ASCEND

Monitoring and Evaluation Report and KPIs definition

Deliverable 6.2

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Abstract

ASCEND aims to accelerate the deployment of Positive Clean Energy Districts (PCEDs) by demonstrating two of them in the Lighthouse Cities (LHCs) Lyon and Munich, besides, bootstrapping the implementation of PCEDs in six multiplier cities.

The Deliverable D6.2 elaborates on the comprehensive set of KPIs established within ASCEND to monitor and evaluate the performance of the implemented solutions and assess their sustainable impact within the demo PCEDs in the LHCs. Following an intensive co-creation process with the LHCs, an extensive list of 88 KPIs has been defined around eight dimensions covering energy performance at building and district scale, urban mobility, ICT, environmental, socio-economic, and governance aspects. The outlined KPIs distinguish between "Core KPIs" and "Optional KPIs".
The first group consists of **30 Core KPIs** that are essential to monitor and evaluate the performance of the demo PCEDs and thus will be calculated for both LHCs. However, the optional KPIs, derived to expand the scientific scope of the monitoring process and to provide a deeper understanding of the performance of PCEDs, prove to be a major challenge for the LHCs from a data collection perspective. Their calculation is optional, subjected to data availability on the demo PCEDs, which can only be decided during the course of the project. Each of the Core KPI is described following a standard ticket covering its name, category (e.g., energy saving), definition (physical sense), description (how to calculate it), input data and mathematical formula.

D6.2 also provides insights into the applied integrated monitoring and evaluation and impact assessment methodology (IMEM) established in ASCEND covering the whole process from the data collection to the KPIs calculation and its automated framework realised within the KPI-engine - which is further elaborated in D6.3. D6.2 should serve as the reference document for managing and carrying out the process of KPIs-based monitoring and impact assessment of the implemented solutions at the demo PCEDs of LHCs and MCs. It outlines the specific data to be monitored on-site to ensure compliance with KPIs calculation.

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Project Partners

Partners	Country	Abbr.
SPL LYON CONFLUENCE	FR	SPL
METROPLE DE LYON	FR	GLY
COMMUNE DE LYON	FR	LYS
HESPUL ASSOCIATION	FR	HES
URBAN PRACTICES	FR	UP
ENERTECH	FR	ETC
LANDESHAUPTSTADT MUNCHEN	DE	LHM
STADTWERKE MUENCHEN GMBH	DE	SWM
MUENCHNER GESELLSCHAFT FUER STADTERNEUERUNG MBH	DE	MGS
GWG Gemeinnützige Wohnstätten- und Siedlungsgesellschaft mbH	DE	GWG
UNICCORN GMBH	DE	UNC
TECHNISCHE UNIVERSITAET MUENCHEN	DE	TUM
ISARWATT EG	DE	IW
AVANCIS GMBH	DE	AVC
SPECTRUM MOBIL GMBH	DE	STA
UNTERNEHMERTUM GMBH	DE	UTUM
MUNICPALITY OF ALBA IULIA	RO	AIM
VILLE DE CHARLEROI	BE	CHA
IGRETEC	BE	IGC
AGÊNCIA DE ENERGIA DO PORTO	PT	PEN
EMPRESA DE AGUAS E ENERGIADO MUNICIPIO DO PORTO EM	PT	AEP
FUNDACAO DE SERRALVES	PT	SRV
ASSOCIACAO PORTO DIGITAL	PT	APD
CESKE VYSOKE UCENI TECHNICKE V PRAZE	CZ	CVUT
OPERATOR ICT AS	CZ	OICT
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
UNIVERSITE DU LUXEMBOURG	LU	UoL
BLUE-SIGHT CONSEIL	FR	BLS
DATEN-KOMPETENZZENTRUM STÄDTE UND REGIONEN GMBH	DE	DKSR
CIVIESCO SRL	IT	CIV
TWENTY COMMUNICATIONS SRO	SK	TWE
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Abbreviations

Acronym	Description
ASCEND	Accelerate poSitive Clean ENergy Districts
CA	Consortium Agreement Data
DMP	Data Management Plan
DOI	Digital object identifier
DH	District Heating
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
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
SWOT	Strengths, Weaknesses, Opportunities, and Threats analysis
SPs	Solution packages
SRT	Self-Reporting Tool
SWOT	Strengths, Weaknesses, Opportunities, and Threats analysis
UDP	urban data platforms
URI	Uniform Resource Identifier
V2H	Vehicle-to-Home

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1. Executive Summary

The aim of ASCEND (Accelerate positive Clean Energy Districts) is to accelerate the deployment of PCEDs as a key enabler of the conceived transformation towards climate neutral cities across Europe. Within this scope, the objective is to evaluate two inclusive, sustainable, and affordable PCEDs in the LHCs Lyon and Munich following a large-scale demonstration of six well proven, standardised, and scalable solution packages (SPs), tailored for the local context to facilitate the cost-effective deployment of PCEDs. The SPs aggregate technical, financial, social, and governmental aspects around PCEDs and cover digital infrastructure & ICT, efficient buildings, RES and related flexibilization options for PCED energy systems beside the deployment of energy communities, sustainable urban mobility, co-created and citizen-centred solutions and an urban orchestrator – a governance body gathering key local stakeholders – to coordinate the PCED implementation and ensure its long-term performance. Furthermore, six so-called multiplier cities (MCs) – Alba Iulia, Budapest, Charleroi, Prague, Porto, Stockholm – will follow an ambitious plan to quickly test and implement appropriate SPs – demonstrated in the LHCs – and thus bootstrapping the implementation of their PCEDs already during the project lifetime which contributes to magnifying the project impact.

ASCEND is establishing an integrated monitoring and evaluation and impact assessment methodology (IMEM) to monitor and assess the performance of demonstrated PCEDs in the LHCs. This methodology covers the entire data value chain, including data collection, transfer to the data platform, cleaning, processing, and final calculation of core KPIs. These KPIs provide measurable metrics for evaluating solution performance and their potential to achieve PCED objectives. Additionally, they offer a quantitative framework for replicating solution packages in the MCs, thus facilitating PCED realisation and supporting the widespread deployment of PCEDs toward climate-neutral cities.

The IMEM applies an automated data collection framework realised by the so-called "KPI engine", an ICT infrastructure for organising data on a standardised, automated, and regular basis. The KPI engine is integrated in an open urban data platform (UDP) that is linked to the local urban data platform of LHCs and MCs to transfer their pre-processed and anonymised data to the KPI-engine endpoint. The KPI engine is empowered with data management capabilities to ensure quality assurance of the collected data, while complying with the privacy and security rules, providing systematic data processing (i.e. exploring, cleansing, blending, profiling) to facilitate the final KPIs calculation, and generating automated notifications to relevant persons about potential issues along with diagnostic results.

The KPIs set is designed to meet the needs of implementing and deploying PCEDs, supporting the transition to clean energy at the urban scale. It is structured around technical, socio-economic, environmental, and governance aspects. Through extensive collaboration with stakeholders from the LHCs and other project partners, ASCEND has developed a comprehensive set of KPIs spanning eight dimensions:

- Integrated smart energy solutions at the building scale prioritise efficiency measures, energy system performance, onsite renewable energy sources (RES), and energy flexibility.
- Integrated smart energy solutions at district scale focus on district energy solutions, managing energy infrastructure and flexibility options to achieve an annual positive energy balance.
- Mobility and transportation
- ICT and digital infrastructure

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- Environmental dimension: Monitoring and reduction of PCEDs' GHG emission.
- Social dimension: Enhance residents' quality of life, satisfaction, and engagement.
- Economic and financial dimension: Evaluate investment and financial performance of the realised solutions.
- City governance and regulation: Monitor local governance involvement.

The systematic process applied in ASCEND for the KPIs' selection results in a set of inclusive indicators with a focus on assessing the districts' energy performance and their aptitude to become PCEDs.
Two categories have been identified: "Core KPIs" (30 indicators) essential for monitoring PCED demo sites, developed in close cooperation with the two LHCs; and "Optional KPIs" (58 indicators) aimed at providing additional scientific insights and advancing PCED development. However, Optional KPIs may pose data gathering challenges or overlap with Core KPIs, they are still considered valuable and are labelled as part of the "recommended" group.

This deliverable provides LHCs and MCs with specific onsite data requirements for KPI calculation, enabling comparison between PCED efforts. LHCs and MCs will decide and be responsible for deploying monitoring infrastructure (WP2, WP3) to collect this data. Further details on the data transfer process will be provided in D6.3 "Manual for the Standardised KPI Engine." Once established and validated within ASCEND, the IMEM will be shared with the Climate Neutral and Smart City Mission (City Mission) to disseminate best practices, provide key policy support information, and promote the deployment of PCEDs across Europe.

This deliverable comprises four chapters and two annexes. Chapter 2 introduces the development status of PEDs, while Chapter 3 discusses existing monitoring and evaluation frameworks for PED projects in Europe. Chapter 4 outlines ASCEND's methodology for establishing the KPI framework. Chapter 5 details the monitoring and evaluation methodology. Annex A lists the selected core KPIs with calculation details. Annex B summarises optional (recommended) KPIs. These annexes also inform the development of the "KPI-Engine" in Task 6.2.

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2. Introduction

The current climate crises call for comprehensive and targeted mitigation and adaptation measures in different areas and at different levels of our economy to enable the desired transformation towards a sustainable and low-carbon future. Prominent initiatives like the Paris agreement and the UN-agenda on Sustainable Development Goals (SDGs) paved the way for coordinated international actions. Within this context cities and urban areas play a vital role in achieving the set climate goals considering that they are currently responsible for around 78% of the world's energy consumption and accounting for more than 70% of global GHG emissions [1]. Furthermore, by 2050, about 68% of the world's population is projected to live in urban areas, up from 55% today [2]. As global governments actively lead the change in steering the clean energy transition, it is pivotal to recognise the indispensable role that cities and urban areas play in developing, implementing and monitoring climate policies. They translate ambitious goals into tangible and concrete actions, leveraging their high potential for effective mitigation and adaptation measures in view of their highly concentrated socio-economic activities and related urban dynamics.
Responding to this challenge, various national and EU initiatives have been launched. One notable example is the ***EU mission of 100 climate-neutral and smart cities*** aimed at expediting the transformation towards resource-efficient and climate-neutral urban environments. Across the EU, numerous cities are actively formulating decarbonisation strategies by 2040/2050.

To achieve the envisioned carbon neutrality, cities need to innovate beyond current practices in the built environment. This entails moving from isolated to integrated approaches, implementing tangible measures through coordinated actions at building, district, and city scales. It necessitates a shift from focusing solely on singular technologies to embracing holistic systems, from individual buildings to entire districts, and from looking at singular solutions to integrated approaches that leverage modern ICT possibilities [3]. This paradigm shift will empower cities navigating the complexity of the ongoing urban transformation, highlighting the imperative for rethinking of how we build and manage urban spaces and districts to pave the way towards inclusive, sustainable, and resilient cities as articulated in SDG11 [4].

Within this scope, the innovative concept of Positive Energy Districts (PEDs) has been initiated by the SET-Plan Action 3.2 of the EU, aiming to accelerate the clean energy transition while promoting sustainable urban transformation [5] [6], [7]. PEDs are considered as a key element to achieve the objective of climate-neutral cities of the future as stipulated in the EU mission, highlighted beforehand. The reasoning behind that is obvious as the expertise acquired at district scale under real-life conditions provide the foundation for an upscaling and replication to city scale. PEDs represent an integrated urban energy concept that combines energy, building, mobility, and ICT solutions to manage urban energy transformations, while tackling technical, legal, financial, and socio-economic challenges to pave the way for successful realisation. Within this context PEDs energy concept leverages a combination of energy demand-supply measures at the district scale to identify the most cost-effective mix. The demand side encompasses elements such as energy efficiency, demand response, and user behaviour. On the supply side, there are on-site RES and storage, incorporating EVs, building/district energy management, and more.

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Building upon the PED concept, PCEDs introduce additional innovative elements by placing a greater emphasis on cleanliness and environmental considerations in the pursuit of sustainable urban transformation. This may include measures to reduce pollution, improve air quality, and enhance overall environmental sustainability, thereby contributing to the achievement of the 2050 climate and zero pollution goals, where cities play a pivotal role.
In this document, whenever the term "PCED" is employed, it should be explicitly linked to "PED" while taking into account these highlighted differences.

Since the start of the PED program as a Joint initiative of SET-Plan, Action 3.2 Smart Cities and Communities, and JPI-UE, the PED concept has gained high attention and extensive study in various programs and initiatives. These include the EERA Joint Programme Smart Cities, the Urban Europe Research Area [6], [7], the PED-EU-NET COST Action [8], and the IEA EBC Annex 83 [9]. The concept has also been integrated into the Driving Urban Transitions (DUT) Partnership and other national and European initiatives follow [5], [10], [3].

Despite these international initiatives, there is a notable lack of tangible testbeds, explicit roadmaps, and business models that demonstrate PED-concepts within real urban settings. Testbeds in the form of real demo projects provide the foundation for **monitoring and evaluation of** the real performance of the implemented solutions and extract appropriate **Key Performance Indicators (KPIs**) for a city-wide **upscaling and replication**. Responding to this need, numerous research and implementation projects are underway to assess the concept of Positive Energy Districts (PEDs), evaluating their feasibility, performance, and replicability under real urban conditions. Europe-wide 28 demo projects addressing the PED concept were implemented or are under implementation or planning [4], [10]. The majority of these projects are funded as lighthouse projects under the H2020 and HEU of SCC funding scheme. The new wave of such demo projects started in 2023, focusing on Positive and clean energy districts. ASCEND (Accelerate poSitive Clean ENergy Districts) is one of those projects that aim to support the above-mentioned goal of accelerating cities' transition towards climate neutrality and social justice across Europe.
In preparation of such demo projects, several key questions need to be addressed to make the PED concept operational and further replicable for citywide deployment. This encompasses definition, planning, implementation, monitoring & impact assessment, and the subsequent broader deployment of PEDs. This includes:

- How should PEDs be defined considering different spatial system boundaries and overall urban contexts?
- How can the individual preconditions of each PED be best employed, considering existing building types, their functionalities and the delivered energy services?
- What planning steps are needed to implement demo projects for PEDs and which experience and lessons-learned are there?
- How should a monitoring & evaluation framework be established and realised and how to extract the key learning messages in the form of quantitative KPIs?
- How can the successful demonstration steer the deployment of PEDs to accelerate the transformation towards smart, sustainable, and climate-neutral city, while enhancing the quality of life?

The subsequent sections offer brief answers to the aforementioned questions.

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3. Planning and Deployment of PCEDs

PEDs represent a pioneering urban energy concept aimed at achieving an annual positive energy balance through optimising the integrated district energy demand-supply, resulting in an efficient, flexible and RE-dependent urban energy system. They combine cutting-edge strategies, including the highest levels of energy-saving practices (energy efficiency and user behaviour), optimal utilisation of local renewable energy sources, and the integration of effective flexibility measures – such as demand side response, local storage, e-mobility (smart and bidirectional EV-charging), intrabuilding synergies, and ICT. Through these measures, PEDs manage the energy exchange among the different buildings and with the wider neighbourhood energy system.

Consequently, PEDs represent an innovative urban energy concept that exceeds the state of the art of plus energy buildings (PEBs) and strives to integrate different building types and functionalities to harness existing synergies and to achieve a clean and liveable urban area. On the other hand, the assertion of PEDs to become a driver of climate neutral cities underscores the need to include urban mobility in their conceptual design. While this introduces additional district energy demand, it also opens opportunities for effective flexibilization, particularly through Vehicle-to-Home (V2H) solutions. Being flexible, energy-efficient and fully dependent on RES not only relieves pressure on regional and national energy infrastructure but also enhances energy security, thereby improving the city's resilience to climate change.

3.1. Definition and types of PEDs

PEDs can simply be labelled as an urban area of different building types and functions that interact mutually and with the city energy system to achieve an annual positive energy balance, where local RE production exceeds its highly efficient energy consumption.

The intensive joint effort to advance and deploy PEDs as a key enabler of sustainable and climate neutral cities results in an operational definition elaborated by JPI Urban Europe and the EERA Joint Programme on Smart Cities within the EU's SET Plan Action 3.2, as follows [4], [10]:

"PEDs are energy-efficient and energy-flexible urban areas or groups of connected buildings which produce net zero GHG emissions and actively manage an annual local or regional surplus production of renewable energy. They require integration of different systems and infrastructure, and interaction between buildings, the users and the regional energy, mobility and ICT systems, while securing the energy supply and a good life for all in line with social, economic and environmental sustainability."

Considering the general feature of the PED concept as an urban energy concept at district scale, its operation – elaborated in the above definition – depends strongly on different factors (Figure 1) that frame the realised type of the PED.

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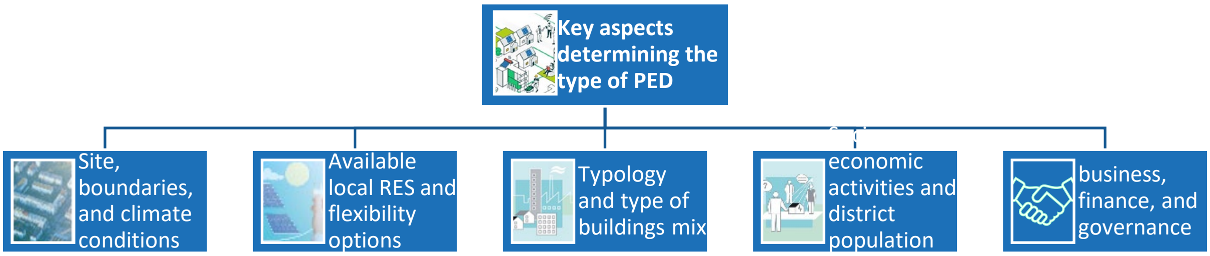

Figure 1: Key aspects framing the realisation of PEDs

The key aspects include the city context and conditions (climate, infrastructure, social, techno-economic and legal aspects), the site and boundary of the district considering population density, typology and building types and mixes (new and retrofitting, residential and non-residential), beside additional aspects related to the local stakeholders, business and finance, and governance.
PEDs realisation is based on three key pillars related to sustainable urban energy system covering energy efficiency, local/regional RES and energy flexibility as shown in Figure 2.

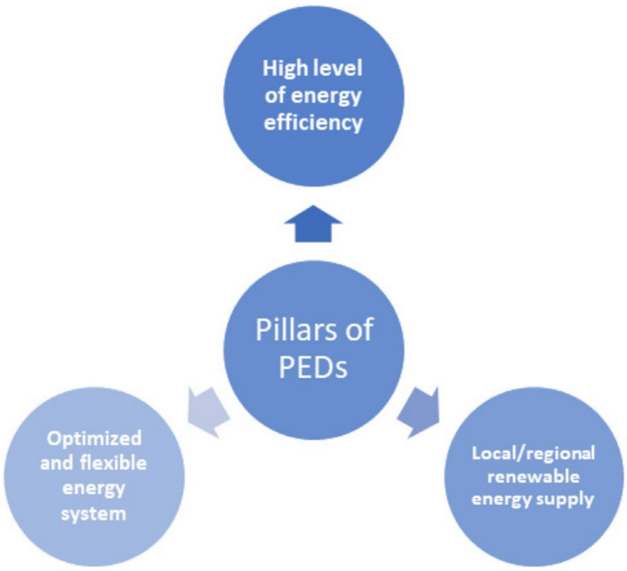

Figure 2: Main pillars of PEDs urban energy system [11]

From the urban energy perspective, a PED is about an energy balance for a defined urban area. Hence, it is crucial to define a spatial boundary within which the aimed positive energy balance can be controlled and achieved. Considering the energy demand, supply and PED internal and external energy flows, two types of district boundaries and consequently two types of PEDs can be considered as depicted in Figure 3, [5], [10]:

A PED with geographical boundary is referred to as “dynamic PED”.

- Geographical boundary: refers to the district geographical area where all RES options are located physically. The PED can achieve its net annual positive energy balance within the geographical boundaries while allowing for dynamic exchanges with the wider

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neighbourhood energy system to compensate for momentary energy surpluses and shortages.

A PED with virtual boundary is referred to as "virtual PED".

- Virtual boundary: is wider than the geographical one and refers to additional – associated – areas located outside the geographical boundary with additional RES options dedicated to the PED. The PED can achieve its net annual positive energy balance within the virtual boundaries while allowing for dynamic exchanges with the wider neighbourhood energy system to compensate for momentary energy surpluses and shortages.

Detailed elaboration on the boundaries and PED functionalities is provided under section 4.2.

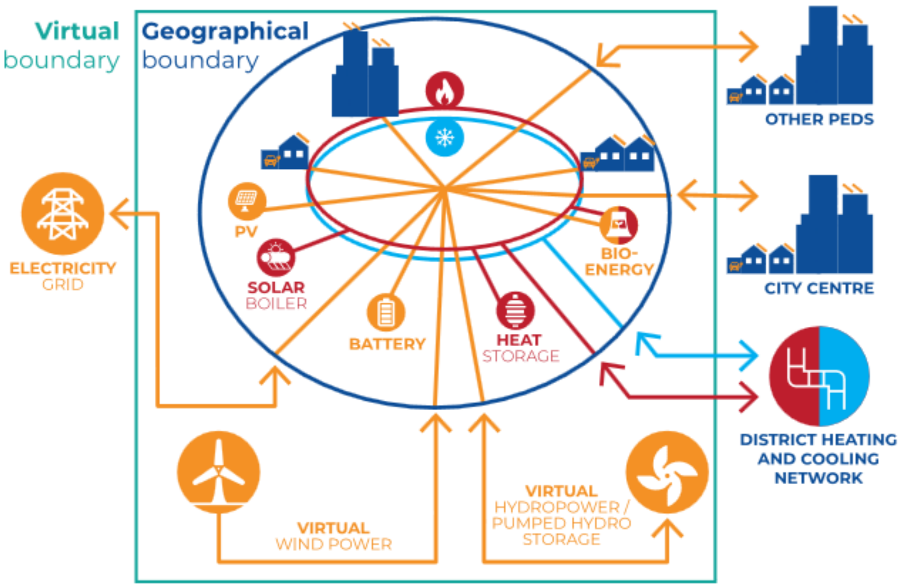

Figure 3: schematic representation of geographical and virtual boundaries applied in defining the types of PEDs energy concept [5]

3.2. The Process of Planning and Implementation of PCEDs

Planning steps for the transformation of an existing neighbourhood differ significantly from those necessary for the development for greenfield PCED as depicted in Table 1. In existing neighbourhoods, PCED development needs to be included into a holistic strategy of urban regeneration and refurbishment to be effective. It typically starts with a SWOT analysis that looks at the existing conditions of the buildings, open spaces, technical and social infrastructures in area as well as at the social conditions of the inhabitants and of the local economy. Energy consumption, greenhouse gas emissions and the potentials for local renewable energy are assessed at this stage. This allows for a first assessment of the technical potential of the area to become a PCED.

On the other hand, the development of a new neighbourhood allows for developing PCED "from scratch". A planning process of such a project would typically start with a political commitment (e.g. a council resolution) to develop the new neighbourhood as a PCED. The following steps encompass the

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conduction of a feasibility study of the PCED followed by a bid for urban design, master planning, PED energy concept and signing a development contract with a real estate developer.

Planning and implementing PCEDs must align with broader urban development processes, incorporating a participatory approach that engages key stakeholders. The requirements to achieve a PED arise from urban, spatial, and energy planning, considering constraints and targets across multiple scales. Focusing on energy performance, which is key by PCEDs, three pillars are essential: maximizing energy efficiency at building and district levels, mindful use of local renewable energy sources, and effective employment of energy flexibility options to balance local energy demand and supply and the interaction with the neighbourhood energy system.

