm) travelled per mode by respondent n collected in survey on workday. |
| D3MBC1_02 | Person kilometres travelled per mode by population. |
| D3MBC1_03 | Population per age group collected in area. |
| D3MBC1_04 | Set of respondents in age group in survey |
| D3MBC1_05 | Change of Pkm in mode in % |
| D3MBC2 | Number of electric vehicles (EVs) deployed |
| D3MBC2_01 | Number of electric vehicles (EVs) deployed |
| D3MBC3 | Number and type of EV-charging stations deployed in the PCED area. |
| D3MBC3_01 | Number of total e-charging stations deployed |
| D3MBC3_02 | Number of bidirectional e-charging stations deployed |
| D3MBC3_03 | share of e-charging stations with bidirectional features (V2G) |
| D3MBC4 | Electricity supplied to EV charging |
| D3MBC4_01 | Electricity consumption by all charging stations in the district |
| D3MBC4_02 | Number of total e-charging stations deployed. |
| D3MBC5 | Energy savings by mobility measures |
| D3MBC5_01 | Total energy consumption mobility (ref) |
| D3MBC5_02 | Total energy consumption mobility (after) |
| D4ICTC1 | Datasets in joint repository |
| D4ICTC1_01 | Number of data points (Anzahl der Datenpunkte) |
| D4ICTC2 | Number of standardized REST APIs |
| D4ICTC2_01 | Number of data points (Anzahl der Datenpunkte (standardisiert)) |
| D4ICTC3 | Share of buildings in the district with smart energy meters |
| D4ICTC3_01 | Total number of buildings in the district |
| D4ICTC3_02 | Number of buildings equipped with smart meters in the PED |
| D4ICTC3_03 | Share of buildings equipped with smart meters within the PED |
| D5ENVC1 | District annual GHG emissions |
| D5ENVC1_01 | Buildings final energy consumption (thermal) |
| D5ENVC1_02 | Buildings final energy consumption (electricity) |
| D5ENVC1_03 | Sum Electricity consumption Mobility |
| D5ENVC1_04 | Sum energy consumption Streetlighting |
| D5ENVC1_05 | Emission factor, gas |
| D5ENVC1_06 | Emission factor, district heating |
| D5ENVC1_07 | Emission factor, electricity supply mix |
| D5ENVC1_08 | Emission factor, fuel oil |
| D5ENVC2 | Annual CO₂- emissions reduction by type of measures implemented |
| D5ENVC2_01 | Buildings final energy consumption (thermal) (before interventions) |
| D5ENVC2_02 | Buildings final energy consumption (electricity) (before interventions) |
| D5ENVC2_03 | Sum Electricity consumption Mobility (before interventions) |
| D5ENVC2_04 | Sum energy consumption Streetlighting (before interventions) |
| D5ENVC2_05 | Buildings final energy consumption (thermal) (after interventions) |
| D5ENVC2_06 | Buildings final energy consumption (electricity) (after interventions) |
| D5ENVC2_07 | Sum Electricity consumption Mobility (after interventions) |
| D5ENVC2_08 | Sum energy consumption Streetlighting (after interventions) |
| D5ENVC2_09 | Emission factor, gas |
| D5ENVC2_10 | Emission factor, district heating |
| D5ENVC2_11 | Emission factor, electricity supply mix |
| D5ENVC2_12 | Emission factor, fuel oil |
| D6SOCC1 | Residents engaged |
| D6SOCC1_01 | Number of individual feedback received within citizen engagement surveys |

| | |
|----------------|--|
| D6SOCC1_02 | Total number of residents living in the PCED during the respective survey year |
| D6SOCC2 | Number of energy communities deployed |
| D6SOCC2_1 | Number energy communities deployed within the PCED |
| D6SOCC3 | Degree of satisfaction with the solutions implemented |
| D6SOCC3_01 | Qualitative answers on degree of satisfaction of individual feedback received within stakeholders' surveys |
| D7ECC1 | Total investment in all new interventions of the PCED |
| D7ECC1_01 | sum of investment related to all energy solutions. |
| D7ECC1_02 | sum of investment related to construction solutions (building, infrastructure). |
| D7ECC1_03 | sum of investment related to mobility solutions. |
| D7ECC1_04 | sum of investment related to ICT solutions. |
| D7ECC1_05 | total floor area of the considered building or building cluster under consideration. |
| D7ECC2 | Total amount of (non-public) investment attracted |
| D7ECC2_01 | Financial reports on implemented solutions |
| D7ECC3 | NPV, PBT, IRR |
| D7ECC3_01 | Initial investment cost |
| D7ECC3_02 | number of periods |
| D7ECC3_03 | technical lifetime of the solution (e.g., 10, 20, 30). |
| D7ECC3_04 | Discount rate |
| D7ECC3_05 | net cash inflow |
| D7ECC3_06 | net cash outflows during a single period t |
| D7ECC4 | Economic value of saved energy and reduced CO2-emission |
| D7ECC4_01 | discounted annual capital investment cost |
| D7ECC4_02 | number of periods (plant lifetime) |
| D7ECC4_03 | Initial investment cost |
| D7ECC4_04 | discount rate |
| D7ECC4_05 | energy consumption before the intervention |
| D7ECC4_06 | energy consumption after the intervention |
| D7ECC4_07 | CO2-emission before the intervention |
| D7ECC4_08 | CO2-emission after the intervention |
| D7ECC4_09 | annual energy saving |
| D7ECC4_10 | annual CO2-emission reduction |
| D7ECC4_11 | Value of energy saving |
| D7ECC4_12 | Value of CO2-emission reduction |
| D7ECC5 | District climate (carbon) dividend |
| D7ECC5_01 | Avoided annual CO2 emissions triggered by the project over all interventions |
| D7ECC5_02 | Applicable CO2 prices (national/EU carbon tax, ETS etc.) |
| D7ECC5_03 | annual carbon dividend |
| D8GVC1 | Number of Key Stakeholders involved |
| D8GVC1_01 | Documentation on solution and project development and implementation |
| D8GVC2 | Evaluation of the level of local authority involvement. |
| D8GVC2_01 | Documentation on solution and project development and implementation |



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