A holistic planning process that includes both qualitative and quantitative assessments is critical. This approach establishes a comprehensive assessment framework, capturing a broad range of performance metrics to enhance understanding and effectiveness of the planned and implemented measures. In addition to KPIs collected from demo sites to monitor PCED performance and assess its sustainability impacts, qualitative insights into the planning and implementation processes are also vital, as elaborated in this section.

Figure 4 illustrates the summary of the Table 1, the methodological stages of planning and implementation for PCEDs. The **urban orchestration** serves as a critical coordination process to align diverse urban systems and engage stakeholders in creating a unified vision and mission for PCED. A core element of this process is utility value analysis, which systematically evaluates energy, mobility, and infrastructure solutions based on their benefits, costs, and alignment with PCED goals. This approach assesses technical feasibility, environmental impact, economic viability, and social acceptance to prioritize strategies that maximize value. By fostering collaboration among stakeholders and citizens, urban orchestration ensures the co-creation of transformative scenarios that enhance urban renewal, improve quality of life, and guide the development of interconnected, sustainable systems. The **action plan** formulates a comprehensive strategic framework, outlining specific objectives, pathways and roadmap to achieve the PCED development in existing and new neighborhoods. The establishment of an **organizational structure** typically led by a municipal department to ensures effective coordination and governance, bringing together relevant stakeholders to oversee the development process. Securing political commitment, such as a council resolution, is essential to formalize support for the PCED initiative. The outcome of this step is the development of skills and expertise within the team, enabling them to manage complex processes, align diverse systems, and drive the district's transformation toward sustainability and energy efficiency. **Feasibility of PCED** is a critical phase that involves strategic land-use planning, pre-assessment of site and renewable energy source (RES) potentials, and the definition of the system boundary and PED goals. For new neighborhoods, this phase focuses on resource and site selection to identify available natural and material resources, optimize their utilization, and strategically evaluate potential development sites. This is followed by the integration of energy solutions, where diverse energy sources and technologies are combined into a cohesive system to enhance energy efficiency, flexibility, and reliability. For existing neighborhoods, the feasibility process begins with a baseline assessment to establish current environmental, social, and economic conditions, providing a benchmark to evaluate project impacts. Subsequently, the integration of existing infrastructure

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ensures the effective coupling of energy sectors, reducing costs and resource demands for new construction while maximizing the capacity of pre-existing systems to support sustainable urban development. **Urban design and infrastructure plan** invites innovative proposals that align with the project's vision, incorporating energy-efficient designs, sustainable mobility solutions, and inclusive urban spaces. This process ensures creative and diverse solutions while fostering stakeholder engagement and public interest. Simultaneously, infrastructure planning focuses on integrating essential systems such as energy, mobility, and utilities, ensuring they align with PED goals. Together, these steps provide a detailed blueprint for the district's physical and functional layout, setting the stage for a sustainable and resilient urban transformation. The **legal and policy framework** focuses on aligning the project with relevant legal and policy guidelines to ensure compliance with national, regional, and local regulations. This step mitigates potential legal challenges and supports the long-term viability of the PCED. Key outputs include policy aspects that align with climate goal frameworks and sustainable urban planning, ownership agreements to clarify responsibilities, energy community guidelines to support collaborative energy initiatives, and funding programs that incentivize energy transitions, such as on-site renewables, retrofitting, or regulated heat pump solutions.

Additionally, zoning certification and development contracts with real estate developers further streamline project execution and ensure regulatory adherence. During the **implementation plan**, the project is executed according to the established urban design plan and legal framework, coordinating various operational and construction stages. It provides the milestones, roadmap for the implementation and the resource allocation of the foreseen budget. The **financial plan** secures financial resources from investors, institutions and funding agencies, providing the necessary capital to realize the project. An iterative feedback loop between the **implementation plan** and the **financial plan** ensures that financial strategies are continuously adjusted to align with evolving project requirements, while implementation schedules and resource allocations are adapted to reflect financial realities. This dynamic interaction promotes flexibility and responsiveness throughout the project lifecycle. Financial plan includes the creation of business models that ensure financial viability while maximizing long-term benefits. These models address funding sources, investment strategies, and cost-sharing mechanisms to support infrastructure, energy solutions, and urban systems. Lessons-learned out of this stage will offer recommendations to support future business-model replication on PCED deployment. A key aspect is the integration of the PCED into an energy community, enabling shared ownership, collective energy management, and revenue generation through energy production and distribution. This approach fosters economic resilience, promotes stakeholder engagement, and ensures the scalability and sustainability of the district's energy solutions. To maintain alignment with project objectives and adaptability to changing conditions or challenges, the **monitoring & impact assesment** phase provides continuous performance tracking. Finally, the **community engagement and stakeholder involvement** component actively involve and informs residents regarding the project, soliciting feedback and addressing any concerns through the whole cycle. This approach fosters local support, mitigate opposition, and ensures the project delivers tangible benefits to the community.

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Table 1: main steps of PEDs planning for the cases of existing and new urban areas.

Planning and implementation steps in existing and new neighbourhoods
• Urban orchestration is the coordination point around the city linking 5 packages (Deliverable 5.1) to co-create the transformation scenarios with key stakeholders and citizens. • Development of an action plan (including detailed financial plan), defining responsibilities & timelines and serving as roadmap for the long-term transformation of the existing or new neighbourhoods. • Set-up of an organizational structure for the transformation phase led e.g., by municipal department for urban renewal and political commitment to develop a PCED (e.g., a council resolution) • Feasibility of the PCED for existing or new neighbourhoods. • Specification of urban design and infrastructure planning. • Legal and policy frameworks for the existing or new neighbourhoods. • Implementation plan for the existing or new neighbourhoods. • Financial Plan including business models, PCED integration into an energy community. • Monitoring and Impact Assessment for the existing or new neighbourhoods. • Considering stakeholder involvement and citizen engagement over the whole process.

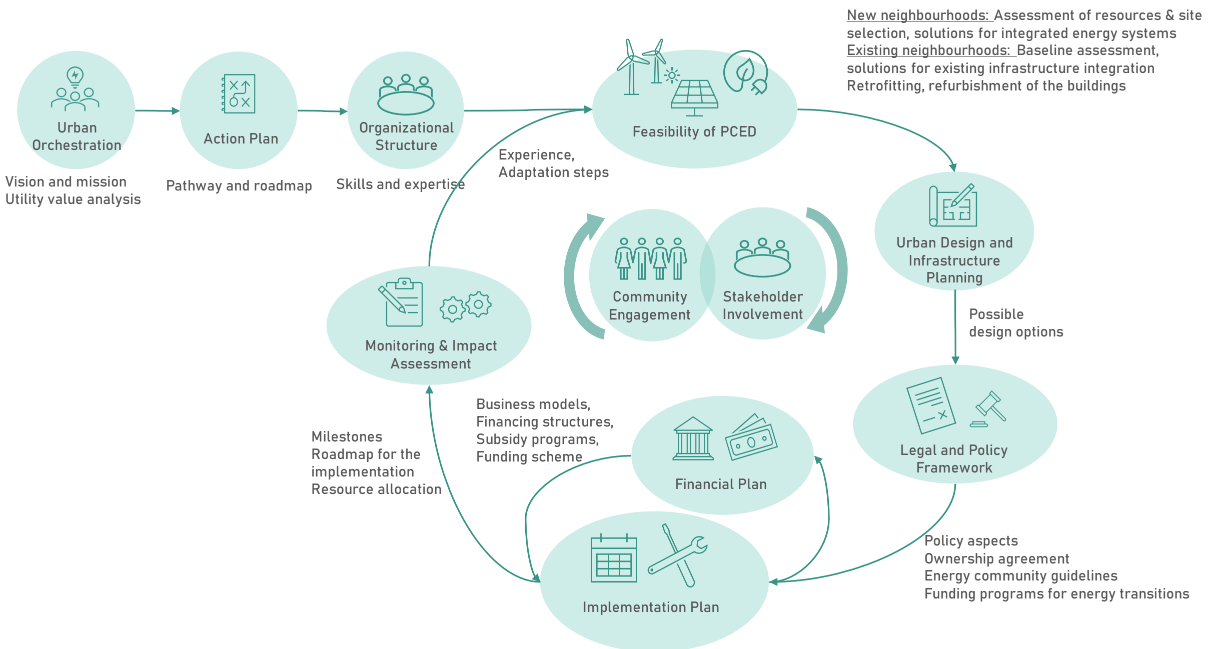

Figure 4: Flow diagram of planning and implementation phases of PCEDs.

The qualitative approach is designed to inform decision-making for PCED design and implementation of PCEDs in both existing and new neighborhoods, facilitating early-stage planning without

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overburdening the stakeholders with complex quantitative evaluation. This approach helps facilitate a seamless transition of neighborhoods into PCEDs. By leveraging expert knowledge on optimal settings for effective planning, we can ensure a smoother implementation process. Ultimately, it is expected that insights gained and lessons learned from these experiences—across domains such as building, energy, and mobility—will be valuable for other communities. Initially, the qualitative planning and implementation process will focus on five domains (environment, technology, social, economic and legal). However, the quantitative process applied in monitoring and evaluation of PCEDs performance (see section 5.3) is expanded to encompass eight domains (integrated energy solutions at building scale, integrated energy solutions at district scale, mobility and transportation, ICT and digital infrastructure, environmental dimension, social dimension, economic dimension and district governance). These insights will be shared with the project's target audiences through the planned PCED booklet (D4.2) and the implementation reports (D2.2, D2.3, and D3.2/D3.3).

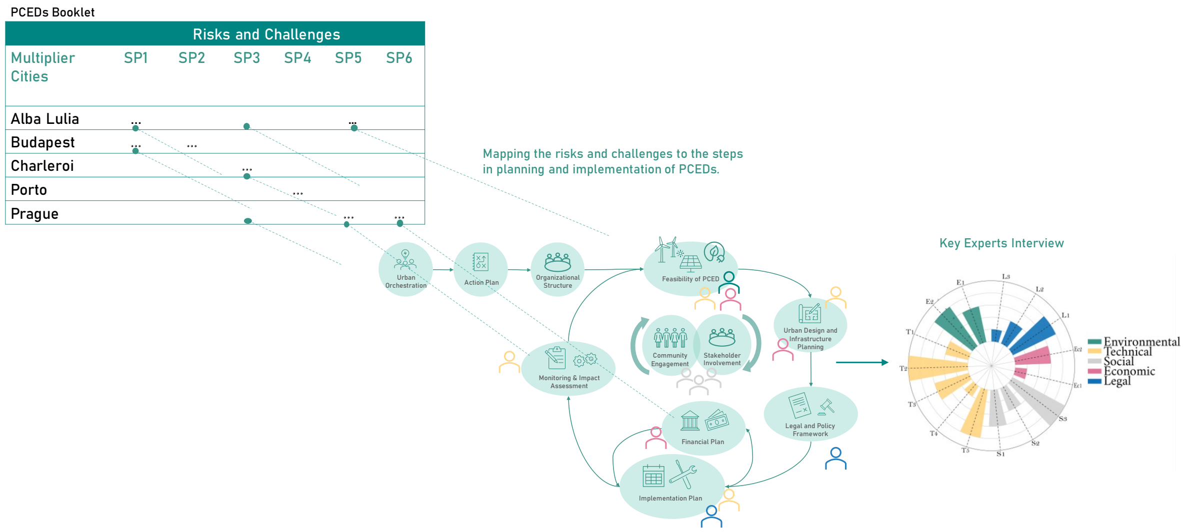

Figure 5: Steps for qualitative interview with key experts.

Under deliverable D4.2, experiences from ASCEND's five multiplier cities regarding six distinct solutions packages have been gathered. While certain Solution Packages, like SP1, SP2 and SP3, show higher readiness levels, others—such as SP4, SP5, and SP6—encounter more obstacles and are less actively mobilized by the multiplier cities at this stage. These cities face challenges in establishing structured short-, medium-, and long-term plans and in creating roadmaps for implementing their PCEDs. The risks and obstacles within these Multiplier Cities have been collected and mapped through the each stages of the planning and implementation stages of the PCEDs. To gather in-depth qualitative data on the planning and implementation of a PCED, expert interviews will be conducted with the key experts from lighthouse cities and experts from outside of the project at each phase outlined in Figure 5. The rating questionnaire in Table 3 (resulted from the challenges of the five multiplier cities) will help these experts provide detailed insights that go beyond quantitative scores, enabling a richer understanding of each stage. Some questions will be tailored to reflect specific characteristics of individual PCED regions, ensuring responses are contextually relevant. Once data is collected, qualitative feedback and quantitative ratings will be analyzed to identify patterns, trends, and areas for potential improvement.

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Table 2 Framework for Qualitative Evaluation of the Planning and Implementation Process of PCEDs

Cluster of PCED	Corresponding step in Figure 4	Key Experts	Rate the statements below based on their impact from 0 (low) to 5 (high)
Environment (Urban, land use=site selection)	Feasibility of PCED Urban design and infrastructure planning	Energy suppliers, Environmental Scientists, Urban Planners	E1: Inadequate baseline assessments can hinder the ability to measure the project's actual impact, compromising evaluation metrics. E2: Failing to thoroughly assess resources available may restrict the optimal use of the site and increase project costs. Open: What are the main environmental aspects guiding your site selection process for new or existing neighbourhoods? Open: How do you mitigate potential environmental risks during implementation of PCEDs? • Rate the importance of the parameters for planning and implementation of PCEDs: • Greenhouse gas emissions for existing and new neighbourhoods. • Increased impact of renewable installations on the landscape. ○ Renewable resources available in the districts for energy production • Current noise level in the existing and new neighbourhood.
Technology	Feasibility of PCED Monitoring and impact assessment Implementation Plan	Energy suppliers, Contractors	T1: Inadequate skilled personnel to implement digital solutions may severely impact the project's technological advancements, limiting its effectiveness. T2: A limited local workforce skilled in large project implementation poses a risk to timely and effective project execution. T3: Challenges in aligning real-time data with energy modelling can lead to inefficient energy management and decision-making. T4: Coordinating multiple large projects simultaneously risks project delays and resource allocation challenges. T5: Delays without proper monitoring mechanisms hinder the project's responsiveness to evolving challenges, diminishing adaptability. Open: How do you approach existing infrastructure integration in complex projects? Open: What are the latest technologies you consider when developing integrated energy solutions?

			Closed: Is the existing infrastructure within the neighbourhood planned to support only the current demand? Can the existing infrastructure be scaled or adapted for future needs? • Rate how effectively are different energy sources integrated from 0 (not effective) to 5 (really effective). • Rate the efficiency level of the integrated energy solution from 0 (not efficient) to 5 (really efficient). • Rate how accurately does the baseline data reflect actual conditions from 0 (lack of data) to 5 (abundant data). • Rate the importance of the parameters for planning and implementation of PCEDs from 0 (not crucial) to 5 (really crucial): ○ Total annual renewable generation of the district, prior to the PCED project (for existing). ○ Availability of public or private roofs, gardens or unoccupied plots, underground galleries (for heat exchange), and other elements where renewable energies can be generated. ○ Potential for improving the energy efficiency of buildings and activities in the neighbourhood ○ Existing public interventions clustered in the area
Social	Stakeholder Involvement Community Engagement	Social scientists	S1: Insufficient engagement with local stakeholders may result in a lack of community buy-in, hindering project acceptance and support. S2: Poor communication among stakeholders can lead to misunderstandings and conflicts, significantly delaying project progression. S3: Challenges in engaging educational institutions can limit outreach and the effectiveness of community engagement efforts. Open: How do demographic aspects of inhabitants (cultural background, education, income, willingness to invest and live in PCEDs, climate advocacy) influence decisions on PCEDs. • Rate the importance of the parameters for planning and implementation of PCEDs from 0 (not crucial) to 5 (really crucial): ○ Prior cooperative projects that have created a community in the neighbourhood. ○ Residents' associations or other associations with active participation and involvement. • Workshops and trainings to raise awareness for the residents

Economic	Financial Plan	Urban planner,	Ec1: Financial constraints and rising costs can jeopardize project viability, making it imperative to secure robust funding channels. Ec2: Legislative barriers may limit the establishment of necessary frameworks for financial backing and investment opportunities. Open: What strategies do you use to ensure a strong return on investment? Open: What are the biggest challenges in securing funding for sustainable projects? Closed: Are financial risk assessments conducted regularly throughout the project? • Rate to what extent did financial management align with project timelines from 0 (didn't align) to 5 (very well aligned). • Rate the importance of the parameters for planning and implementation of PCEDs from 0 (not crucial) to 5 (really crucial): ○ Estimated investment of the main measures that could be implemented. • Existing investments in energy or urban planning within a specific district can work synergistically with the PCED (Positive Energy District). This collaboration could potentially lower the initial investment needed for the PED by consolidating efforts and resources within one area, thus enhancing efficiency and focus on that district's development.
Legal	Legal and policy Framework	Government Officials, Legal advisors, Regulators agencies Investors, Banks	L1: A complex project framework without adequate support may lead to misalignments in the execution of the master plan, risking project delivery. L2: Unclear regulatory environments can lead to significant delays and potential costs associated with compliance. L3: Bureaucratic hurdles can significantly impede project timelines and increase costs. L4: Insufficient coordination between government agencies and regulatory bodies may create gaps in enforcement and hinder the timely approval of projects. Open: What strategies do you use to address and resolve regulatory challenges ? • Rate to what degree were potential legal issues anticipated and addressed from 0 (not anticipated) to 5 (anticipated all). • Rate how comprehensive is the master plan in addressing project goals from 0 (not comprehesive) to 5 (very comprehesive). • Rate how effectively were changes in regulations managed during the project from 0 (not effectively) to 5 (very effective).

Key Experts in the Planning Phase:

- Urban Planners and scientific organizations: Responsible for designing the layout and integrating sustainability principles into the district's design for existing and new neighbourhoods.
- Local Government Officials: Involved in policy-making, permitting, and providing funding or support for planning processes.
- Community Stakeholders: Residents, businesses, and community organizations that provide input and feedback on planning proposals.
- Energy Experts: Specialists who advise on energy efficiency strategies and renewable energy options.
- Architects and Engineers: Professionals who contribute technical expertise on building designs and infrastructure.
- Real estate, construction, planning (industries providing technology if the tech is new testing and research)
- Financial Institutions and Investors: Banks and and Venture Capital Firms (provide loans or structured financial instruments), funding agency
- Legal Advisors and Regulatory Experts: Environmental and Land Use Lawyers (zoning laws, environmental regulations, and permits), contract lawyers

Key Experts in the Implementation Phase:

- Project Managers: Oversee the execution of the planned strategies and ensure that timelines and budgets are met.
- Contractors and Builders: Responsible for the physical construction and installation of energy systems and related infrastructure.
- Local Government Officials: Continue to play a role in monitoring compliance with regulations and policies during implementation. (MA20)
- Community Stakeholders: Remain involved by participating in initiatives, providing feedback, or helping to disseminate information.
- Energy Providers: Utility companies and energy service providers who may be involved in providing services or infrastructure necessary for energy distribution.

3.3. PEDs deployment

The question here is how can the effective deployment of PEDs support the transformation towards smart, sustainable and climate neutral city while raising their quality of life?

Since its initiation in 2016, the PED-concept has triggered plenty of research and implementation activities supported by numerous national and EU initiatives to realise, test and enable an EU-wide deployment of PEDs as declared in the EU initiative of SET-Plan, Action 3.2 Smart Cities and Communities. However, these extensive activities disclose that the PED-concept still faces high challenges on the way of its deployment. Such challenges require new concepts and innovative solutions to overcome a multitude of interdisciplinary facets covering technological, financial, regulatory and societal issues related to PEDs. This is due to the fact that PED is not only an energy standard, but rather an integrated concept jointly covering energy and urban planning, social, economic, technical, environmental, political and legal aspects beside mobility and ICT that need to be adapted and tailored to the local conditions of the respective city. The focus of such a concept is to maximize and exploit the synergies resulting from the various building types and energy forms of the studied district and its neighbourhood to achieve the desired positive annual energy balance. The core technological measures lie in the greatest possible improvement of energy conservation and energy efficiency together with the optimized utilisation of locally available renewable energy sources and unlocking existing synergies of sector coupling. The flexible interaction with the wider energy system together with local storages (for power and heat) is crucial to fulfil the requirement of achieving a positive annual energy balance. Alongside of solving the mentioned challenges of PED realisation, it is vital to establish suitable business models for accelerate the deployment of PEDs. This applies for each of the mentioned three pillars as well for the whole PED-setting within different urban areas and typologies. More on this topic can be found in this SCIs-publication[1]. As elaborated later the introduced six SPs within ASCEND provide a good foundation for a sustainable business model that can be tailored to the needs of the respective city.

In summary an effective deployment strategy of PEDs needs to consider the following key aspects:

- PED is an innovative concept for urban clean energy transition at district scale, serving as a key enabler for climate neutral cities.
- PEDs represent a transitional concept from PEBs that utilises intersections of different building types and harness their existing synergies. It could also make use of economy of scale in terms of energy capacity investment, utilising low value local renewable energy resources at the district scale like the 4GDH.
- PEDs require the highest level of energy saving, full dependency on local renewable energy supply and integration of effective and diverse flexibility measures like demand response, local storage, intrabuilding synergy and interaction with the wider regional energy system.
- The operationalization of the PED concept must navigate the intersection of urban planning and integrated energy planning in a sustainable manner, considering persistent regulatory,

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1 https://smart-cities-marketplace.ec.europa.eu/insights/solutions/solution-booklet-positive-energy-districts

legal, and financial constraints, to enable the aspired innovative concept of PED that far surpasses the state of the art of current energy-efficient buildings.

- The set-up of PED is influenced by various factors, determining its realization, including site and boundaries, typology and type of buildings, climate conditions, available local RES and flexibility options, as well as additional socio-economic activities and district population density.
- Introducing suitable Key Performance Indicators (KPIs) is essential for assessing the realization and operation of PEDs, focusing on key criteria such as maximum energy consumption, minimum local energy supply, and flexibilization gaps.

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4. Monitoring and evaluation frameworks for PCEDs

The development and deployment of PCEDS are key drivers in the journey toward climate-neutral cities, significantly advancing European climate goals, including the SET-ACTION PLAN [7].
Successful proof of concept and large-scale deployment of PCEDs rely on real-life demonstrations, which is the focus of numerous completed and ongoing national and EU projects centered on PED development.
These projects serve as testbeds to showcase the functionality of various PED solutions, monitor and evaluate their performance under real conditions, and assess their impact using a comprehensive set of Key Performance Indicators (KPIs). These KPIs, which cover **technical, socio-economic, environmental, and legal** aspects of integrated solutions across energy, building, mobility, and ICT sectors, depend heavily on monitoring data collected over one to two years via an automated or semi-automated framework. This framework comprises a monitoring infrastructure of ground-based meters and sensors connected through a standardised interface to manage data collection, transfer, and processing for the final KPIs' calculation. The KPIs not only measure the project's sustainable impact but also help determine if the demonstrated district meets PED requirements. Additionally, these KPIs lay the foundation for scaling and replicating the implemented solutions across entire cities, supporting the widespread adoption of PEDs.

Given that PEDs involve integrated and systemic solutions at the district level, the ASCEND project aims to make a substantial contribution to this collective effort by scaling up and accelerating the establishment of positive and clean energy districts, thereby driving the transformation of urban areas toward climate-neutral cities.

ASCEND's overarching goals are to make cities healthier, more inclusive, and climate-neutral, while accelerating the deployment of cost-effective PCED solution packages. The project includes large-scale demonstrations in two Lighthouse Cities (LHCs), leveraging existing knowledge from Smart Cities Projects to deliver proven and cost-effective solutions packages for cities across Europe. These solution packages are designed to address the entire district life cycle, focusing on performance, maintenance, and continuous improvement through an urban orchestrator.

By iterating between the development and deployment of solution packages within LHCs and Multiplier Cities (MCs) throughout the project, ASCEND aims to foster a wave of PCED replication among partner cities, not only after the project but during its course. The project is committed to delivering two inclusive and affordable PCEDs in Lyon and Munich, effectively initiating PCED implementations in MCs such as Alba Iulia (Romania), Budapest (Hungary), Charleroi (Belgium), Prague (Czech Republic), Porto (Portugal), and Stockholm (Sweden). Ultimately, ASCEND seeks to scale solution packages for a broad community of cities and investors across Europe, with results widely dissaminated within the smart cities community.

4.1. The need for monitoring frameworks

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Establishing a monitoring framework is essential for providing data-informed decision making. The collected monitoring data enables the calculation of adequate KPIs to track and assess the PEDs performance, enhance overall energy efficiency and the use of RES, identify areas for improvement, and optimize the district energy system to achieve the set target of positive energy balance. A monitoring framework contributes to raising awareness of citizen and relevant stakeholder, thereby strengthen their engagement to enhance PED performance. Besides, the monitoring framework serves as a cornerstone for assessing the sustainability of the tested solutions -i.e., SPs- and their broader scalability. This, in turn, facilitates the large-scale deployment of PCEDs, contributing to a mainstream, long-term, and sustainable city transformation towards climate neutrality taking into account the specific framework conditions of each city.
In brief, the monitoring framework serves as the foundation for assessing both the direct and indirect impacts of the project, resulting from its immediate implementation and the envisioned long-term replication.

With the monitoring framework in place, the collected data and derived KPIs provide hands-on information to monitor and optimise the overall performance of the district energy system. This process also generates valuable experiences and lessons learned in terms of techno-economic, regulatory, and policy incentives, contributing to.:

- Supporting the effort of smart cities, smart management systems and ICT Apps for urban services;
- Stimulating the cooperation among R&D institutions, industry and construction companies to enable cost-effective technological innovations for PED;
- Fostering the technological innovation to reach robust solution for the long-time storage of heat and electricity;
- Developing a systematic toolbox to help projects avoiding common mistakes and learn from existing examples
- Establishing policy incentives to stimulate industry, construction companies and individual for adopting PEDs concept;
- Dealing with the urgent task of distributing costs for transforming existing building stock into PEDs.
- Helping in establishing advanced business models to deal with the persisting challenges of PEDs deployment.

4.2. Key Characteristics of Positive and Clean Energy Districts

There have been several attempts to agree on a common definition of Positive Clean Energy Districts (PCEDs). The Joint Programming Initiative Urban Europe [10] published a white paper in 2020 on a “Reference Framework for Positive Energy Districts and Neighbourhoods”. This framework was based on the outcomes of implemented projects and seeks to implement the contribution of critical stakeholders of city authorities, research organizations, industry, energy suppliers, and citizens' organizations. Vandeveyvere et al. propose an operational definition of PEDs based on the outcomes

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of the Horizon 2020 SCC Lighthouse project +CityxChange [12]. They argue that the definition of PEDs should be divided into four subtypes, depending on the boundaries considered.

To provide a more common definition, the IEA is currently working on the IEA-EBC Annex 83 on Positive Energy Districts (PEDs) [9] which focuses on developing an in-depth definition of PEDs, related innovative technologies, and planning tools besides planning and the decision-making process needed to establish and deploy PEDs. V. Albert-Seifried [13] proposes a comparison of the existing PEDs definition frameworks based on different parameters, including the calculation of the balance, the scale considered, the boundaries of the districts, the key energy concepts, and the non-energy consideration.

This part presents the results of the review of the existing definition and characterization frameworks for Positive Energy Districts. A detailed analysis of the dimensions to be considered and the chosen definition within ASCEND is presented in the following part. This is important as a basis for the PCEDs assessment framework.

4.2.1. Boundaries

Operational observations from the running projects highlight the need for a flexible definition considering the locations specificities and design differences of PEDs. The first step to characterize PEDs projects is to define the system boundaries. The EERA Joint Programme Smart Cities (May 2019, Brussels) describes two different types of system boundaries differing in the energy generation type [14], [15], [12]

- **Geographical boundary**: Spatial-physical limits of the PED that enclose groups of buildings, open space, urban infrastructure and related local energy infrastructures.
- **Virtual boundary**: encloses additional RES facilities located outside the PED geographical boundaries but owned collectively by the PED community (e.g., an offshore wind turbine or geothermal heat supply facility[2]). A second, more relaxed but controversial option might be that the PED has no ownership in the RE facility but has a contract to buy part of its energy production or even buy Green Energy Certificates. This option is questionable when considering whether we can then label the district as a PED. Some ideas from JPI-UE, SET-Plan Action 3.2 suggest considering such a district as a "PED candidate."" [16], [5]

A PED with geographical boundaries capable of achieving an annual positive energy balance, while facilitating dynamic energy exchanges with the neighborhood energy system to offset momentary energy surpluses and shortages, is termed a “Dynamic PED” (Figure 4). Within this category, if a PED can attain a net energy balance at any given moment based solely on its onsite renewable energy (RE) production without any energy imports, it is referred to as an autonomous PED. However, this type is notably less feasible due to its extreme difficulty to achieve.

[2] This would apply for the case of geothermal energy district heating in Munich that belong to the city and will supply Harthof with RE heat. One can articulate that the residents of the district have ownership to use such community asses.

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A PED that achieves an annual positive energy balance within virtual boundaries, incorporating dynamic exchanges with the neighborhood energy system to compensate for momentary surpluses and shortages, is termed a "Virtual-PED" (Figure 4).

Going beyond the concept of different types of boundaries, current European project are highlighting the need to develop location context factors. In a recent publication for the +CityxChange project, H. Vandevyvere [12] proposes a characterization approach based on a bottom-up methodology to consider the location context factors that can impact the feasibility of PEDs. It includes urban density, heritage, mobility, and climate. Similarly, A. Bruck developed four GIS-based characterization parameters to characterize PEDs in Europe and enable comparison and replicability: (1) Heat demand density (2) Floor space index (3) Residential building share (4) Climate zone [[17]. X. Zhang [18] proposes an analysis of 60 existing projects in Europe to characterize PEDs through six different attributes: initiation year, location, project area, financial model, type of buildings involved, and energy technologies. In the same direction, S. Schneider proposes a distinction of PEDs types based on energy services included: building operation for the PED-Alpha, adding the mobility energy consumption for the PED-Beta and the embodied energy for the PED-Omega. In this approach, the concept of PEDs boundaries is overcome by the definition of contextual targets. Indeed, the choice of the PEDs type targeted is based on the consideration of context factors to obtain the targeted positive energy balance, such as urban density, mobility and climate contexts [19].

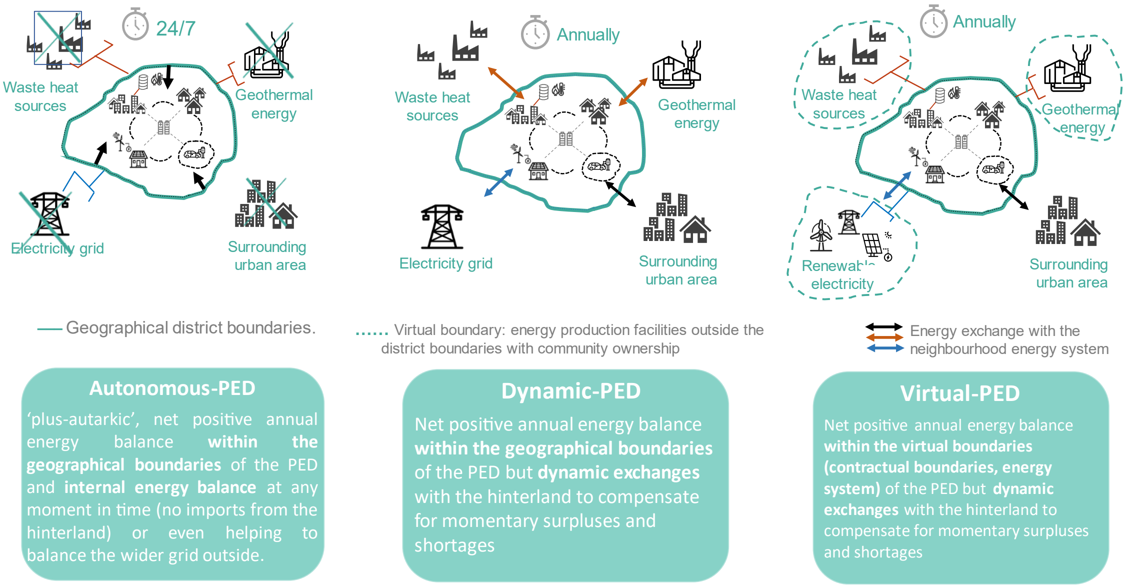

Figure 6: Flexible PED boundary definitions

Within ASCEND, the PCEDs boundaries will be the geographical one which will be considered to assess the PCED performance, including the local energy grids (district heating).

4.2.2. Energy balance

While it is commonly agreed that the PEDs' energy balances must be positive, the temporal scope still diverges in literature with some focusing on an hourly balance but most definitions assuming an annual positive energy balance [[20]. Considering buildings' embodied energy, an energy balance may consider the entire life-cycle [[21][9]. Additionally, the end-use sectors included in the balance

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calculation vary between PEDs definitions and projects. Accounting for roughly one-fourth of the energy demand in urban neighbourhoods, decarbonizing the mobility's energy demand is a crucial aspect to be considered in PCEDs planning. Both the JPI framework and the first key findings of the IEA Annex 83 show that PCEDs could benefit from electrification and sector coupling. European PED projects such as CityxChange, Atelier and POCITYF included e-mobility in the scope of their studies [22]. The vehicle's technology and consumer behaviours influence the energy demand for mobility. However, the inclusion of e-mobility raises questions regarding carbon accounting, as the external charging electricity is not. Besides, although several studies attempting to define a standardized energy balance calculation [23], [24], there is no agreement on the calculation basis for the energy balance, namely if the balance should be calculated with primary or final energy [25]. The PED boundary definitions adhered to within ASCEND were established by JPI urban Europe [26] and are already depicted (Figure 4).

Within ASCEND, the energy balance will be placed at the district boundary, i.e., final energy level where the energy consumption sectors are located encompassing of households, services, industry and mobility as applicable in the considered PED. The energy balance is the results of the district energy consumption, local production, storage and exchange across the district boundaries (import and export). For the dynamic PED the local RE produced within the district boundaries is considered. For the virtual PED, in addition to local RE production, the contractual regional RE (located outside the PED boundaries in PED-associated areas) will also be considered (Figure 5) The balance will be calculated on an annual basis. The choice of energy level (final, secondary, primary) and the timeframe is highly dependent on data availability of the LHCs.

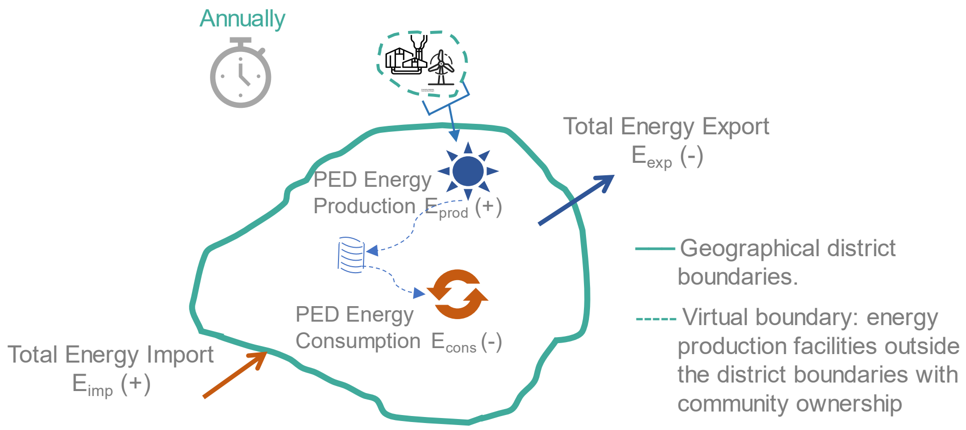

Figure 7: simplified district energy balance

Given the definition of district energy balance as a system with defined boundaries exchanging energy with the surrounding neighbourhood over a specified period, it can be elaborated upon at both the final and primary levels and converted from one to each other. The choice will be to the option that favours achieving the positive energy balance of the district. Thus, it may be advisable to reconsider the current primary energy balance setting proposed for PEDs, given the challenges posed by imported energy supply chains that are beyond the control of the PED itself. This places additional pressure on PED to achieve its goals, particularly within the context of national energy systems. Instead, the focus should shift towards a PED energy balance convention that emphasizes enhancing overall district energy performance (from its boundaries and inwards) to facilitate achieving a positive energy

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balance. This entails prioritizing improvements in terms of energy saving of the demand side and increasing local renewable energy production, thereby aligning PED objectives more closely with achievable measures at district scale. The energy balance calculation will be elaborated in more details in D6.3.

Regarding mobility energy consumption, a graded approach can be employed to assess the annual energy balance of Positive Energy Districts (PEDs) both with and without mobility considerations. This approach allows for a detailed examination of the challenges posed by mobility energy demand within the PED balance, while also recognizing its benefits as a dynamic energy flexibility option.

4.2.3. Renewable energy supply

A core element of the definition of PEDs highlighted by JPI in the white paper on PEDs Reference Framework is that PEDs' energy balance should only consider the energy supply from local and regional renewables. However, the framework especially highlights the high RES' dependency on local and regional conditions, meaning that each solution is tailored to the prevalent conditions. A clear concept of local and regional energy supply remains unclear in the reviewed frameworks. Most of the existing European PEDs projects include on-site and off-site RES [21].

Figure 6 provides an overview on renewable energy supply options and possible interactions between energy conversion technologies in flexible PED energy systems.

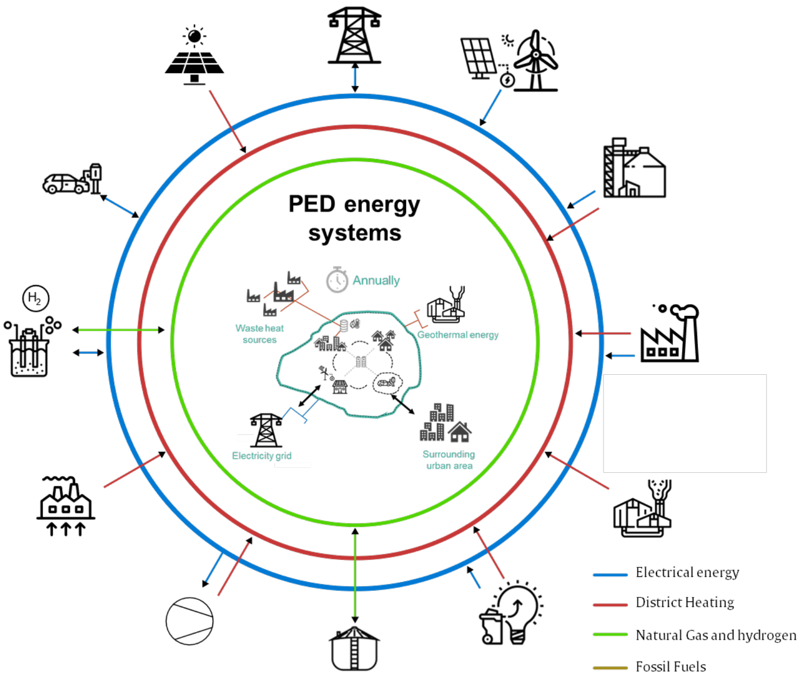

Figure 8:Renewable energy supply options and energy conversion technologies in flexible PED energy systems

Within ASCEND, the concept of on-site refers to the renewable energy produced within the geographical boundaries of the district. In that case, it is mainly electricity produced by PV panels on building's rooftops.

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4.2.4. Energy flexibility

Within the regional energy system, a PED promotes self-consumption by offering optimized flexibility for instant demand-side management or storage capacities. This allows for balancing and optimization, peak shaving, load shifting, demand response, and reduced curtailment of RES. The results of the flexibility analysis conducted within the POCITYF project show that energy flexibility is a technical challenge and includes legal and governance requirements [27]

Within ASCEND, several energy flexibility solutions will be tested and assessed. This includes mainly electrical and thermal energy storage systems. The details of the implemented measures are presented in the LHCs PCEDs implementation roadmaps in the deliverables 2.1 and 3.1.

4.2.5. Environmental performance

Both the SET Plan and the JPI framework state that PEDs should achieve annual net-zero greenhouse gas emissions on operational scale. Although, most of the PED projects in Europe focus on reducing the Greenhouse gas emissions, the calculation of greenhouse method is not discussed in detail and is specified individually.

Within ASCEND no specific measures are targeting environmental performance, but it is intrinsically linked to energy efficiency improvements and switch to clean energy systems measures.

4.2.6. Innovation and ICTs

The SET Plan definition mentions that PEDs will "ideally" be "developed in an open innovation framework, driven by cities cooperating with industry and investors, research and citizen organizations." ICT and Data Management is described as enablers to achieve PEDs objectives in the JPI White Paper but should follow the guiding principle of inclusiveness, quality of life, and social sustainability. To this extent, Baer compares different PEDs case studies in Norway, Baer highlights that not only technological innovation, but also social innovation is crucial for the offtake of PEDs projects [28], [28].

Within ASCEND the use of ICT and digitalisation as an enabler to achieve the objectives of the PCEDs are embodied in SP1, developed in both LHCs and in the MCs. Besides, the KPIs engine developed within WP6 aims at supporting the digitalisation of the PCEDs developed.

4.2.7. Social quality

The JPI framework mentions that PED should increase the quality of life of its inhabitants as a guiding principle. The value for the citizens should go beyond economic benefits and include social and environmental aspects. In that sense, there is the need to overcome the potential new technology acceptance challenges among the population to develop PEDs projects. As highlighted by the survey results on PEDs design preferences conducted in Switzerland [29], the design strategies to improve quality of life depend on the area's specificities and the stakeholders' frameworks and strategies.

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Within ASCEND, the social quality will mainly be assessed through the implementation of energy communities and the interaction with local stakeholders throughout the project.

4.3. Existing frameworks to evaluate PCEDs

KPIs-based monitoring & evaluation frameworks are widely used to assess the impact of urban projects. At the city level, work has been done to develop a systematic framework to enable the impact assessment and comparison of different projects. For example, within the Citykeys and the SCIS[3] frameworks a systematic method is proposed to evaluate the impact of Smart City projects. At district level, there is no standardized method to evaluate the impact of the developed project. Regarding Positive Energy Districts, each PED project within the H2020 subsidy develops its own KPI list depending on the objectives included in the project's scope. Other initiatives are used to measure the sustainability performance of a district. Those so-called district certifications are based on the same model as building performance certifications. The following part reviews the existing district assessment frameworks and how they can be used within ASCEND.

[3] Meanwhile known as Smart City Marketplace (SCM).

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4.3.1. KPIs-list developed within other PEDs projects

The review of existing Positive Energy Districts projects in Europe presented in Table 2 shows that each project followed a similar methodology to develop the KPIs list. It starts with identifying the scope of the projects. A first KPIs pool is obtained through a literature review. This list is then discussed with local stakeholders, and the feedback leads to the final KPI list used for the project impact assessment. Besides, most of the reviewed frameworks focus on the implementation phase. Only the Making City project developed a framework to assess the performance of PEDs during the planning phase. All reviewed frameworks focus on the same dimensions as pointed out in the PED's definition: (1) energy performance, (2) environmental performance, (3) economic performance, (4) ICT, (5) Mobility, (6) Social Impact, and (7) Governance. ~~Despite~~ In addition to these similarities in the methodology and the scope of the assessment, further dimensions and ~~different~~ KPIs ~~scopes~~ are used within the different frameworks to account for project specific objectives. Finally, the concept of "Clean" districts is addressed only through the environmental impact calculation in the existing frameworks and focuses mainly on the objective of reducing Greenhouse gas emissions.

Table 3: Existing PEDs assessment frameworks from H2020 EU projects(GS, P and O stands for the project monitoring stage. GS: goal setting, P: planning and O:operation).

Name of the framework	Focus (1)	Detail of the categories assessed	Assessment method	GS	P	O
POCITYF [30]	PEDs	(1) Energy (2) Environmental (3) Economic (4) ICT (5) Mobility (6) Social (7) Governance (8) Propagation	KPIs			x
CityxChange [31]	PEDs	(1) Energy efficiency (2) Economic (3) social (4) regulatory	KPIs			x
ATELIER	PEDs	(1) Energy performance (energy efficiency, renewable energy and flexibility) (2) Life cycle environmental impacts (3) Economic impact and business development (4) Mobility (5) Citizen engagement and social impacts (6) Upscaling, replication and governance.	KPIs			x
Making City PED design [32]	PEDs	*City diagnosis approach:* (1) city level indicators (2) existing city plans (3) city components (resource analysis, urban macro-form analysis, land-use context,	GIS assessment / KPIs	x	x	

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		energy infrastructure analysis, social aspects). *Impact assessment:* (1) Energy and environment (2) mobility (3) economy (4) system flexibility (5) social and residents.				
SPARCs [33]	PEDs	(1) energy (2) mobility (3) new economy (4) urban innovation (5) ICT (6) overall social indicators.	KPIs		x	x
Syn.ikia H2020 [34]	SPEN	(1) Energy and Environmental (2) Economic (3) Indoor Environmental Quality (4) Social indicators (5) Smartness and Energy Flexibility.	KPIs		x	x
Response [35]	PEDS	(1) Energy (2) Environment (3) Mobility (4) ICT (5) Economic (6) Social (7) Governance (8) Propagation	KPIs			

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4.3.2. Existing certifications framework to assess district sustainability

The review of the existing PEDs assessment frameworks highlights a gap regarding the assessment of clean energy district. This dimension is particularly important to assess the performance of the PCEDs developed within ASCEND and account for the project's specific objectives. The existing district sustainability certification frameworks can be useful in addressing this gap. A stronger focus is put on assessing the environmental impact, beyond the calculation of the GHG emissions, through assessment dimensions such as ecology and natural system. Table 3 presents the reviewed frameworks and the dimensions assessed. Besides, these certification frameworks also include indicators to evaluate the quality of PEDs projects during the planning phase.

Table 4: Existing sustainable districts certification frameworks

Name of the framework	Focus (1)	Detail of the categories assessed	Assessment method	GS	P	O
BREEAM Communities [36]	SD	(1) Governance (2) Social and economic wellbeing (3) Resources and energy (4) Land-use and ecology (5) Transport and movement.	Credits	x	x	x
LEED Neighbourhood Development [37]	SD	(1) Smart location and linkage (2) Neighbourhood Pattern and design (3) Green infrastructure and buildings (4) Innovation and design process (5) Regional priority credits	Credits	x	x	x
LEED for cities and communities [38]	SD	(1) Integrative process (governance) (2) Natural system and ecology (3) Transportation and land-use (4) Water efficiency (5) Energy and Greenhouse gas emissions (6) Material and resources (7) Quality of life (8) Innovation	Credits	x	x	x
DGNB Urban Districts [39]	SD	(1) Environmental quality (2) Economic quality (3) Sociocultural and functional quality (4) Technical quality (5) Process quality	Credits	x	x	x

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5. Methodology of KPIs Selection in ASCEND

ASCEND aims at providing a test bed to demonstrate the realisation of PCEDs in two LHCs. It seeks to monitor and evaluate the performance of the implemented district solutions as well as the overall project impact. The ultimate goal is to achieve sustainable PCEDs that can be replicated and thereby advancing the transformation towards climate neutral cities.

To attain the project's goals, establishing a monitoring framework is crucial. This framework enables data-based decision-making, where the collected monitoring data serves as the foundation for calculating relevant KPIs, to monitor and evaluate the performance of the implemented solutions and to assess their impact at the district level.

Considering the various domains to be monitored to assess a PED setting with focus on sustainable urban transformation and clean energy transition, several groups of KPIs need to be incorporated, covering the overall energy performance at building and district scales, the role of urban mobility, and the needed ICT solutions to enable an efficient, clean, and flexible district energy system.

Beyond the technical aspects, it is imperative to also consider socio-economic, environmental, and governance aspects that complement the framework regarding sustainability performance and further replication of PCEDs.

Furthermore, the careful selection of KPIs needs to account for the distinctive settings and conditions of each demo city, encompassing local development targets, regulations, and standards. This consideration ensures the alignment of the implemented PCED with the overreaching city´s development targets. Offering a set of KPIs customized to the local context not only ensures alignment but also streamlines the cost-effective deployment of PCEDs.

Lastly, stakeholder involvement in the definition and selection of the KPIs is important to ensure a balanced co-creation process that responds to the need of all involved city actors. Besides, it informs the LHCs and MCs on the specific data to be monitored on-site to comply with the calculation of the selected KPIs. The process of KPIs development applied and developed within ASCEND is depicted in in Figure 7. The process of KPIs development strives to generate a cohesive and inclusive set of KPIs crafted to provide evidence on the feasibility and cost-effectiveness of the implemented solutions to achieve the goal of a PCED in both LHCs.

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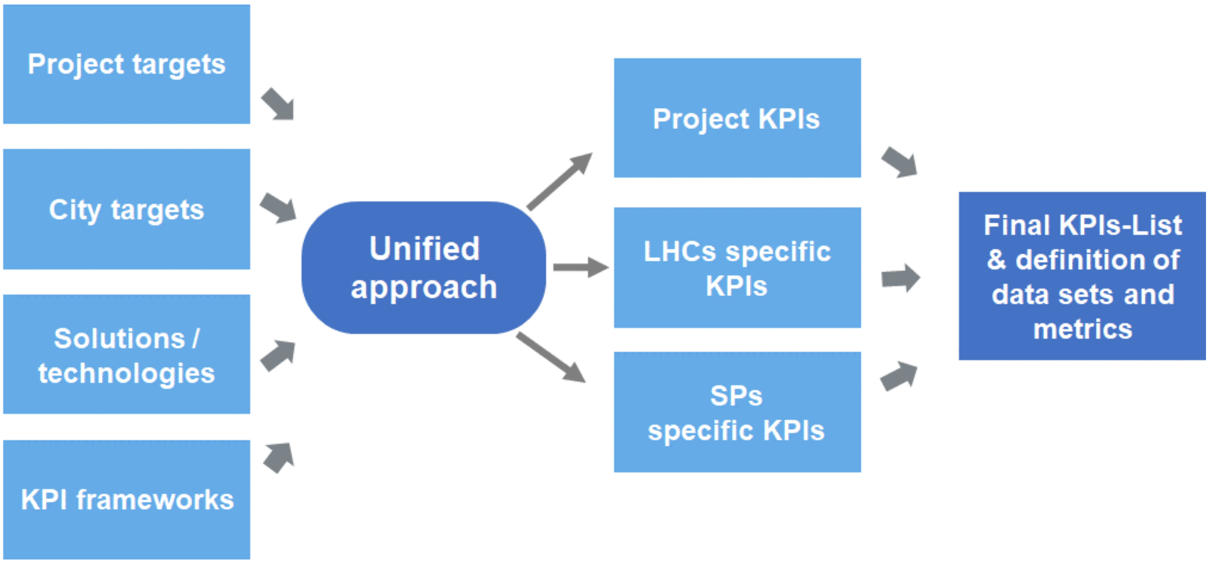

Figure 9: steps of the KPIs development process

5.1. Scope definition of KPIs

Monitoring PEDs is about addressing a multitude of aspects related to the realisation and operation of such an innovative urban energy concept. These aspects range from different energy technologies and their meaningful interaction and integration within the existing system, over citizen engagement and stakeholder involvement, social justice, and acceptance, up to creating composite business models and solving legal questions [40]. Those requirements build the overall context for defining and selecting the KPIs that can be aggregated into technical, spatial, temporal and sustainable domains.

5.1.1. Technological scope

PCEDs are not only about integrated clean energy solutions. They embody an “integrated sustainability concept” encompassing sustainable urban transformation blended seamlessly with the clean energy transition to achieve a vibrant urban district for a better quality of life at city scale. With this in mind, PEDs integrate different technological aspects covering clean, efficient and flexible energy solutions as well as ICT, digital infrastructure, urban mobility solutions, and frugal buildings.

- Clean, efficient and flexible energy solutions is the deployment of local renewable energy solutions and efficient conversion technologies. Through dynamic and flexible technologies (e.g., energy grids and storage facilities) they are adaptable to balance energy demand and supply. Energy grids will enable the development of local energy communities making the current consumer to prosumer.
- ICT: the integration of ICT and digital tools and infrastructure help achieving smart energy management and facilitate the optimization of the district energy performance.
- Buildings: Zero-carbon frugal buildings with high energy performances and self-consumption systems, powered by clean and locally produced renewable energy.
- Mobility: public spaces and mobility are decarbonized to make PCEDs breathable and more liveable, with the deployment of alternative mobility means for passenger travels and freight via electro and micro-mobility.

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These technological aspects are very well reflected in the Solution Packages (SPs), ASCEND aims to develop and implement in both LHCs beside their selected deployment in the MCs. The introduced Six SPs

aim to design, implement, and roll out inclusive, cost-effective PCEDs that aggregate technical, business model and financing components as depicted in Figure 8. They are standardized and adapted to suit the local context and the needs of individual districts.

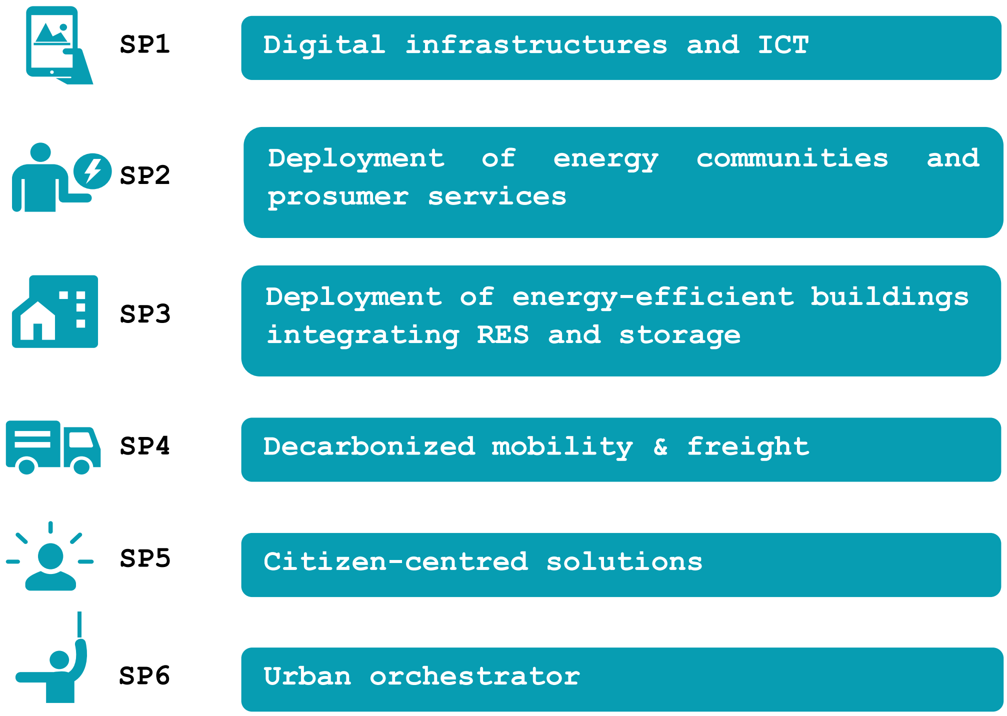

Figure 10: The six solution packages developed in ASCEND

A solution package is a bundle of different technologies and concepts. Therefore, several dimensions are necessary to evaluate a solution package. Conversely, a PCED objective can be achieved by combining different solution packages. Therefore, the contribution of each SP to the overall impact of the PCED is challenging to measure. However, SP-specific KPIs are defined to evaluate each solution package's financial quality and impact. A detailed description of the SPs implemented in the LHCs are described in Deliverable 2.1 and Deliverable 3.1. The technological roadmaps have been detailed for the MCs in deliverable 4.2.

5.1.2. Spatial scope

Most of the previously outlined SPs will be implemented at the district scale in the LHCs. However, SP3 focuses on the building level, aiming at deploying energy-efficient buildings, integrating RES and storage. Therefore, the evaluation framework developed within ASCEND focuses on the two main spatial scales: the district scale, aiming at becoming a PCED, and the building scale where SP3 is implemented.

PCED: The PCED scale refers to functional boundaries of the geographical area identified by the LHCs and the MCs for the PCED demonstrator. As already elaborated, this PCED type refers to the

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“Dynamic PED” that flexibly interacts with the neighbourhood energy system (via import and export of energy) to achieve an annual energy surplus.in this case the net energy export should exceed the import on annual basis. As outlined in the section 03.2 the local district heating and electricity networks are included in the analysis as flexibility options. However, for the case of external energy supply with clean energy source -like the case of geothermal district heating supply in Munich- the PCED will refer to a “Virtual PED” that stays under special contractual agreement with the district heating provider. Figure 9 shows the PCED area of the LHCs. The assessment at district level relies mainly on the aggregation of the different technological solutions implemented within the district boundaries.

Buildings: SP3 focuses on the development of energy-efficient buildings, including the implementation of building renewable energy systems. The building scale will enable an assessment of the SP3 impact on energy demand, flexibility, and supply.

Figure 11: PCED area in the LHCs. Lyon Confluence (left), Harthof in Munich (right)

5.1.3. Temporal scope

The evaluation framework developed within ASCEND aims to analyse the implemented solutions' impact on a short-term scale, which means between one and two years after the implementation. The calculated KPIs will be used on a longer time scale to evaluate the scalability and the replicability of the SPs implemented. The temporal restriction of the performance assessment is mainly due to the temporal limitation of the project.

The temporal scope of the KPI definition framework not only refers to the temporal scope of solution monitoring itself, but also to the temporal scope within the definition of KPIs. This mainly refers to the differentiation between annual, sub-annual and solution lifetime time scales. While most KPIs express solution performance characteristics on annual basis, also considering cumulative annual effects e.g., total annual RES production within the district (D2EDC4), other KPIs consider sub-annual effects that are cumulated to represent an annual value, e.g., the dynamic PCED energy balance (D2EDO11), which accounts for the local energy demand-supply balance on hourly level. Additionally, economic KPIs consider multi annual effects such as dynamic cash flows to correctly discount cash flows of

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implemented solutions across their technical lifetime, extending the temporal scope of the monitoring framework to multi-annual in such cases.

5.1.4. City context

The feasibility of PCEDs depends highly on the local context regarding building density, potentials for local renewables, governance frameworks, citizen engagement and economic aspects beside others. Therefore, the attainability of positive energy balances depends on the local city context, which subsequently needs to be accounted for in the evaluation and comparison of PED projects. The local context regarding the above-mentioned aspects is therefore detailed for each PED site in deliverables 2.4 and 3.4. To properly reflect the varying framework conditions for the implementation of PCEDs, while allowing arbitrary geographical balance limits that respect the ~~nature~~ individual nature of construction and renovation projects and districts, the ongoing discussion around the definition of PED requirements and goals recently introduced so called context factors.

These context factors should aim to adjust the general requirements and ambitions of a PED (generally speaking about the positive energy balance) by considering the local framework conditions, potentially allowing for negative energy balances while still following the ambitions regarding sustainability that are demanded by PCEDs [41]. As the discussion of context factors in the framework of PEDs has been only recently started, there is no commonly agreed methodology to define such context factors yet. ASCEND will follow the developments regarding this topic throughout the project duration and will consider any new developments within the developed monitoring framework.

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5.2. Selection of KPIs Dimensions

The dimensions to evaluate the performance of the implemented solutions in the LHCs and MCs PCEDs demonstrators are based on the review of existing KPIs frameworks for PEDs and the analysis of the specific pillars' implementation and objectives of the PCEDs developed within ASCEND (see section 3.3).

The following sections elaborate on the collection of the eight dimensions, presented in Figure 10, the solution packages covered and the KPIs encompassed. Details on the dimensions and their use in the assessment framework of ASCEND are given in this section.

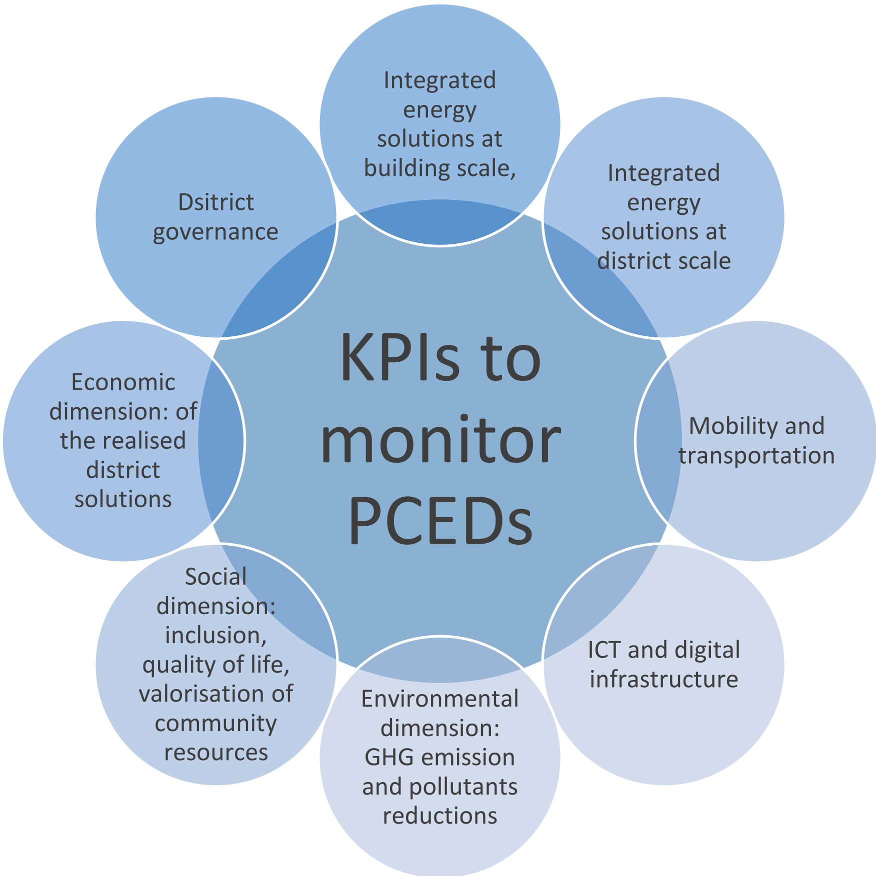

Figure 12: KPI dimensions considered in the ASCEND assessment framework

5.2.1. Co-creation process for the KPIs selection

The final KPIs list to monitor and assess the impact of the implemented solutions to fulfil the objectives of PCEDs has been developed following a co-creation process presented in Figure 11. The objective of this co-creation process was to bridge the gap between the technical expectations for KPIs measurement and actual monitoring capabilities of the LHCs within the project scope. Therefore, the co-creation process intends to support in:

1. Ensuring that all the dimensions included in the Positive Energy District definition presented in section 3.2 are reflected in the KPI framework.

- Guaranteeing that the KPI framework developed is relevant for cities and that the data required for their calculation can be monitored within the project scope.

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First KPI pool generation

The first part of this co-creation process consisted of a top-down approach. The dimensions and the first KPI list of evaluation framework have been identified based on the review of the of the main objectives of PCEDs presented in part 1 and on an intensive review of the monitoring and evaluation frameworks developed within European projects related to PEDs. This first part resulted in a structured document including a classification of KPIs by dimensions, sub-dimensions, and related SPs.

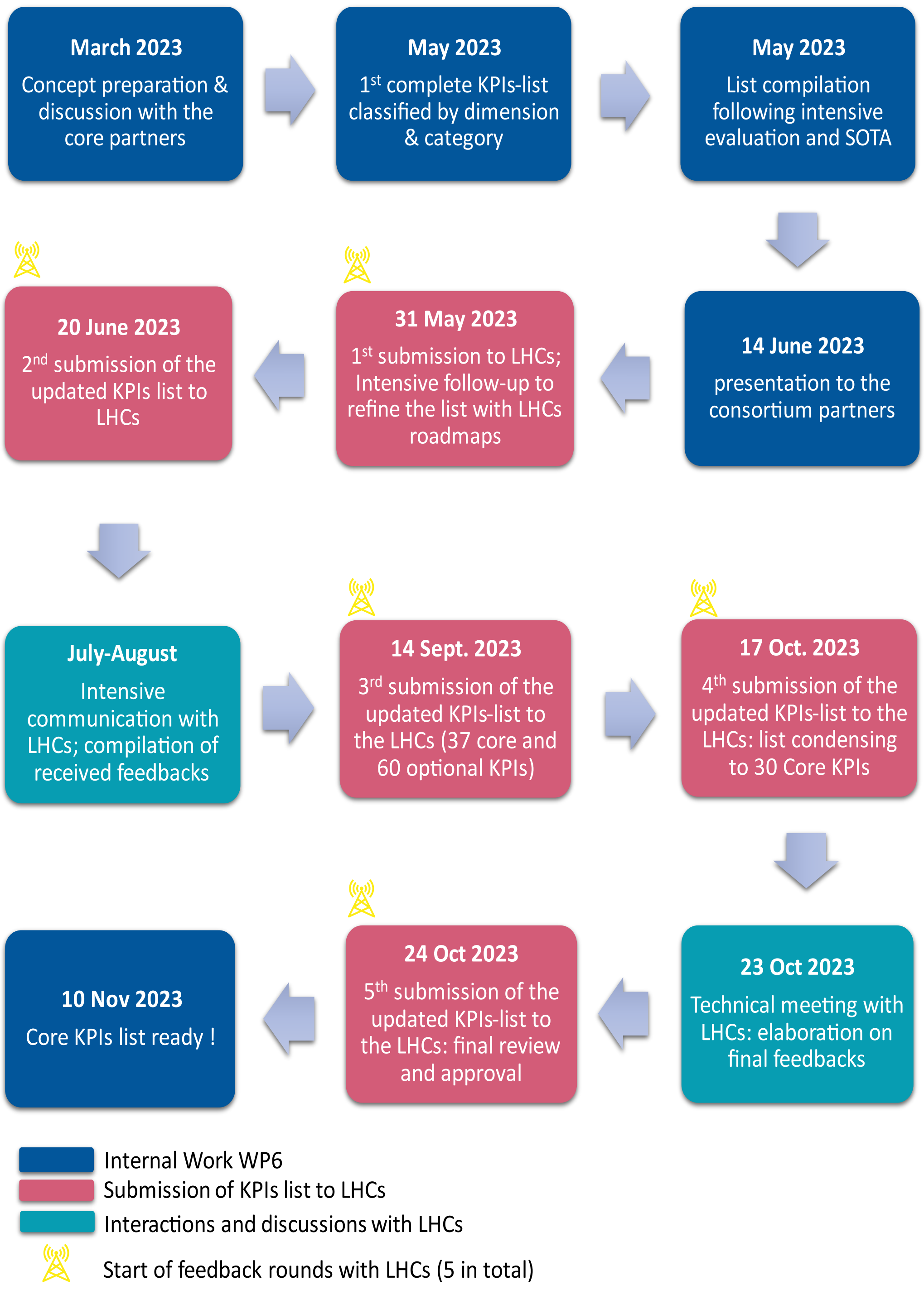

Figure 13: Co-creation process methodology for KPIs list development within ASCEND

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Feedback rounds and adaptation of the KPIs list

From this first version of the KPIs list onwards, the core partners and the LHCs have been included in the KPIs selection process following a bottom-up approach.

- The inclusion of all the project partners:

A first workshop was organized with the core partners and the LHCs to agree on the structure of the KPIs list (dimensions and solutions packages included). It has been decided that the KPIs list will be divided between core KPIs and recommended KPIs as presented in part 4.2.1.

Deeper discussions occurred with DKSR to identify the links and requirements for the KPI engine.

To align the activities between the different WPs, the list of KPIs for the economic dimensions has been developed together with R2M and the WP5 core team.

- The inclusion of external stakeholders:

The established co-creation process of KPIs development were extended to include external experts in addition to internal project stakeholders of LHCs and SPs owners. This includes an interaction with EU representatives involved in the development and update of the Self Reporting Tool (SRT) within the Smart Cities Marketplace (SCM) [42]. The exchange encompassed a presentation on the approach and development history, framework, and list of already existing KPIs in the SCM[4]. This also included the simple list of recently included KPIs in the SRT to account for monitoring and evaluation of PEDs. The outcomes of this high-level exchange have been included in the process of KPIs development of ACSEND project. In general, the discussion highlighted that the KPIs are based on individual actions and can be aggregated various ways (geographic, technology, etc), KPIs are (pilot) project based, not city based. Nevertheless, project-based Key Performance Indicators (KPIs) imply, under certain conditions, the potential for further replication at the district and city scale. This is a crucial consideration in the long-term scope of Smart City and Community (SCC) lighthouse projects, which aim to lay the foundation for widespread replication. Furthermore, the description of some KPIs was aligned with the updated SCIS guideline on KPIs description "monitoring KPI guide" [[43]. This alignment is of strategic importance as it makes use of the so far established SCIS KPIs framework and helps facilitate the later effort of filling ASCEND monitoring results into the SRT.

In addition, in the final stage of the KPIs development, both the monitoring methodology and the set of the developed KPIs, were presented to the Task Group-Monitoring & Evaluation of Scalable cities to receive feedback and recommendation from the experts of the task group.

- The key role of the LHCs:

From the beginning onwards, the LHCs were involved in the decision-making process for the selection of the KPIs list. Indeed, in total, five rounds of feedback, including sharing the current version of the KPIs list and planning extensive bilateral feedback meetings were performed and necessary to reach an agreement on the KPIs list. The main challenge was to align the KPIs selection with the objectives of PCEDs, while considering the specificities of the ASCEND project scope and the differences of the

[4] Rudy Rooth. Self Reporting Tool discussion, Monitoring and Evaluation task group meeting, May 10 2023.

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solutions developed in the two LHCs presented in the roadmaps in deliverables 2.1 for Lyon, and 3.1 for Munich. Table 4 displays the key take-aways for each feedback round.

Table 5: Feedback rounds for the KPIs list definition

Date	Activity	Outcomes
M4	1st Submission of the KPIs-list to LHCs for comments and feedback	Intensive communication and follow-up with the LHCs to refine the first KPI pool in respect with the LHCs roadmap.
M5	2nd submission of the updated KPIs list to LHCs	Bilateral communication with LHCs to discuss and coordinate final selection of **core KPIs**. Specific intensive discussion to finalise economic KPIs with R2M & WP5
M7	3rd submission of the updated KPIs-list to the LHCs and SPs.	37 Core KPIs and 60 optional indicators are extracted. Open points for discussion in D1, D2, D3 and D5
M8	4th submission of the updated KPIs-list to the LHCs	Agreement on the core KPIs for D1, D3 still not reached. Different focuses observed by both LHCs. The list reduced to 30 Core KPIs
M8	5th submission of the updated KPIs-list to the LHCs	Agreement and approval still needed by LYN regarding D1, D3.

5.2.2. Selected Core KPIs

The definition of the overall list of KPIs for PCEDs-monitoring followed an intensive process that started with a SOTA around monitoring and evaluation of integrated energy solutions at district scale with particular focus on PEDs and the so far accumulated experiences from running and recently closed project in the area of SCC. This effort benefited from the involvement of WP6-lead in the Monitoring & Evaluation Task Group[5]. The KPIs definition takes at the initial stage a flexible structure that allows to generate a comprehensive and inclusive list of KPIs considering the overall scale and scope of PCEDs as a large urban area -entailing multiple buildings, public space, urban infrastructure, and mobility- seeking to tackle the clean energy transition by optimising the district energy system towards annual positive energy balance. This results in a set of integrated and sustainable urban energy solutions around local RES, energy efficiency and diverse energy flexibility options (Table 5). The energy domain is a focal point of PCEDs and thus requires an extensive set of indicators to monitor and assess the performance of the district energy system. These indicators are crucial for achieving the scope of PCEDs, which is to attain an annual positive energy balance in line with sustainable urban development goals..

[5] SCC1 COLLABORATION FRAMEWORK. MONITORING & EVALUATION TASK GROUP

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Considering the scale and scope of PCED monitoring, the initially created general KPIS-list was restructured and categorised into so-called dimensions that address the main domains of PCED monitoring. Around these eight dimensions several solution groups were defined in alignment with the integrated solutions planed in the demo sites of both LHCs. Each solution group resulted in several KPIs, totalling 88 KPIs, which were further divided into two sub-categories: 30 Core KPIs and 58 recommended (optional) KPIs. This division was conducted based on the established co-creation process with the stakeholders of both LHCs.

5.2.1. List of Core KPIs

Table 5 depict the list of 30 Core KPIs disaggregated by the 8 dimensions. The following section provide a short description of each of the Core KPIs, whereas **Annexes-A** provides a detailed description of each KPI following standard Ticket. The ticket includes name, identifier, definition, description, input data and calculation formula for each KPI.

Table 6: List of core KPIs for Monitoring & Evaluation for ASCEND

Abbreviation	KPI Name	Unit
D1 – Integrated energy solutions at building level		
D1EBC1	Building energy demand and consumption (before and after intervention: target, simulated and measured)	
D1EBC2	On-site installed RES capacity for power and heat supply	
D1EBC3	On-site renewable power and heat production (measured)	
D1EBC4	Annual energy demand-supply balance of the building	
D2 - Integrated energy solutions at district level		
D2EDC1	PCED annual final energy demand/consumption (measured)	
D2EDC2	Total final energy savings of the PED	
D2EDC3	Total RES installed within the district (for power and heat supply)	
D2EDC4	Total RES production within the district (power and heat)	
D2EDC5	Smart energy storage capacity	
D2EDC6	PED annual demand-supply balance	
D2EDC7	Self-supply-ratio	
D3 - Mobility and Transport		
D3MBC1	Change towards sustainable and clean modal split (for passenger and freight & logistics)	
D3MBC2	Number of deployed EVs (passenger & freight)	
D3MBC3	Number of EV-Charging stations deployed in in the PCED area. Of which (%) EV-Charging stations allowing smart bidirectional charging	
D3MBC4	Electricity supplied to EV charging	
D3MBC5	Energy savings by mobility measures (measured and simulated)	
D4 - ICT		
D4ITC1	Data sets in joint repository	
D4ITC2	Standardized REST APIs	
D4ITC3	Share of buildings in the district with smart energy meters	

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D5 - Environmental sustainability		
D5ENC1	District annual GHG emissions	
D5ENC2	Annual CO_2- emissions reduction	
D6- Social sustainability		
D6SOC1	Residents engaged	
D6SOC2	Number of energy communities deployed	
D6SOC3	Degree of satisfaction with the solutions implemented	
D7 - Economic sustainability		
D7ECC1	Total investment in all new interventions of the PCED	
D7ECC2	Total amount of (non-public) investment attracted	
D7ECC3	Payback period/NPV/IRR	
D7ECC4	Economic value of savings (for energy saving and CO_2-emission)	
D7ECC5	District Climate Dividend	
D8 - Governance		
D8GVC1	Number of Key Stakeholders involved	
D8GVC2	Involvement of city administration	

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5.3. Description of Core KPIs

5.3.1. D1: Integrated energy solutions at building level

The first dimension covers integrated solutions at the building level. As buildings are at the core of the PED concept, this dimension can be regarded as the most central to monitor and evaluate impacts. It covers energy efficiency and renewable energy supply solutions that are implemented on the individual building level and accordingly limits its impact evaluation scope to individual buildings. Typical solutions that can be attributed to D1 include building envelop refurbishments, the replacement of heating systems, the on-site installations of RES, e.g., solar systems or heat pumps, on-site installations and use of batteries and other energy storage technologies, and the implementation of demand side management measures. The solution packages addressed by D1 include SP1, SP2 and SP3.

Besides, buildings provide a good basis of comparison for the effectiveness and efficiency of investments in sustainable energy technologies, as energy demand and supply in buildings is a well-researched topic with multiple well documented case studies. The monitoring of the proposed KPIs will help to contextualize the achievements made by the implementation of the SPs, providing a sound basis for replication.
To cover the specific solutions implemented in the ASCEND, a set of 4 core KPIs to evaluate the impact of the solutions was derived within the co-creation process between WP 6 and the LHCs, outlined in section 4.3.1.
Figure 12 indicates the four core KPIs defined for D1: Integrated energy solutions at building scale.

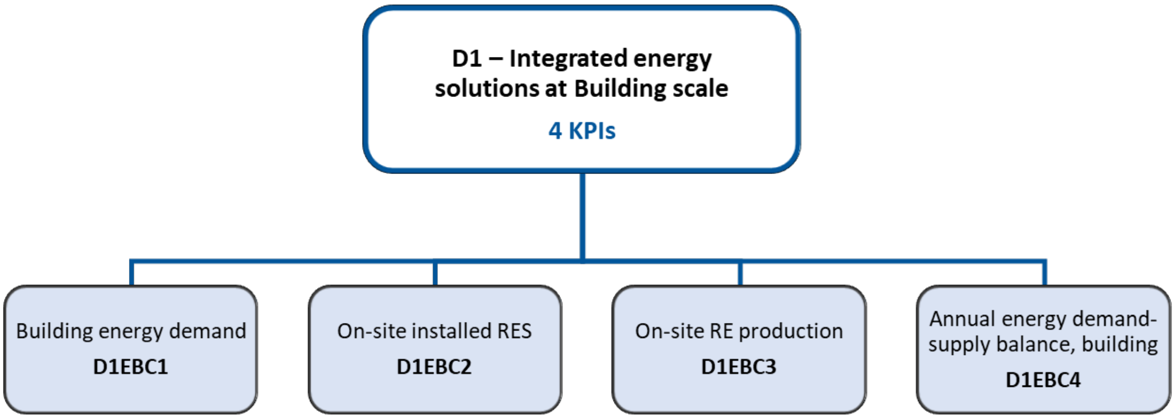

Figure 14: Overview on core KPIs in D1: Integrated energy solutions at building level

The KPIs reflect the solutions implemented within the PCEDs of the LHCs. These include building energy refurbishments (including heating system switches), achieving energy efficiency standards higher than the national regulations in the case of new constructions, the installation and monitoring of local renewable energy supply capacities (mainly rooftop PV systems), and the achievements of positive energy balances at the building scale on annual basis.

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5.3.2. D2: Integrated energy solutions at district level

The second dimension of KPIs relates to the spatial scope of the district level and therefore represents the most important KPI dimension to evaluate the concept of PCEDs. The monitoring concept for this dimension aims not only to monitor the PCED energy balance and evaluate whether the requirements of a PCED, introduced by the European framework [26], are met, but also to monitor the implementation of solutions that enable the tapping of synergies related to energy demand and supply on the district level, e.g., energy communities, energy storage solutions etc.
Figure 13 indicates the seven core KPIs defined for D2: Integrated energy solutions at district level.

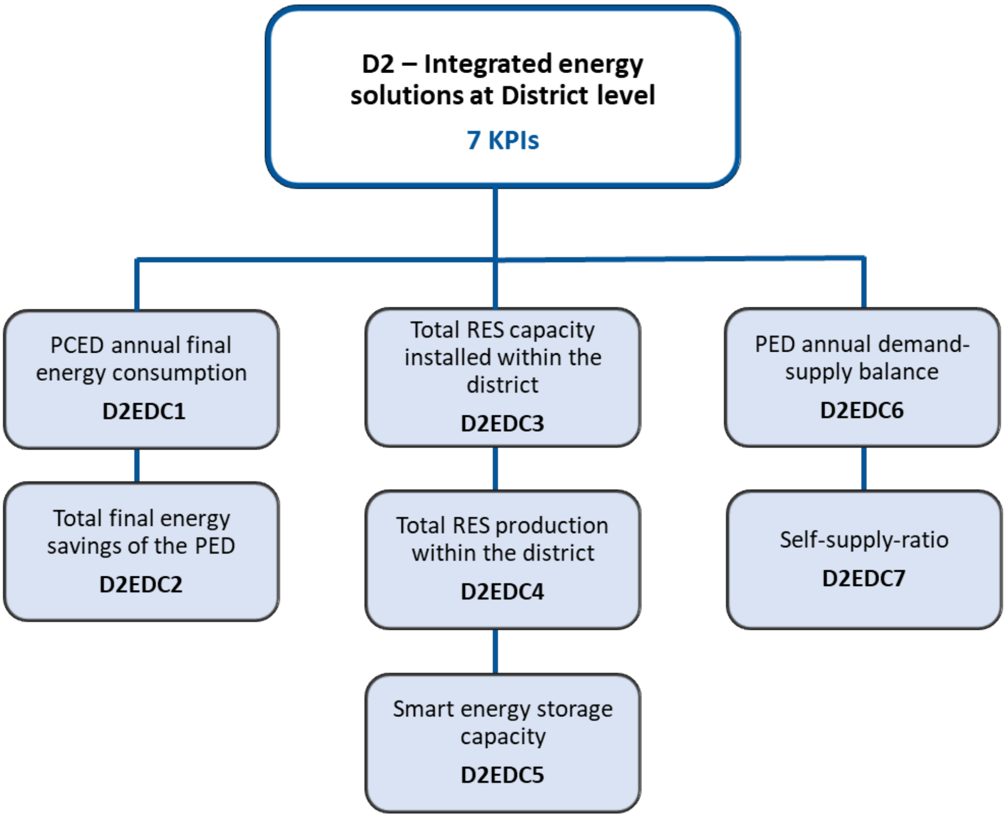

Figure 15: Overview on core KPIs in D2: Integrated energy solutions at District level

The solutions that are covered by this dimension include the cumulative solutions at building level, e.g., refurbishments and RES supply technologies installed at the buildings, but also energy demand and supply technologies that cannot be attributed to individual buildings, but are included in the PED energy balance, like street lighting, open space PV, mobility related energy demand and other energy consuming infrastructure. Additionally, it is important to note that the KPIs cover energy demand and supply balances considering various temporal aggregation levels, e.g., annual or hourly level, depending on data availability. This allows the assessment of solutions that target the optimization of local energy use and introduction of flexibilization options that aim to increase self-sufficiency.

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5.3.3. D3: Sustainable mobility

The third dimension for KPIs to be covered within ASCEND relates to the solutions implemented regarding sustainable mobility. The monitoring aims to identify behavioural changes towards a more sustainable modal split in the mobility of residents within the PCED. In the context of ASCEND, mobility related energy demand is included in the PED energy balance[6], therefore, Dimension 3 is of high importance for the overall evaluation of the PED. The KPIs further aim to reflect the implementations of solutions that enable sector coupling between the mobility and energy sectors, e.g., bidirectional charging stations

Figure 14 indicates the five core KPIs defined for D3: Sustainable Mobility.

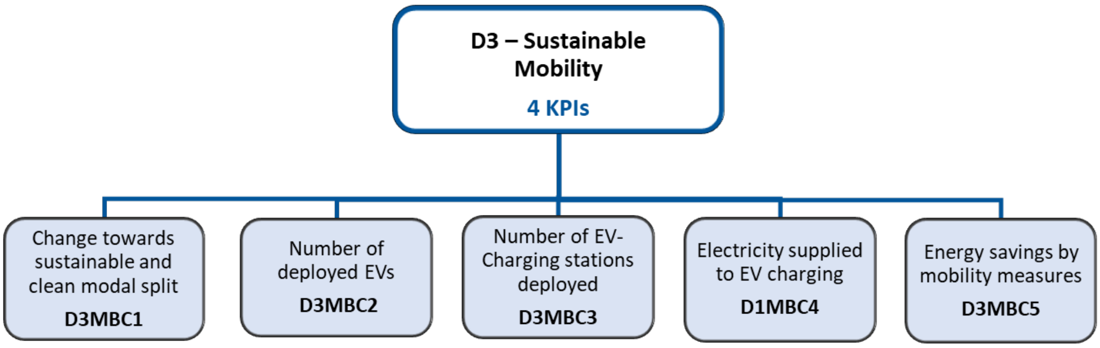

Figure 16: Overview on core KPIs in D3: Sustainable Mobility

The solutions covered by this dimension include the deployment of charging stations, EVs, and the testing of new mobility concepts (including freight) and land use concepts for parking spaces within the PCED areas.

[6] The mobility related energy demand will be included in the scope of the energy balance calculations for the PCED developed in the two LHCs if the necessary data are available and can be collected within the framework of the project (see details in Annexes-A)

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5.3.4. D4: ICT and digital infrastructure

The fourth dimension for KPIs to be covered within ASCEND relates to the application of ICT technologies in the implementation and monitoring of solutions. It aims to quantify the datasets covered within the KPI engine, developed in WP 6 as part of solution package 1. Additionally, digitalized energy meters are covered, even if they should not be part of the KPI engine. Figure 15 indicates the three core KPIs defined for D4: ICT.

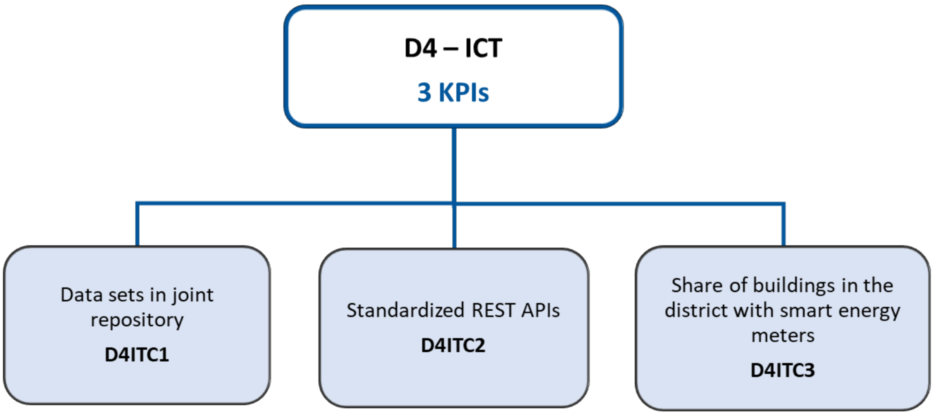

Figure 17: Overview on core KPIs in D4: ICT

This dimension can be regarded as integral part of the overall monitoring concept, as it entails the KPI engine that is to calculate and disseminate the KPIs per PCED.

5.3.5. D5: Environmental Dimension

The fifth dimension for KPIs to be covered within ASCEND relates to the assessment of the environmental performance of the implemented solutions.[26] emphasizes the importance of environmental aspects in the assessment of PCEDs, arguing that a positive energy balance should also entail low GHG emissions. Following this rationale, D5 mainly targets the assessment of annual GHG emissions and achieved reductions by the PED implementation. Figure 16 indicates the three core KPIs defined for D4: ICT.

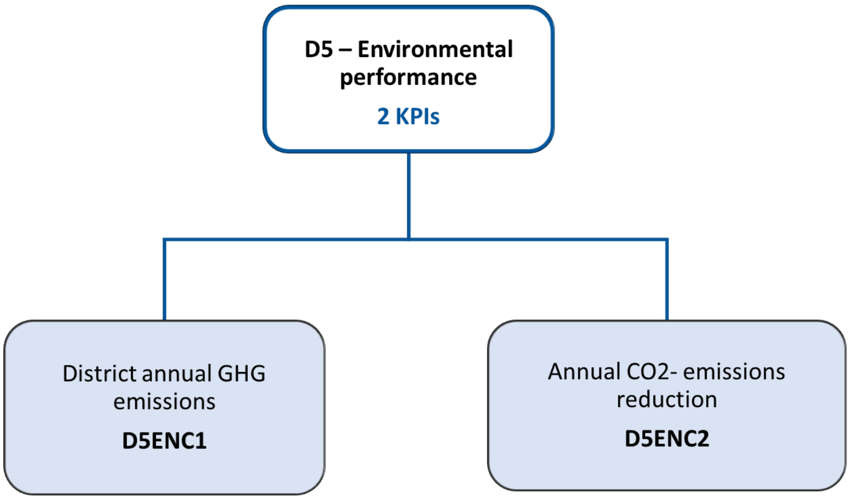

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Figure 18: Overview on core KPIs in D5: Environmental performance

This dimension is affected by all solutions that result in energy efficiency improvements or energy carrier switches. This mainly relates to building energy refurbishments, the switch to carbon neutral heating options and the use of alternatives to fossil-fuel powered cars and trucks in the passenger and freight transportation. Offsets of GHG emissions can be considered through potential exports of electricity generated from renewable sources from the PED to the grid.

5.3.6. D6: Social Dimension

The sixth dimension for KPIs to be covered within ASCEND relates to the assessment of social implications induced by the implemented solutions. Like for D5, the inclusion of D6 is motivated by the PED definition followed in ASCEND [26]a good life for its inhabitants, following social sustainability. D6 therefore aims to cover this social sustainability across various aspects ranging from the implementation of energy communities that benefit the local residents to the assessment of their satisfaction with the implemented solutions, creating a feedback loop that allows for refinement of the SPs before replication.
Figure 17 indicates the three core KPIs defined for D6: Social performance.

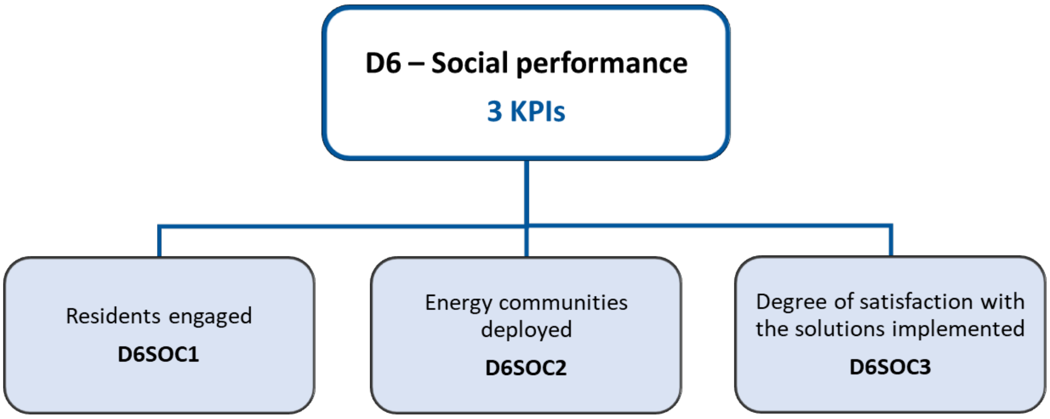

Figure 19: Overview on core KPIs in D6: Social performance

This dimension is affected by multiple solutions ranging from PV installations and their integration in the overall image of the PED to the integration of residents in energy communities and their perceived benefit from this.

5.3.7. D7: Economic and Financial Dimension

The seventh dimension for KPIs to be covered within ASCEND relates to the assessment of the economic performance of the implemented solutions. Like D5 and D6, the integration of D7 follows the three pillars of sustainability and the [26] performance of SPs is naturally of high importance for their replication. Therefore, D7 aims to evaluate economic performance of individual SPs based on several economic KPIs, like the net present value, the dynamic payback period or the internal rate of return. Additionally, D7 aims to account for the overall investments made to achieve the PED,

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differentiating between public and private investments, therefore aiming to provide benchmarks for the replication of the overall PED concept.
Figure 18 indicates the five core KPIs defined for D6: Social performance.

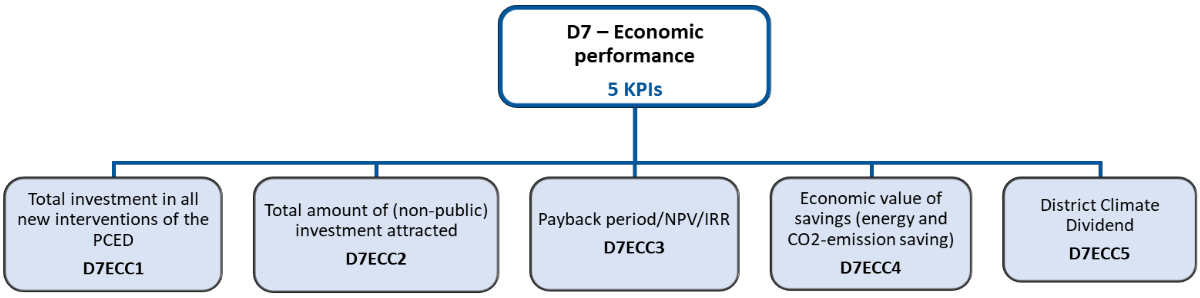

Figure 20: Overview on core KPIs in D7: Economic performance

D7 targets mainly individual solutions that can be attributed to direct investments and related efficiency gains or energy or cash returns such as the refurbishment of buildings, the installation of local RES supply technologies and the development of energy infrastructure.

5.3.8. D8: Governance Dimension

The eighth and final dimension for KPIs to be covered within ASCEND relates to the assessment of new governance frameworks tested within the implementation of the PCEDs. D8 aims to assess the involvement of the city administration in the implementation of the PCEDs by targeted surveys. The feedback from these stakeholders is of high importance for the replication of PCEDs, as city administrations play a vital role in the implementation of PCEDs, as they can impose specific requirements on local development areas and moderate the interests of other stakeholders involved in the implementation of the PED. Figure 19 indicates the two core KPIs defined for D6: Social performance.

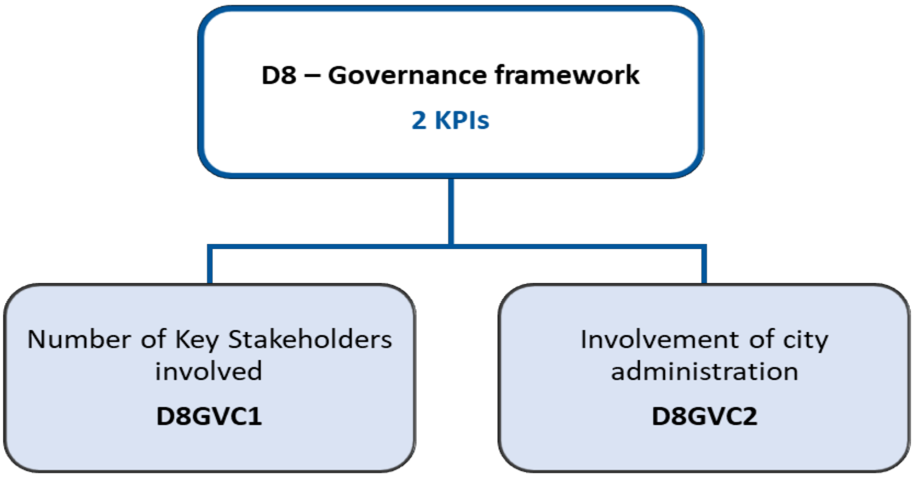

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Figure 21: Overview on core KPIs in D8: Governance framework

The main solution targeted by D8 is the PED orchestrator from SP6, as this role is designed to moderate the different stakeholders involved in the implementation process and is designed as potentially new governance role for the implementation of PCEDs.

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5.4. List of Optional KPIs

The list of the resulting 58 optional (recommended) KPIs can be found in **Annexes-B**.

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6. Monitoring Methodology

ASCEND has established an integrated monitoring and evaluation methodology (IMEM) that will be advanced based on the experience gained from previous lighthouse city projects like Smarter Together [3]. The IMEM comprises 5 main steps covering:

- Setup of monitoring infrastructure at the demo sites of the LHCs.
  1. Data collection and transfer to the data platforms of both LHCs.
  2. Submitting the data to the KPI-engine for further processing, including quality check, cleansing and visualisation
  3. KPIs calculation
- KPIs-based Impact assessment and further replication.

The implemented solutions to achieve the PCEDs in both LHCs follow the previously presented set of 6 solution packages. Monitoring these solutions and evaluating their impacts using the derived KPIs provides the quantitative basis and the necessary knowledge and experience to help optimize the process of PCEDs implementation.

This outcome is essential for the further rollout and replication of the SPs in the MCs alongside the PCEDs deployment in both LHCs and beyond. In supporting the PCEDs deployment process, the IMEM aims to comprehensively evaluate the implementation processes of the respective demo sites in both LHCs, spanning from the planning phase to the implementation and the subsequent future replication as illustrated in Figure 20. This entails offering a clear view on the implementation processes and influential factors including citizen engagement, stakeholder involvement, and technical, administrative, and legal challenges.

Given that PEDs embody a novel concept whose full functionality is yet to be demonstrated, it is valuable to collect information about challenges, barriers, and best practices encountered during the implementation phase. Taking into account the specific framework conditions of each city, these findings establish a robust practical foundation for the citywide scaling-up and replication of the SPs and the deployment of PCEDs in the pursuit of climate neutral cities.

Details on the monitoring methodology will be given in deliverable 6.3 “Manual for the Standardized KPI Engine”. The use of the collected monitoring data as input parameters for the KPIs calculation are elaborated in the KPI tickets in **Annexes-A.**

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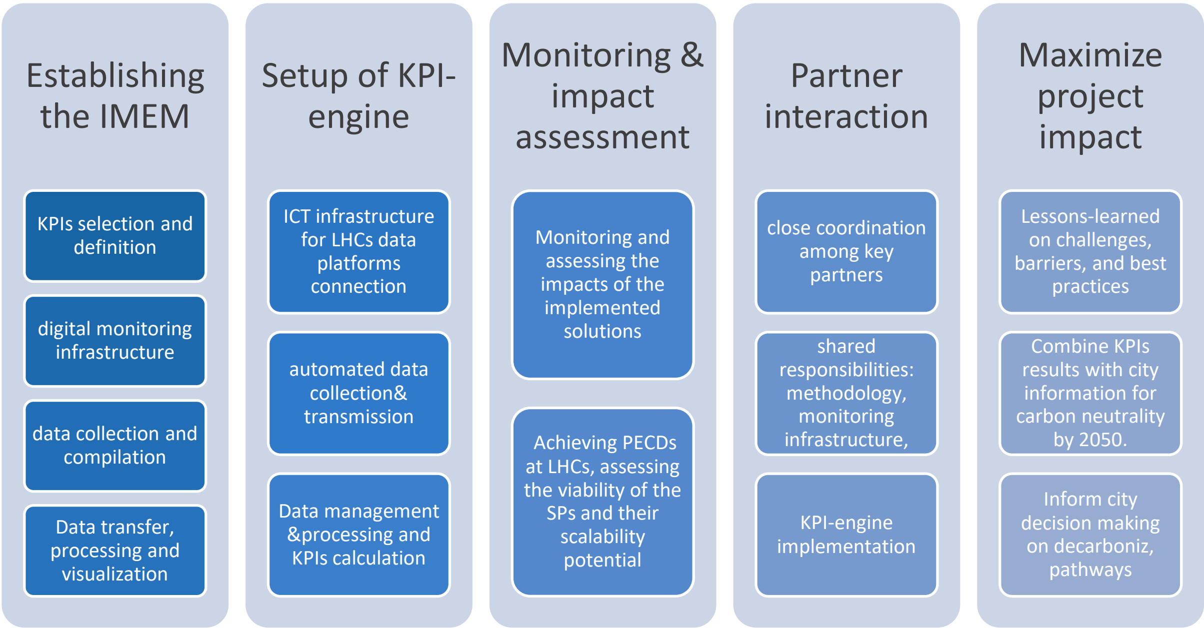

Figure 22: summary of steps and objectives along the whole process of monitoring & evaluation and impact assessment of the implemented PCEDs within ASCEND (IMEM: integrated monitoring and evaluation methodology).

6.1. Monitoring data

The calculation of the KPIs relies fundamentally on the quality of the input data. Monitoring data has to be measured directly from the implemented solutions of the demo sites using the established monitoring infrastructure -and not synthetically generated or simulated- so they reflect the real performance of the considered system. Besides, they should ensure a certain level of quality for a correct KPIs calculation. For this purpose, collected monitoring data undergo a systematic data processing for quality check, cleansing and analysis. Thereby collected data are checked for completeness following the anticipated data records for the considered measurement period. This implies checking timestamps and meter readings to locate any missing values beside identifying and outliers using standard data cleaning algorithms.

The so prepared and cleaned data provide the input for the KPIs calculation. Generally, two types of KPIs-calculation can we differentiated:

- Direct KPIs-calculation from monitoring data: The system perfomance can be directly assessed based on the monitoring data collected, based on the established monitoring infrastructure (e.g.: meters data processing such as building space heating and DHW)
- Indirect KPIs-calculation from monitoring data: This is applicable, particularly for ICT, mobility, and environmental measures that cannot be directly assessed through quantitative monitoring process. These aspects necessitate a qualitative process, such as surveys and additional estimation schemes. For instance, certain ICT applications related to energy system flexibilization may shift the load to different time periods, indirectly impacting required local energy storage capacity and the amount of direct renewable energy consumption. This indirect financial and technical impact requires further estimations. Similarly, assessing reduction on traffic and the resulting CO2 emission reduction in the district due to mobility initiatives like E-car sharing and biking/walking requires a workaround at the district scale to

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monitor such effects. For this reason, ASCEND consider conducting "surveys" at the demo PCEDs as elaborated below.

In general, it is important to highlight that monitoring data collection is confronted with several challenges like privacy, security and cost issues. Details on the data management framework used within ASCEND are provided in Deliverable 6.1 "Data Management Plan".

6.2. Monitoring infrastructure in the LHCs

A simplified schematic representation of the monitoring concept applied in both LHCs is presented in Figure 21. Following the setup of the monitoring infrastructure, consisting of meters and measurement sensors (for heat, electricity, gas,…) and related logistic for data acquisition (e.g., M-Bus modules, signal converters), the data are collected automatically or semi-automatically using local data logger and then transferred to the local data platform of the LHCs. subsequently, they are further submitted to the KPI-engine for further processing, evaluation, and KPIs calculation. The sampling frequency of data measurement depends on the underlying process of the measured parameters and varied between 15 minutes and one hour for most of the energy consumption and production data.

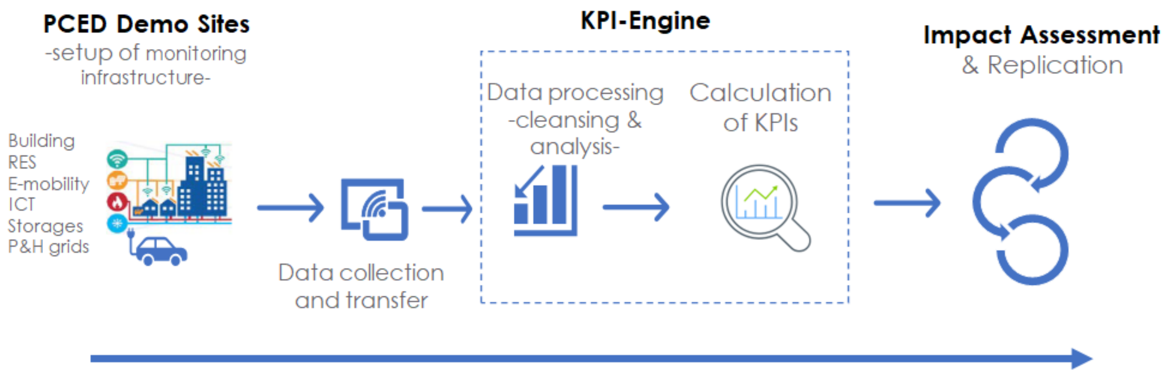

Figure 23: schematic representation of the main steps of the integrated monitoring and evaluation and impact assessment process (P&H: power and heat, RES: renewable energy supply)

Detailed description of monitoring infrastructure, data collection and processing are provided in D6.3 (KPI-engine).

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6.3. Surveys of Citizen and Stakeholder

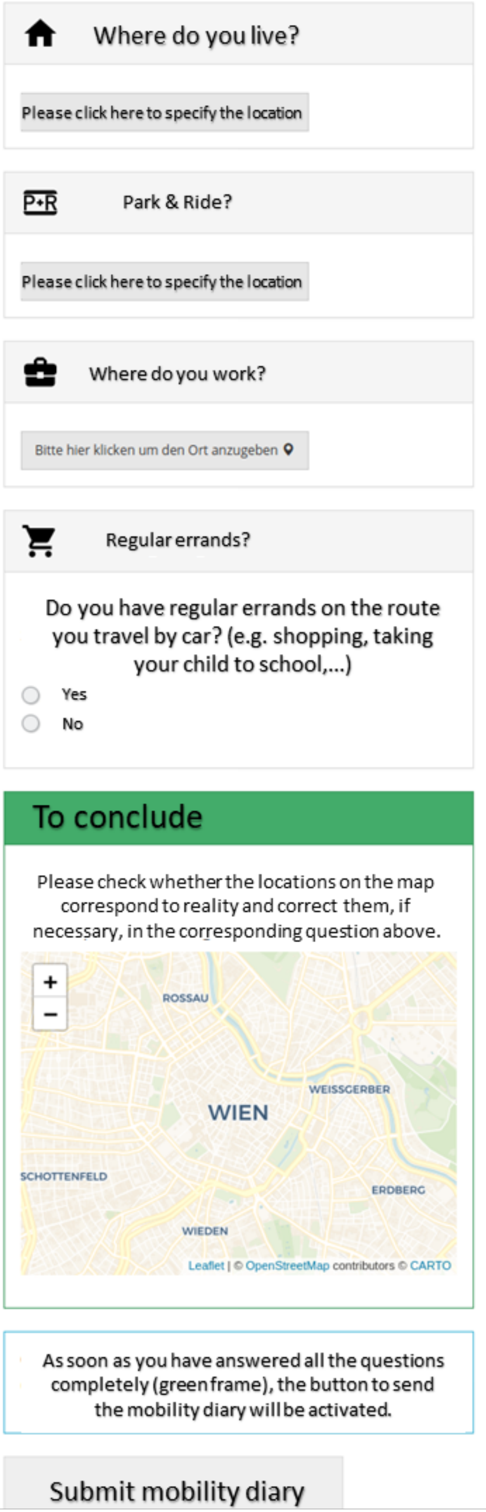

Figure 24: AIT collection tool for mobility behaviour that will be adapted to collect mobility information at both demo PCEDs in Lyon and Munich.

To support the monitoring and evaluation process, ASCEND plans to conduct surveys at the demo PCEDS of Lyon and Munich to provide complementary qualitative and quantitative input data for the KPIs calculation of Mobility and Social dimensions. Such surveys provide an effective concept for engaging with citizen and stakeholders and involving them in the M&E process.

Two surveys are planned before and after the interventions. The first is a “baseline survey” aiming to provide initial baseline data to establish a reference point to evaluate the impact of the implemented measures. The secund one to evaluate the effect of the interventions on the group of surveyed persons.

Both surveys will be used to collect general information about the respondent’s household like means of transport, available driving licenses and transport cards, and socio-economic information. In addition, mobility behaviour will be collected using a diary tool like the one in Figure 22. This data will be used to calculate the mobility behaviour of residents of the area. In addition, information about online shopping will be collected to estimate delivery traffic in the area. The information calculated from the information of the first survey will be used as a baseline to compare the differences of mobility behaviour after the implementation of measures.

The secund survey will be conducted after implementation of the measures and aims to collect feedback about system performance and the change triggered by the implemented measures. Next to a second collection of mobility behaviour and general information, the survey will collect information about the visibility, and success of the implemented measures.

Additionally, a survey for target stakeholders will be developed to gather information about the pilot regions to complement the citizen survey. Here information about the regions will be collected before and after the implementation of the measures to collect important changes in the regions that cannot be collected through citizen surveys.

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7. Conclusions

Deliverable D6.2 outlines a comprehensive set of KPIs aimed at monitoring and evaluating the performance of PCEDs in the LHCs Lyon and Munich, as well as in six multiplier cities.

Through an extensive co-creation process involving stakeholders from both LHCs and other project partners, a list of 30 Core KPIs spanning eight dimensions was developed. These dimensions encompass energy performance at both building and district scales, urban mobility, ICT, environmental, socio-economic, and governance aspects. The core KPIs, agreed upon with the LHCs, represent the focal point of our monitoring and evaluation efforts for the demo PCEDs. Additionally, a set of 58 optional KPIs was identified to gradually broaden the scientific scope of the monitoring process and gain deeper insights into PCED performance. However, their calculation is not mandatory for the LHCs as it presents a significant challenge in terms of data collection. Their computation is contingent upon data availability, a determination to be made over the course of the project.

Additionally, the document offers insights into the integrated monitoring and evaluation methodology (IMEM) established in ASCEND, serving as a guide for managing KPI-based monitoring and impact assessment.

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9. Annexes-A Core KPIS

Description of Core KPIs-Tickets

9.1. Annex A-1: Descriptions of KPIs

This annex follows a systematic approach to describe the 30 core KPIs that have been extracted based on an intensive co-creation process with the LHCs Lyon and Munich.
Each KPI is described by a standard label, referred to as a "Ticket" that includes name, identifier, dimension, and category of its belonging within the KPIs-list, the physical definition and unit, its calculation approach, related mathematical formula, and the needed input data for its quantitative calculation. A subcategory is devoted to elaborating on the related monitoring infrastructure, data collection process and sampling rate.
All the listed KPIs will be calculated for both LHCs7 based on **input data** provided by them. The main group of the input data refers to the monitoring data that measure the performance of the implemented solutions at the demo PCEDs using the onsite monitoring infrastructure. The other source of data refers to buildings, district and energy infrastructure specifications, climate and environmental data, social and demographic data for the demo PCEDs and LHCs, financial and economic data on cost, expenses, and financial metrics beside regulatory and legal data like building and industry standards. Another source of data are the results of **surveys** conducted during the project implementation, mainly to assess social and mobility measures.

9.2. Calculation approach

The calculation approach is elaborated in the related tickets of the KPIs selected in ASCEND. This approach follows the calculation methodology applied in other SC lighthouse projects that follow the Smart Cities Marketplace (SCM) Self-Reporting Guide [28]. Several documents have been consulted covering technical monitoring guidelines, definition of KPIs and data needed for their calculation.
The Technical Monitoring Guide[8] elaborates on the requirements of data collection entailing data quality, time frame, identification, and meters/sensors. Besides, it addresses the specifications of the monitoring plan, the characterization of the data to be provided, and their collection procedures. This applies for the main pillars of the so-called "field of actions" entailing energy, building, mobility, and ICT as usually addressed in SC lighthouse projects. ASCEND is following these guidelines, but due to its focus on PCEDs, it incorporates additional pillars, in particularly to comply with the energy requirements at district level as elaborated among the selected 8 dimensions of KPIs definition. These aspects are evident in the tickets detailing the ASCEND core KPIs. Calculating the impact of certain intervention requires the provision of baseline data on the initial state of the system. Regarding the methodology of data collection, it is important to distinguish between retrofitting of an existing system (e.g., building refurbishment) and developing an entirely new one (e.g., new build). For retrofit

[7] There are few exceptions where some of the KPIs will be calculated by one or the other LHCs. This is mentioned at the related KPI ticket.
[8] https://smart-cities-marketplace.ec.europa.eu/insights/publications/technical-monitoring-guide

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projects, a baseline is set by monitoring relevant data one year -or more – before the renovation begins, reflecting existing conditions in the buildings of interest.
For new system development, the baseline is established by standardizing the proposed scenario using design data, i.e., building energy modelling (BEM) under quasi real conditions like climate, number of occupants, control strategies. Another source of baseline data is the building energy certificates and the applied national regulations for refurbished and new buildings for residential and non-residential building (e.g., EU-regulations[9,10], dena[11], OIB GUIDELINE[12], TABULA[13]). Such regulations define ambitious targets that could be considered as target indicators, serving as benchmarks against which the effectiveness of the intervention measures can be assessed.

9.3. Supporting parameters for the KPIs calculation

In order to calculate the KPIs, there is a need for specific factors, which are specific for each demo site of the LHCs like climate data, building and technology specification beside other supporting parameters that are semi-standardised at national and EU level that might include:

- Technical data: conversion factors between the energy levels (e.g., final to primary), efficiency of the applied technologies (boilers, heat pumps, etc), building characteristics (e.g., building type and age, gross floor area, roof top,
- Economic data: national prices for energy carriers such as electricity and gas.
- Environmental data: GHG emission factors for specific fuels as well as the grid emission factors for electricity and district heating.

9.4. Definition of energy levels

Along the energy supply chains from the extracted resources to the delivered energy services the energy system distinguish different energy levels that are sequentially connected via so-called conversion technologies.

- **Primary energy:** Energy in its naturally occurring form (crude oil, NG, coal or uranium at the mining level or Biomass at the production level)
- **Final energy:** Energy delivered to the end-consumers. It excludes losses in conversion, distribution and transmission, the energy sector's own consumption and the non-energetic use of energy.
- **Useful energy:** The actual energy used by the consumer (heat, motive power, lighting etc.) to perform an energy service. It differs from the final energy by the efficiency of the conversion devices at the end-use level.
- **Energy service:** The served needs of the consumer to fulfil essential functions and enhance the quality of life. It encompasses cooking, illumination, processing, comfortable indoor

[9] https://epbd-ca.eu/wp-content/uploads/2018/08/CA-EPBD-IV-France-2018.pdf
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[13] https://episcope.eu/welcome/

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temperature, refrigeration, telecommunications, transportation, etc. It results from the utilisation of useful energy beside other services and goods (capital, know-how, labour).

Note: Within this document, the phrases "energy demand" and "energy consumption" are used interchangeably to describe the energy needs of the consumer (end-user). However, it is required to slightly distinguish between them, especially when addressing monitoring and evaluation processes. "Energy consumption" specifically refers to the energy actually used by the consumer and will be based on monitored data. "Energy demand" pertains to the calculation of the energy needs of the consumer and is based on modelling and simulation.

Energy carriers

Final energy forms delivered to cover district energy demand encompass:

- Gasoline, Diesel (for mobility only)
- Biodiesel, Ethanol (for mobility only)
- Natural gas
- LPG
- Biomass
- Heavy fuel oil
- Electricity (locally generated or from grid)

Energy consumption sectors

They encompass household, services (all building types expet household), transport sector (passenger and freight), manufacturing industry, construction, urban agriculture.

Definition of a building

The term "building" represents a structure with a roof and walls used for living, work or other service activities. It refers to the physical boundaries of the building envelope, which can encompass multiple postal addresses.

Floor area of the building:

To enable the comparability between buildings, the performance indicator is related to the size of the building (e.g. gross floor area or net floor area, heated floor area) and the considered time interval (e.g. year)

Presenting the KPIs in different units:

Each KPI is calculated following an unambiguously defined formula with one main unit. However, for some KPIs other derived units are recommended as they provide addiotionl information. Example: achieved buildinging energy saving is expressed in kWh/a. However, it is adviaslabe to relate it to the building floor area, i.e., kWh/m^2.a or express it in percentage [%] of the total baseline building energy demand $Energy\ saving/Building\ energy\ demand\ \cdot 100$

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D1 Integrated energy solutions at building scale

KPI description					
Abbreviation	D1EBC1	**Dimension**	D1	**Category**	Building energy consumption and energy saving
Name	**Building energy demand/consumption**				
Definition	Depending on data availability, this KPI can express monitored retrospective energy consumption of a building or modelled building energy demand, following standardised calculation methods. Hence, the two terms "energy consumption " and "energy demand" are distinguished, wheas monitored energy consumption is the preferred expression for this KPI. The term "building" refers to the physical boundaries of the building envelope, which can encompass multiple postal addresses. Building final energy demand/consumption before and after the intervention (e.g., refurbishment) refer to the total final energy provided to the building to ensure its proper performance for a certain period (hour, day, year). It can further be expressed as a specific value relating the final energy to the building floor area. Subject to the data availability, the final energy demand can be distributed by energy form and end-use. • Final energy forms: district heating, electricity, oil, gas, biomass • Useful energy (end-uses): space and water heating, cooking, cooling, appliances, lighting.				
Unit	$kWh, \frac{kWh}{m^2.a}$				
Description	Energy demand/consumption: referes to the delivered final energy by sector and energy form. It provides deep insight into the energy performance of the respective building and allows for identifying energy efficiency and CO_2 reduction potentials. Subject to the data availability, two categories of final energy demand/consumption are consulted: • Monitored KPI: refers to the real measured consumption. Monitoring data is to be adjusted by the respective weather conditions and occupancy of the building. • Simulated KPI: refers to the building energy performance certificates (EPC) or results of static building simulations (conducted by the LHCs or the building developers). Example: EPC Energy classes from A-G[14]				

[14] https://www.entranze.eu/files/downloads/D5_1_3/ENTRANZE_Integration_of_report_D5.1_D5.2_D5.3_final.pdf

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	Energy saving: Calculation based on the comparison of the energy consumption/demand after the intervention with the baseline energy consumption/demand . *Note: national regulation define requirements on energy performance for new and refurbished buildings which can be further consulted for comparison purpose*[15]	
KPI calculation		
Monitoring Framework	Monitoring infrastructure	Heat, power and gas meters to measure final building energy consumption.
	Data collection process	Covering both data of baseline and after the interventions: • Meter reading of demo sites (15‘, h) for electricity, gas, and DH consumption (as appropriate). This process can be automated via urban data platform of the LHCs (see KPI-engine) • Data transmitted from building owners or energy providers. The collected energy consumption is mostly aggregated (based on bills monthly or annually). • Meta data from energy performance certificate (EPC) e.g.: data transmission by building owners
	Data monitoring interval	annual
	Baseline comparison	YES (monitored)
	Physical scope	Building
	Solutions Packages involved	SP3, SP1
Input Parameters	A_b (m²): Floor area of the building (refurbished or new) HDD (°C . d/ a): heating degree days (Source: LHCs) CDD (°C . d/ a): cooling degree days (Source: LHCs or open-source data); only applies when the building is cooled. NF_{Wt} : Weather normalization factor, based on the calculation of the difference between the monitored year HDDs and an average year HDDs. NF_{Oc} : Occupancy normalization factor, based on the calculation of the difference between the monitored year occupancy and an average occupancy rate.	

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	$FE_{B,a}$(kWh/a): achieved final building energy consumption (monitored). It is the sum of FE devoted to cover thermal and electricity demand. $FE_{B,r}$ (kWh/a): reference final building energy demand (target, simulated or monitored baseline data). It is the sum of FE devoted to cover thermal and electricity demand. FE_{s} (kWh/a): Final energy saving of the building resulting from building efficiency measures and switching to new heating system
Calculation formula	$FE_{B,a} = \sum_{i=1}^{n} FE_{B,a,i}$; i: energy carrier (elec. , district heating, gas, biomass) $FE_{B,r} = \sum_{i=1}^{n} FE_{B,r,i}$ i: energy carrier (elec., district heating, gas, biomass) $FE_{B,s} = (FE_{B,r} \cdot NF_{r,Wt} \cdot NF_{r,Oc}) - (FE_{B,a} \cdot NF_{a,Wt} \cdot NF_{a,Oc})$ Above KPIs can be calculated as specific values relative to building floor area $\frac{FE_B}{A_b} \left(\frac{kWh}{m^2.\ a}\right)$ or inhabitant The energy saving can additionally be calculated as relative value to the reference energy demand. $FE_{s-sp} = 1 - \frac{FE_s}{FE_r}$ (%)
References	Klimaactive-2020 ENTRANZE EU-SCIS, Monitoring KPI Guide. 2018 https://smart-cities-marketplace.ec.europa.eu/insights/publications/technical-monitoring-guide

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<table>
<tr><th colspan="7">KPI description</th></tr>
<tr><td>Abbreviation</td><td>D1EBC2</td><td>Dimension</td><td>D1</td><td>Category</td><td colspan="2">RES and energy storage infrastructure</td></tr>
<tr><td>Name</td><td colspan="6">On-site installed RES capacity for building power and heat supply</td></tr>
<tr><td>Definition</td><td colspan="6">Total renewable power and heat capacities installed onsite at the considered building</td></tr>
<tr><td>Unit</td><td colspan="6">kWp</td></tr>
<tr><td>Description</td><td colspan="6">PV and micro wind, solar thermal (installed at rooftop, facades, and open space), heat pump, geothermal and biomass. As the various local RES technologies entail different economic and technical performance, individual KPIs are to be provided per technology type.</td></tr>
<tr><th colspan="7">KPI calculation</th></tr>
<tr><td rowspan="6">Monitoring framework</td><td colspan="3">Monitoring infrastructure</td><td colspan="3">No meters. Only technology specification</td></tr>
<tr><td colspan="3">Data collection process</td><td colspan="3">Monitoring data, datasheets, modelling</td></tr>
<tr><td colspan="3">Data monitoring interval</td><td colspan="3">annual</td></tr>
<tr><td colspan="3">Baseline comparison</td><td colspan="3">NO</td></tr>
<tr><td colspan="3">Physical scope</td><td colspan="3">Building</td></tr>
<tr><td colspan="3">Solutions included</td><td colspan="3">SP2, SP3</td></tr>
<tr><td>Input Parameters</td><td colspan="6">$P_{B, th}$: building installed thermal RE capacities for heat pump, solar thermal and geothermal.
$A_{B, ST}$: m² of building installed solar thermal collectors.
$P_{B, ele}$: building installed peak power capacities for PV and micro wind.</td></tr>
<tr><td>Calculation formula</td><td colspan="6">$P_{B,\text{ the, total}} = \sum_{i=1}^{n} P_{B,th,i}$; i: building $intalled\ therml\ capcities$</td></tr>
</table>

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	$P_{B,\,elec,\,total} = \sum_{i=1}^{n} P_{B,ele,i}$; i: building $intalled\ power\ capcities$

KPI description					
Abbreviation	D1EBC3	**Dimension**	D1	**Category**	**RES and energy storage infrastructure**
Name	**On-site renewable power and heat production (measured)**				
Definition	Renewable power and heat production based on monitoring data				
Unit	kWh				
Description	As the various local RES technologies entail different economical and technical performances, individual KPIs are to be provided per technology type of heat and power RES based on the collected meter data.				
KPI calculation					
Monitoring framework	Monitoring infrastructure	Heat and power meters to measure the electricity and heat production			
	Data collection process	Monitoring data of local supply technologies, simulations based on local context			
	Data monitoring interval	annual			
	Baseline comparison	NO			
	Physical scope	Building			
	Solutions included	SP2, SP3			
Input Parameters	E_{PV} (kWh): annual energy supplied by PV E_{Wn} (kWh): annual energy supplied by wind E_{ST} (kWh): annual energy supplied by solar thermal collectors. E_{HP} (kWh): annual energy supplied by heat pumps (heat source side) E_{GeT} (kWh): annual energy supplied by geothermal energy.				

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	E_{WH} (kWh): annual energy supplied by waste heat incineration. E_{RE} (kWh): Total annual energy supplied by local renewable energies. **If applicable, this KPI is completed with the information about local energy storages for power and heat (Thermal, Battery, V2H). Installed storage capacities is measured in kWh. Description of storage capacities is given in D2EDC5 for the district/PED level.*
Calculation formula	$E_{RE,th} = E_{HP} + E_{ST} + E_{GeT} + E_{WH}$ local renewable thermal energy production $E_{RE,ele} = E_{PV} + E_{Wn}$ local renewable electric energy production $E_{RE} = E_{RE,ele} + E_{RE,th}$ Total local renewable energy production In addition to the annual values, the amounts of local renewable energy productions can also be presented on an hourly, daily or monthly basis to generate respective load curves. * In the case of heat pumps, only heat sources are counted for calculating the energy production.

KPI description					
Abbreviation	D1EBC4	**Dimension**	D1	**Category**	**Building energy balance**
Name	**Annual building energy balance (demand-supply balance)**				
Definition	Net energy flows of the building (import – export) and internal balance (local production and consumption)				
Unit	kWh				
Description	The KPI provides information which annual energy balance the respective building has (e.g., zero or positive balance) and how far it contributes to achieving the overall positive energy balance at district level.				
KPI calculation					
Monitoring framework	Monitoring infrastructure	No additional infrastructure required.			
	Data collection process	Monitoring of building energy consumption Monitoring data of local supply technologies, simulations based on local context			
	Data monitoring interval	Annual			

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<table>
<tr><td rowspan="3"></td><td>Baseline comparison</td><td>YES</td></tr>
<tr><td>Physical scope</td><td>Building</td></tr>
<tr><td>Solutions included</td><td>SP1. SP2. SP3</td></tr>
<tr><td>Input Parameters</td><td colspan="2">E_{imp} (kWh): Sum of all energy imports
E_{exp} (kWh): Sum of all energy exports
E_{cons} (kWh): Sum of all locally consumed energy over all energy carriers on building level (including storage charge)
E_{prod} (kWh): Sum of all locally produced RE over all energy carriers on building level (in addition to storage discharge)
E_{Net-B} (kWh): Annual building energy balance</td></tr>
<tr><td>Calculation formula</td><td colspan="2">$E_{Net-B} = E_{prod} - E_{cons}$
Depending on data availability, the balance can also be calculated considering the following:
$$E_{Net-B} = E_{exp} - E_{imp}$$
The above two equations result from the equation of building energy consumption balance as follow:
$$E_{cons} = E_{prod} + E_{Imp} - E_{exp} \rightarrow E_{prod} - E_{cons} = E_{exp} - E_{Imp} = E_{net}$$
Note: Based on the building annual energy demand and local RES, the building self-supply ratio (R_{B-SS}) can be derived as the ratio of locally produced RE to the building final energy consumption (annually or monthly):
• $R_{B-SS}\ (\%) = \frac{E_{prod}}{E_{cons}} \cdot 100$
Examples:
for a zero-energy building (ZEB) $R_{B-SS} = 1\ (on\ annual\ basis)$
for positive energy building (PEB) $R_{B-SS} > 1\ (on\ annual\ basis)$</td></tr>
</table>

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D2 Integrated energy solutions at district level

KPI description					
Abbreviation	D2EDC1	**Dimension**	D2 Integrated energy solutions at district level	**Category**	PCED energy demand/consumption and saving
Name	**PCED annual final energy demand/consumption (measured)**				
Definition	Depending on data availability, this KPI can express either the monitored energy consumption of a building or the modelled energy demand, following standardised calculation methods. Hence, the terms "energy consumption " and "energy demand" are differentiated, whereas monitored energy consumption is the preferred expression for this KPI. The term "building" refers to the physical boundaries of the building envelope, which may encompass multiple postal addresses. Aggregated district final annual energy demand by energy carrier and consumption sector covering buildings (residential + service), mobility (freight + personal mobility) and optionally industry and urban agriculture (if applicable). The building sector calculation is based on D1EBC1 for simulated and monitored KPIs.. To accounbt for the critical role of mobility sector the district energy demand will be expressed with and without mobility sector: To provide better insights into the contribution of individual demand sectors, this KPI will be expressed in two versions: • District final energy demand including all sectors, • Total district final energy demand excluding mobility sector				
Unit	kWh				
Description	The annual final energy consumption/demand of the whole district by consumption sector (building, mobility, industry, …) and energy carrier (electricity, DH, Gas, motor fuels, …) is essential for the assessment of the positive energy balance of the respective district. The total building final energy consumption is calculated by summing up the monitored final energy consumption (or modelled with validated tools) for each individual building (residential + service). The calculation is based on D1EBC1 (for the simulated and monitored KPIs). The mobility energy consumption is calculated/estimated based on the modal split and the average distance covered within the district boundaries (covering freight and passenger mobility). This data is obtained from local mobility surveys supplemented by additional data from national or city statistics. Public and street lighting as well as industrial and urban farming activities (if applicable)., are monitored at the district scale. The same applies to In cases where this KPI is claculated based on both monitored and simulated data, this should be clearly indicated.				

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<table>
<tr><th colspan="3">KPI calculation</th></tr>
<tr><td rowspan="6">Monitoring framework</td><td>Monitoring infrastructure</td><td>No specific infrastructure required (same infrastructure than the one in D1, D3)</td></tr>
<tr><td>Data collection process</td><td>Monitoring and modelling of energy consumption across demand sectors within PED boundaries</td></tr>
<tr><td>Data monitoring interval</td><td>Annual</td></tr>
<tr><td>Baseline comparison</td><td>NO</td></tr>
<tr><td>Physical scope</td><td>District</td></tr>
<tr><td>Solutions included</td><td>SP1, SP2, SP3, SP4, SP5</td></tr>
<tr><td>Input Parameters</td><td colspan="2">$FE_{DB,\,a}$(kWh/a): achieved buildings final energy consumption (monitored). It is the sum of FE devoted to cover thermal and electricity demand of all buildings in the district (See also input for D1EBC1).
$FE_{DM,\,a}$(kWh/a): achieved final mobility energy consumption (monitored, estimated). It is the sum of FE devoted to cover all considered mobility solutions in the district over all energy carriers (electricity, gasoline, diesel).
$FE_{DO,\,a}$(kWh/a): achieved final energy consumption (monitored, estimated) covering all remaining consumers (street lighting, industry, urban farming…) as applicable.
$FE_{D,\,a}$(kWh/a): achieved final district energy consumption.
$FE_{D,\,m}$(kWh/a): modelled final district energy consumption.</td></tr>
<tr><td>Calculation formula</td><td colspan="2">$FE_{DB,\,a} = \sum_{j=1}^{J} FE_{DB,\,a,\,j}$; J: number of buildings in the district
$FE_{DM,\,a} = \sum_{l=1}^{L} FE_{DM,\,a,\,l}$; L: number of mobility solutions in the district
$FE_{DO,\,a} = \sum_{k=1}^{K} FE_{DO,\,a,\,k}$; K: number of remaining consumers (other than buildings and mobilities)
Total monitored final energy consumption over all energy carriers and demand sectors within the district boundaries:
$FE_{D,\,a} = FE_{DB,\,a} + FE_{DM,\,a} + FE_{DO,\,a}$
The total modelled final energy consumption is calculated in the same way as above: $FE_{D,\,m} = FE_{DB,\,m} + FE_{DM,\,m} + FE_{DO,\,m}$
Total district energy demand by energy carrier: $FE_D = FE_{D,\,a} + FE_{D,\,m}$</td></tr>
</table>

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ASCEND

<table>
<tr><th colspan="6">KPI description</th></tr>
<tr><td>Abbreviation</td><td>D2EDC2</td><td>Dimension</td><td>D2 Integrated energy solutions at district level</td><td>Category</td><td>PCED energy demand/consumption and saving</td></tr>
<tr><td>Name</td><td colspan="5">Total final energy savings of the PED</td></tr>
<tr><td>Definition</td><td colspan="5">Aggregation of annual energy saving over all measures and consumption sectors of the PED calculated based on the difference of annual total final energy consumption before and after the intervention. This includes buildings, mobility, and others, as applicable. It is calculated in absolute as well relative values (relative to baseline final energy and inhabitants).

*Check: correlated to the achieved PCED annual final energy demand compared to the baseline energy demand by energy form.</td></tr>
<tr><td>Unit</td><td colspan="5">kWh, %</td></tr>
<tr><td>Description</td><td colspan="5">Final energy reduction achieved by all the implemented measures in all sectors[1] of the district (buildings, mobility, conversion of heating systems, others):

• Building sector:

Aggregation of the final energy reduction achieved after the intervention in each individual building (see detailed description at the building scale D1EBC2). The calculation of the achieved saving will cover both monitored and simulated[2] KPIs distinctly subject to the data availability. This implies that a comparison between monitored and simulated data is precluded. Savings will be expressed as a comparison between model results or between monitoring results based on data availability and two distinct KPIs will be provided.

• Mobility sector:

The energy savings achieved by the mobility sector can be directly extracted from the calculation of the indicator D3MBC5.

[1]Other end-use sectors such as industry, agriculture and public lighting are excluded from the scope of this analysis, as no measures developed within the LHCs in ASCEND aim at decreasing energy consumption in these sectors.

[2] For buildings in the PCED without monitoring infrastructure (expected in MUC) similarity pattern with other monitored buildings in the district will be consulted.</td></tr>
<tr><th colspan="6">KPI calculation</th></tr>
<tr><td rowspan="2">Monitoring framework</td><td colspan="2">Monitoring infrastructure</td><td colspan="3">No specific infrastructure required</td></tr>
<tr><td colspan="2">Data collection process</td><td colspan="3">Monitoring of building energy consumption

Monitoring of charging infrastructure</td></tr>
</table>

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		Modelling of mobility energy demand based on mobility studies. Modelling based on local context
	Data monitoring interval	Annual
	Baseline comparison	YES
	Physical scope	District
	Solutions included	SP1, SP2, SP3, SP4
Input Parameters	See input parameter for DC2C1. $FE_{DB,\,R}$(kWh/a): Sum of monitored energy consumption in building sector across all energy carriers in the baseline situation (reference). $FE_{DB,\,a}$(kWh/a): Sum of monitored energy consumption in building sector across all energy carriers after the interventions. $FE_{DB,\,m,\,R}$(kWh/a): Sum of modelled energy consumption in energy consumption in building sector across all energy carriers in the baseline situation (reference). $FE_{DB,\,m}$(kWh/a): Sum of modelled energy consumption in building sector across all energy carriers after interventions.	
Calculation formula	$FE_{DS.,\,a} = FE_{DB,\,R} - FE_{DB,\,a}$ $FE_{DS.,\,m} = FE_{DB,\,m,\,R} - FE_{DB,\,m}$ $FE_{S,rel} = 1 - \frac{FE_{DB,\,a}}{FE_{DB,\,R}}$ The sum of energy saving over buildings, mobilities and others (as applicable) makes the total district energy saving.	

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KPI description					
Abbreviation	D2EDC3	**Dimension**	D2 Integrated energy solutions at district level	**Category**	PCED RES and energy storage infrastructure
Name	**Total installed RE capacity for the district power and heat supply**				
Definition	Total renewable power and heat capacities installed (onsite and locally within the virtual PED boundaries, if applicable), as a result of the project. The definition is analogous to D1EBC2.				
Unit	kW				
Description	Accumulated RE capacities installed over the whole PED during the project. Individual sub KPIs are provided per group of technology (PV, heat pump, etc) to account for related economic and technical performance.				
KPI calculation					
Monitoring framework	Monitoring infrastructure	No specific infrastructure required			
	Data collection process	Monitoring data, datasheets, modelling			
	Data monitoring interval	Annual			
	Baseline comparison	NO			
	Physical scope	District			
	Solutions included	SP2, SP3			
Input Parameters	$P_{D,\ th}$: district installed thermal RE capacities for heat pump, solar thermal and geothermal. $A_{D,\ ST}$: m² of district installed solar thermal collectors. $P_{B,\ ele}$: building installed peak power capacities for PV and wind.				
Calculation formula	$P_{D,\ total} = \sum_{J=1}^{N} \left(P_{D,th,i} + P_{D,ele,i}\right)\ ;\ j: \text{district}\ intalled\ electic\ and\ therml\ capcities$				

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KPI description					
Abbreviation	D2EDC4	**Dimension**	D2 Integrated energy solutions at district level	**Category**	PCED RES and energy storage infrastructure
Name	Total RE production of the district (for power and heat supply)				
Definition	Total renewable power and heat production onsite (and locally within virtual PED boundaries, if applicable), as a result of the project.				
Unit	kWh/a				
Description	Accumulated RE capacities installed over the whole PED during the project. Individual sub KPIs are provided per group of technology (PV, heat pump, etc) to account for different economic and technical performances.				
KPI calculation					
Input Parameters	$E_{D,PV}$ $\left(\frac{kWh}{a}\right)$: annual district energy supplied by PV $E_{D,Wn}$ $\left(\frac{kWh}{a}\right)$: annual district energy supplied by wind $E_{D,ST}$ $\left(\frac{kWh}{a}\right)$: annual district energy supplied by solar thermal collectors. $E_{D,HP}$ $\left(\frac{kWh}{a}\right)$: annual district energy supplied by heat pumps (heat source side) $E_{D,GeT}$ $\left(\frac{kWh}{a}\right)$: annual district energy supplied by geothermal energy. $E_{D,WH}$ $\left(\frac{kWh}{a}\right)$: annual district energy supplied by waste heat incineration. $E_{D,RE}$ $\left(\frac{kWh}{a}\right)$: Total district annual energy supplied by local renewable energies.				
Monitoring framework	Monitoring infrastructure	Heat and power meters to measure the electricity and heat production (PV, ST, HP)			
	Data collection process	Monitoring data, datasheets, modelling			
	Data monitoring interval	Annual			
	Baseline comparison	NO			
	Physical scope	District			
	Solutions included	SP2, SP3			
Calculation formula	$E_{D,RE,th} = E_{D,HP} + E_{D,ST} + E_{D,GeT} + E_{D,WH}$ district RE production (thermal)				

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	$E_{D,RE,ele} = E_{D,PV} + E_{D,Wn}$ district RE production (electric) $E_{B,RE} = E_{D,RE,ele} + EB_{D,RE,th}$ Total district RE production In addition to the annual values, the amounts of local renewable energy productions can also be presented on an hourly, daily or monthly basis to generate respective load curves. * In the case of heat pumps, only heat sources are counted for calculating the energy production.

KPI description					
Abbreviation	D2EDC5	**Dimension**	D2 Integrated energy solutions at district level	**Category**	**Energy flexibility and storage capacity**
Name	**Smart energy storage capacity**				
Definition	Total storage capacity for electricity and heat storage.				
Unit	kWh and kW *Battery storage is measured in two ways. Rated power capacity (in kW) and Energy storage capacity (kWh). The last one is more convenient as it measures the maximum amount a battery can store.*				
Description	Local energy storage capacities play an important role in enabling PCEDs. With the rising share of intermittent RE, they offer important flexibility option for a high-level integration of RE resulting in reduced RE curtailment, heightened self-consumption of local RES, imposed load-levelling, and improved system reserves and grid reliability. These contribute to optimising district energy system towards positive energy balance. In general, energy storage capacities at district scale cover electric battery capacities and EV batteries available for bi-directional charging linked to PV panels and with V2G capability, and thermal storages. A controller evaluates the optimal use depending on different criteria like temperature, availability, or state of charge. A separate reporting of power and heat storage will be considered. If applicable new capacities installed during the project will be compared with existing baseline storages to account for capacity increase. If applicable there will be differentiation between short- and long-term heat storage options.				
KPI calculation					
Monitoring framework	Monitoring infrastructure		No specific infrastructure required		
	Data collection process		Datasheets		
	Data monitoring interval		Annual		

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	Baseline comparison	NO
	Physical scope	District
	Solutions included	SP1, SP2, SP3
Input Parameters	SC_B (kWh): Cumulative added stationary electric battery energy storage capacity in the district SC_{V2G} (kWh): Cumulative battery electric vehicle (BEV) capacity with V2G capability in the district (estimation) SC_{th} (kWh): Cumulative added thermal storage capacities	
Calculation formula	$SC_{el} = SC_B + SC_{V2G}$: Battery energy storage capacity S_{Cth} : Thermal energy storage capacity	

KPI description					
Abbreviation	D2EDC6	**Dimension**	D2	**Category**	**Energy balance of the PED**
Name	**Annual energy demand-supply balance of the PED**				
Definition	Total annual energy consumption of the PED put in relation with the net energy supply (annual energy import (-) from and export (+) to the neighbourhood energy systems). This balance shows how far the district can achieve the set target of PED.				
Unit	kWh				
Description	This KPI provides information whether the respective district has an annual positive energy balance to fulfil the PED requirements. The KPI includes the sum of energy flows via the PED boundary covering all energy carriers (power, district heating, natural gas etc.) and consumption sectors (buildings, mobility, public infrastructure, and industry if applicable). The KPI can be calculated based on the external or internal balance: - The internal balance considers local energy consumption and supply on annual basis. - The external balance considers energy exports and imports (+import – export), which already includes self-consumption of local PV supply. Depending on data availability, the demand-supply balance can be calculated based on the internal or external energy balance. *In case of long-term storage availability (e.g., heat) we need to account for the stock change on annual basis).				

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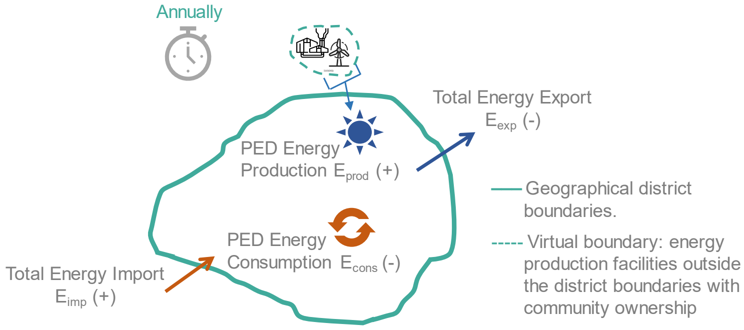
<table>
<tr><th colspan="3">KPI calculation</th></tr>
<tr><td rowspan="6">Monitoring framework</td><td>Monitoring infrastructure</td><td>Substations energy import and export (DH, electricity, NG) corresponding to the PED geographical boundaries beside other RES within the virtual boundaries (see chapter 3.2)</td></tr>
<tr><td>Data collection process</td><td>Monitoring of building, mobility and other energy consumption (as applicable)
Monitoring data of local RE supply technologies (supported by additional simulations based on local context)</td></tr>
<tr><td>Data monitoring interval</td><td>Annual</td></tr>
<tr><td>Baseline comparison</td><td>YES</td></tr>
<tr><td>Physical scope</td><td>Building</td></tr>
<tr><td>Solutions included</td><td>SP1, SP2, SP3, SP4, SP5</td></tr>
<tr><td>Input Parameters</td><td colspan="2">E_{imp} (kWh/a): Sum of all energy imports by energy form
E_{exp} (kWh/a): Sum of all energy exports by energy form
E_{cons} $\left(\frac{\text{kWh}}{\text{a}}\right)$: Sum of all local energy consumption by energy form (including storage charging)
E_{prod} (kWh/a): Sum of all locally produced energy over all energy carriers of the district (including storage discharge). This also includes energy production facilities located outside the district boundaries – virtual boundary – with community ownership (like in Munich).</td></tr>
<tr><td>Calculation formula</td><td colspan="2">$E_{balance} = \sum_{i=1}(E_{prod,i} - E_{cons,i}) > 0$
Depending on data availability, the balance can also be calculated considering the following:
$$E_{balance} = \sum_{i=1}(E_{exp,i} - E_{imp,i}) > 0$$
i: energy carriers of electricity, district heating, Biomass, NG, and oil products (as applicable).
Both internal and external balances are interrelated and merge into one another.</td></tr>
</table>

	$\sum_{i=1}(E_{prod,i} + E_{imp,i}) = \sum_{i=1}(E_{cons,,i} + E_{exp,i})$  *Note:* *the district energy balance will be established at the district boundary level and inwards, where district energy consumption occurs, taking into account any associated conversion and transmission losses when locally genrated renewable energies are provided for onsite consumption, storage or further exported to the public grid.*

KPI description						
Abbreviation	D1EDC7	**Dimension**	D2	**Category**	**Energy balance of the PED**
Name	**Self-supply-ratio (SSR)**					
Definition	SSR is the ratio of locally produced renewable energy of the PED to the PED final energy consumption for a given period (h, d, m, a). Separate ratios for power and heat supply are considered.					
Unit	%					
Description	This KPIs compares the locally produced renewable energy (heat and electricity are calculated independently) to the total final energy demand of the district for the considered time interval (hourly, daily, monthly, annually). This KPIs indicate how far the PED can cover its demand in a certain period through locally produced RE. For a functioning PED the annual SSR shall be higher than one.					
KPI calculation						
Monitoring framework	Monitoring infrastructure			No additional infrastructure required		
	Data collection process			Monitoring of district energy consumption Monitoring data of local supply technologies, simulations based on local context		

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<table>
<tr><td rowspan="4"></td><td>Data monitoring interval</td><td>Annual</td></tr>
<tr><td>Baseline comparison</td><td>YES</td></tr>
<tr><td>Physical scope</td><td>District</td></tr>
<tr><td>Solutions included</td><td>SP1, SP2, SP3, SP4, SP5</td></tr>
<tr><td>Input Parameters</td><td colspan="2">$E_{RE-prod}$ (kWh/a): Sum of annual RE production of the district disaggregated by power and heat.

E_{cons} $\left(\frac{\text{kWh}}{\text{a}}\right)$: Sum of annual district energy consumption disaggregated by power and heat.

E_{RE-exp} $\left(\frac{\text{kWh}}{\text{a}}\right)$: Sum of annual RE export outside the district boundaries disaggregated by power and heat.

SSR: Self-supply ratio</td></tr>
<tr><td>Calculation formula</td><td colspan="2">$SSR = \frac{E_{RE-prod}}{E_{cons}}$ (%)

The ratio is calculated for power (SSR_P) and heat (SSR_H) separately. If PED condition achieved, then SSR>1.

*Note: another indicator, so-called Self-sufficiency ratio (SFR) can be extracted based on the above KPI. SFR refers to RE production directly used within the district to its final energy consumption (annually). Here the locally generated RE will be reduced by the exported amount:

$SFR = \frac{E_{RE-prod} - E_{RE-exp}}{E_{cons}}$</td></tr>
</table>

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D3 Sustainable Mobility

<table>
<tr><th colspan="6">KPI description</th></tr>
<tr><td>Abbreviation</td><td>D3MBC1</td><td>Dimension</td><td>D3 Mobility</td><td>Category</td><td>Sustainable modal split</td></tr>
<tr><td>Name</td><td colspan="5">Change towards sustainable and clean modal split.)</td></tr>
<tr><td>Definition</td><td colspan="5">Share of sustainable modes in the total modal split of district transport activity before and after the intervention. (Calculated based on annual pkm and tkm of the district). Data basis: mobility survey bevor and after the intervention. In particular, the change in modal split from motorised individual transport towards walking, cycling and public transport and EVs will be calculated. The calculation will be based on mobility patterns of residents reported in two surveys. The modal splits will be extrapolated by upscaling the sample data to population data.

For freight deliveries, the number of packages received in a given time period will be collected in the survey. The resulting delivery traffic will be extrapolated and evaluated with delivery fleet information available from logistics companies and literature.</td></tr>
<tr><td>Unit</td><td colspan="5">%</td></tr>
<tr><td>Description</td><td colspan="5">Quantifying the shift towards sustainable and clean urban mobility. This includes:
• Passenger mobility: share of biking and walking, EVs and public transport.
• Freight: E-transporter, H2-Transporter…</td></tr>
<tr><th colspan="6">KPI calculation</th></tr>
<tr><td rowspan="6">Monitoring framework</td><td colspan="2">Monitoring infrastructure</td><td colspan="3">No additional specific monitoring infrastructure needed</td></tr>
<tr><td colspan="2">Data collection process</td><td colspan="3">Two surveys, one before the intervention to calculate current modal splits</td></tr>
<tr><td colspan="2">Data monitoring interval</td><td colspan="3">Two surveys in project lifetime, before and after possible interventions</td></tr>
<tr><td colspan="2">Baseline comparison</td><td colspan="3">Data from first survey will serve as baseline (Checked vs data from large mobility surveys for validation of methodology if available)</td></tr>
<tr><td colspan="2">Physical scope</td><td colspan="3">District</td></tr>
<tr><td colspan="2">Solutions included</td><td colspan="3">S1, S4</td></tr>
</table>

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Input Parameters	Pkm_{n}^{mode} : Person kilomenters travelled per mode by respondent n collected in survey on work day. Pkm_{pop}^{mode} : Person kilometres travelled per mode by population. $Pop^{ageroup}$: Population per age group collected in area. $N_{agegroup}$: Set of respondents in age group in survey MSC^{mode} : Change of Pkm in mode in %
Calculation formula	$$\Delta Pkm^{mode} = Pkm_{pop}^{mode} - \sum_{agegroups} \sum_{n \in N_{agegroup}} \frac{Pop^{ageroup} Pkm_{n}^{mode}}{\lvert N_{agegroup} \rvert}$$ $$MSC^{mode} = \frac{\Delta Pkm^{mode}}{Pkm_{pop}^{mode}}$$

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KPI description					
Abbreviation	D3MBC2	**Dimension**	D3 Mobility	**Category**	**Sustainable mobility infrastructures**
Name	**Number of electric vehicles (EVs) deployed**				
Definition	Number of electric vehicles (EVs) deployed within ASCEND within the boundaries of the PCED.				
Unit	#				
Description	Accounting for the number of EVs rolled-out by the end of the project. it offers the possibility to monitor the impact of mobility measures deployed in the area towards decarbonising mobility in the district (passenger + freight).				
KPI calculation					
Monitoring framework	Monitoring infrastructure	No additional specific monitoring infrastructure needed			
	Data collection process	Vehicle registration statistics within the geographical boundaries of the district.			
	Data monitoring interval	2 times: before and after interventions			
	Baseline comparison	YES			
	Physical scope	District, limited application in Lyon			
	Solutions included	SP4, S1			
Input Parameters	Number of EVs licensed to individuals and companies within the PCED[16]				
Calculation formula	○ number of passenger EV rolled-out by the end of the project covering: e-cars, e-buses, e-bikes (as applicable). ○ number of freight/logistic EVs rolled-out by the end of the project covering E-van, e-trucks, e-cargo-bike, e-forklift (as applicable)				

[16] This KPI is only relevant if the measures implemented in the district are directly targeting the electrification of the passenger and freight fleet. In Lyon, this KPI has been identified as not relevant by the consortium partners.

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KPI description					
Abbreviation	D3MBC3	**Dimension**	D3 Mobility	**Category**	Sustainable mobility infrastructures
Name	**Number and type of EV-charging stations deployed in the PCED area**.				
Definition	Total number of charging points/stations for EVs and share of bidirectional charging stations among those in the PCED.				
Unit	#, %				
Description	This KPI provides the number of charging stations for EVs in the PCED. It also expresses the number of bidirectional charging stations, providing an indication on the level of electricity flexibilization.				

KPI calculation		
Monitoring framework	Monitoring infrastructure	No additional specific monitoring infrastructure needed
	Data collection process	Survey / accounting
	Data monitoring interval	Annual
	Baseline comparison	Yes
	Physical scope	District
	Solutions included	SP1, SP2, SP4
Input Parameters	N_{CS} : Number of total e-charging stations deployed. N_{BDC} : Number of bidirectional e-charging stations deployed. R_{BDC} (%) : share of e-charging stations with bidirectional features (V2G) *<u>Note:</u>* *See also D2EDC5 regarding battery electric vehicle (BEV) capacity with V2G capability in the district (estimation)*	
Calculation formula	$N_{CS} = \sum_i N_{CS,i}$; *i: charging stations deployed in the district* $N_{BDC} = \sum_i N_{BDC}, i$; *i: bidirectional charging stations deployed in the district* $R_{BDC} = \frac{N_{BDC}}{N_{CS}} \cdot 100$	

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KPI description					
Abbreviation	D3MBC4	**Dimension**	D3 Mobility	**Category**	Sustainable mobility infrastructures
Name	**Electricity supplied to EV charging**				
Definition	Annual electricity provided for EV-charging within the boundaries of the district.				
Unit	kWh/a				
Description	This KPI gives information on the electrification of the mobility through the calculation of the total electricity supplied to EV charging before and after interventions.				
KPI calculation					
Monitoring framework	Monitoring infrastructure		Electric meters (hourly) (at least 1 year of measurement) for each sub-station.		
	Data collection process		Survey/ accounting and monitoring		
	Data monitoring interval		Annual		
	Baseline comparison		Yes		
	Physical scope		District		
	Solutions included		SP1, SP2, SP4		
Input Parameters	FE_{EV} (kWh/a): Electricity consumption by all charging stations in the district[17] N_{CS} : Number of total e-charging stations deployed.				
Calculation formula	$FE_{EV} = \sum_{i=1}^{NCS} FE_{ev,\,i}$; i: number of charging station in the district				

[17] The calculation of this KPI is largely dependent on data availability. Envisioned difficulties to collect these data have been pointed out by the two LHCs.

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KPI description					
Abbreviation	D3MBC5	**Dimension**	D2 Integrated energy solutions at district level	**Category**	**PCED Energy demand/consumption and energy saving**
Name	Energy savings by mobility measures				
Definition	Annual final energy savings of transport sector (passenger & freight) calculated based on total final energy demand before and after the intervention				
Unit	kWh/a				
Description	Final energy reduction achieved due to the realised mobility measures at district scale. The mobility energy savings are calculated based on evolution of modal split, car ownership and average annual distance travelled within the district boundaries. This information is to be obtained via local mobility studies or national statistics. Mobility studies are to be conducted before and after the implementation of mobility measures.				
KPI calculation					
Monitoring framework	Monitoring infrastructure	No additional specific monitoring infrastructures needed			
	Data collection process	Mobility surveys and modelling to collect Pkm (See D3MB_C1) Questionnaire about modal splits			
	Data monitoring interval	Annual			
	Baseline comparison	YES			
	Physical scope	District			
	Solutions included	SP4			
Input Parameters	$FE_{Mob,ref}$ (kWh/a): Sum of all mobility related energy demand/consumption in the PED obtained by surveys and modelling in the baseline situation (ref), i.e., resulting from initial mobility surveys.				

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	$FE_{Mob,after}$ (kWh/a): Sum of all mobility related energy demand/consumption in the PED obtained by surveys and modelling after the interventions (deployment of mobility solutions in the PED). Data will heavily depend on the second mobility surveys.[18] $FE_{Mob-sav}$(kWh/a): cumulative annual energy saving by all mobility measures
Calculation formula	$$FE_{Mob-sav} = FE_{Mob,ref} - FE_{Mob,after}$$

[18] Concerns were raised during the KPIs development phase by Lyon regarding data availability for the identified input parameters.

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D4 ICT and Digital Infrastructure

KPI description					
Abbreviation	D4ICTC1	**Dimension**	D4 ICT	**Category**	New ICT developments and services
Name	**Datasets in joint repository**				
Definition	Number of datasets that can be retrieved from the KPI engine developed by DKSR per LHC and dimension.				
Unit	#				
Description	This KPI provides information on the number of datasets that are handled within a joint repository and can be accessed by the relevant consortium members, i.e., the KPI engine. It therefore measures the functionality and performance of the KPI engine developed within WP6.				

KPI calculation		
Monitoring framework	**Monitoring Infrastructure**	No additional specific infrastructure is needed
	Data collection process	Information to be provided by the KPI-engine and urban data platforms
	Data monitoring interval	Annual
	Baseline comparison	No
	Physical scope	-
	Solutions included	All solutions that are monitored with KPIs
Input Parameters	Metadata from the KPI-engine and urban data platforms	
Calculation formula	NA	

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KPI description					
Abbreviation	D4ICTC2	**Dimension**	D4 ICT	**Category**	**New ICT developments and services**
Name	Number of standardised REST APIs				
Definition	Number of APIs provided by the KPI engine that comply with the REST architecture per LHC and dimension.				
Unit	#				
Description	This KPI provides information on the number of datasets that can be accessed via the KPI engine and that follow the REST architecture for web services. It therefore measures the functionality, the user-friendliness and performance of the KPI engine.				
KPI calculation					
Monitoring framework	Monitoring infrastructure	No additional specific monitoring infrastructures needed			
	Data collection process	Information to be provided by the KPI engine			
	Data monitoring interval	Annual			
	Baseline comparison	No			
	Physical scope	-			
	Solutions included	All solutions that are monitored with KPIs			
Input Parameters	Metadata from the KPI-engine and urban data platforms				
Calculation formula	NA				

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KPI description					
Abbreviation	D4ICTC3	**Dimension**	D4 ICT	**Category**	Smart and sustainable buildings
Name	Share of buildings in the district with smart energy meters				
Definition	Share of buildings within the PCED that is equipped with smart meters for electricity consumption metering				
Unit	%				
Description	Smart meters enable temporally resolved energy consumption monitoring, which allows assessments regarding dynamic PED energy balances, grid implications and flexibility potentials within a PED. It therefore provides an indication on the quality of energy monitoring within a PED.				
KPI calculation					
Monitoring framework	Monitoring infrastructure	No additional specific monitoring infrastructures needed			
	Data collection process	Counting of respective buildings			
	Data monitoring interval	Annual			
	Baseline comparison	No			
	Physical scope	Buildings and PED			
	Solutions included	Energy-related solutions			
Input Parameters	N_B: Total number of buildings in the district $N_{B,SM}$: number of buildings equipped with smart meters in the PED $S_{B,SM}$: share of buildings equipped with smart meters within the PED				
Calculation formula	$S_{B,SM} = \frac{N_{B,SM}}{N_B} \cdot 100\ (\%)$				

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D5 Environmental Dimension

KPI description					
Abbreviation	D5ENVC1	**Dimension**	D4 ICT	**Category**	**GHG emissions**
Name	District annual GHG emissions				
Definition	Total energy related GHG emissions in the district before and after the interventions by energy demand sector.				
Unit	tCO_2-eq./a				
Description	District GHG inventory is an important indicator to assess the current level of district GHG-emission and the impact achieved by the implemented measures. Specification by sectors and measures will show the effectivity and priority of mitigation measures to be employed on the way of carbon neutral district. Supporting indicators like GHG/cap and GHG/m2 can help comparing the demo district performance (before and after intervention) with the LHC and national emission. The calculation method refers to IPCC tier 2 approach (using country or city specific emission factors by fuel). Accordingly annual energy related GHG emissions can be calculated based on the annual final energy consumption by sector and fuel (D2EDC1)and by using related regional/national emission factory for each fuel (i.e., electricity, district heating, natural gas, oil products, waste).				
KPI calculation					
Monitoring framework	Monitoring infrastructure	No additional specific monitoring infrastructures needed			
	Data collection process	Monitoring, survey, national average values			
	Data monitoring interval	Annual			
	Baseline comparison	No			
	Physical scope	District			
	Solutions included	SP2, SP3, SP4, SP5			
Input Parameters	(See also D2EDC1) $FE_{DB,\,a}$(kWh/a): achieved buildings final energy consumption (monitored). It is the sum of FE devoted to cover thermal and electricity demand of all buildings in the district (See also input for D1EBC1).				

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	$FE_{DM,\,a}$(kWh/a): achieved final mobility energy consumption (monitored, estimated). It is the sum of FE devoted to cover all considered mobility solutions in the district over all energy carriers (electricity, gasoline, diesel). $FE_{DO,\,a}$(kWh/a): achieved final energy consumption (monitored, estimated) covering all remaining consumers (street lighting, industry, urban farming…) as applicable. The sum of FE devoted to cover all other demand in the district. $GHG_{Bilding}$ (tCO2-eq./a): annual building sector emission. $GHG_{Mobility}$ (tCO2-eq./a): annual mobility sector emission. GHG_{other} (tCO2-eq./a): annual other sectors emission i: energy carrier of electricity, district heating (DH), NG, oil products, waste (as applicable) f_{CO2} : CO2-emission factor per final energy carrier. For district heating and imported electricity from public grid, regional grid emission factors of the considered city is used.
Calculation formula	$GHG_{Bilding} = \sum_i (FE_{DB,\,a,\,i} \cdot f_{CO2,\,i})$, i: energy carrier $GHG_{Mobility} = \sum_i (FE_{DM,\,a,\,i} \cdot f_{CO2,\,i})$, i: energy carrier $GHG_{other} = \sum_i (FE_{DO,\,a,\,i} \cdot f_{CO2,\,i})$, i: energy carrier $GHG_{disrict} = GHG_{Bilding} + GHG_{Mobility} + GHG_{other}$
Reference	EU-SCMP:https://smart-cities-marketplace.ec.europa.eu/insights/publications/self-reporting-tool-key-performance-indicators-guide 2006 IPCC Guidelines for National Greenhouse Gas Inventories

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KPI description					
Abbreviation	D5ENVC2	**Dimension**	D5 Environmental	**Category**	**GHG emissions**
Name	Annual CO2- emissions reduction by type of measures implemented				
Definition	This KPI describes the annual energy-related CO2 emissions reduction by types of measures implemented within the boundaries of the district.				
Unit	tCO2-eq./a				
Description	The annual CO2 emissions reduction reflects the impact of the implemented measures resulting from following decarbonisation drivers:: Energy savings measures: • CO2-reduction due to energy saving by energy demand reduction in buildings: building efficiency measures (building refurbishment and any other measurable effects of DSM) and switch to alternative heating systems (efficiency improvement and substitution of fossil fuels by clean energy options (see D1EBC1) • CO2-reduction due to energy saving and switching to alternative mobility modes (D3MBC6) Switching to alternative energy supply systems: • fuel switch: CO2-reduction due to increased contribution of RES for power and heat (see D2EDC4) The calculation approach is as described in D5ENVC2				

KPI calculation		
Monitoring framework	Monitoring infrastructure	No additional specific monitoring infrastructures needed
	Data collection process	Monitoring, survey, national or local average value
	Data monitoring interval	Annual
	Baseline comparison	Yes
	Physical scope	District
	Solutions included	SP2, SP3, SP4, SP5
Input Parameters	See also D2EDC2 and D5ENVC1) The same input as in D5ENVC1 beside the energy consumption in the baseline year (reference). The change of emission factors by fuel between baseline year and years of	

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	monitoring and after intervention are considered following the updated regional/national emission factors. $R_{GHG\ (tCO2/a)}$: annual GHG reduction
Calculation formula	$$R_{GHG,Building} = \sum_i (\mathrm{FE}_{\mathrm{DB,R,i}} \cdot \mathrm{f}_{\mathrm{CO2,R,i}} - \mathrm{FE}_{\mathrm{DB,\ a,\ i}} \cdot \mathrm{f}_{\mathrm{CO2,a,i)}}$$ $$R_{GHG,Mobility} = \sum_i (\mathrm{FE}_{\mathrm{DM,R,i}} \cdot \mathrm{f}_{\mathrm{CO2,R,i}} - \mathrm{FE}_{\mathrm{DM,\ a,\ i}} \cdot \mathrm{f}_{\mathrm{CO2,a,i)}}$$ $$R_{GHG,other} = \sum_i (\mathrm{FE}_{\mathrm{DO,R,i}} \cdot \mathrm{f}_{\mathrm{CO2,R,i}} - \mathrm{FE}_{\mathrm{DO,\ a,\ i}} \cdot \mathrm{f}_{\mathrm{CO2,a,i)}}$$ $$R_{GHG,District} = R_{GHG,Building} + R_{GHG,Mobility} + R_{GHG,other}$$ Additionally, relative emission reduction by sector can be calculated by putting the sector reduction to the total district reduction. Other specific parmaters like per floor area nd per capita can be also extracted.
Reference	See D5ENVC1

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D6 Social Dimension

KPI description						
Abbreviation	D6SOCC1	**Dimension**	D6 Social	**Category**	**Citizen engagement**	
Name	Residents engaged					
Definition	Percentage of residents that have been reached and/or are activated by citizen engagement activities developed in the project. In this case, the terms reached/activated refers to the number of responses received in the local surveys to be prepared. It is related to the total number of residents living within the PCED boundaries.					
Unit	%					
Description	The KPI provides insights into how effectively the residents of the PCED have been informed and integrated about the implemented solutions. It expresses number of feedbacks that have been provided by the residents in relation to the total number of inhabitants.					
KPI calculation						
Monitoring framework	Monitoring infrastructure			No additional specific monitoring infrastructures needed		
	Data collection process			Statistical data, survey feedbacks		
	Data monitoring interval			Annual		
	Baseline comparison			No		
	Physical scope			District		
	Solutions included			SP5		
Input Parameters	Number of individual feedbacks received within citizen engagement surveys. Total number of residents living in the PCED during the respective survey year					
Calculation formula	will follow the approach applied in the planned surveys.					

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KPI description					
Abbreviation	D6SOCC2	**Dimension**	D6 Social	**Category**	**Citizen engagement**
Name	Number of energy communities deployed				
Definition	Number energy communities deployed within the PCED				
Unit	#				
Description	This KPI provides insights to the number of energy communities that have been deployed throughout the project duration. If the data are available and accessible for the ASCEND consortium, the number of households integrated in the energy communities (D6SOO2), and the number of residents participating to the energy communities (D6SOO1) will be calculated to complete this KPI.				

KPI calculation		
Monitoring framework	Monitoring infrastructure	No additional specific monitoring infrastructures needed
	Data collection process	Survey / Accounting
	Data monitoring interval	Annual
	Baseline comparison	No
	Physical scope	District
	Solutions included	SP2, SP5
Input Parameters	Number of energy communities deployed in the PCED.	
Calculation formula	NA	

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KPI description					
Abbreviation	D6SOCC3	**Dimension**	D6 Social	**Category**	**Citizen engagement**
Name	Degree of satisfaction with the solutions implemented				
Definition	Evaluation of the degree of satisfaction of different groups of stakeholders.				
Unit	Likert scale				
Description	This KPIs provides insight on the satisfaction of different groups of stakeholders and acceptance of the implemented solutions. This is based on the feedbacks collected through locally distributed surveys regarding for example: technical performance, user-friendliness, comfort, aesthetical aspects, and cost.				

KPI calculation		
Monitoring framework	Monitoring infrastructure	No additional specific monitoring infrastructures needed
	Data collection process	Survey / Accounting
	Data monitoring interval	At the end of the project
	Baseline comparison	No
	Physical scope	District
	Solutions included	SP5
Input Parameters	Qualitative answers on degree of satisfaction of individual feedbacks received within stakeholders' surveys.	
Calculation formula	will follow the approach applied in the planned district surveys.	

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D7 Economic Dimension

KPI description					
Abbreviation	D7EC_C1	**Dimension**	D7 Economic	**Category**	Financial performance
Name	**Total investment in all new interventions of the PCED**				
Definition	Total investment costs refer to the sum of all capital expenditure (Capex) incurred during the project implementation to deliver a solution. They cover costs for planning, studies, engineering, construction, equipment, and Tax.				
Unit	€ (in constant price of a defined reference year, e.g., 2023).				
Description	This KPI allows the calculation of other economic KPI. It further provides insights into how much investment had to be provided to realize the solutions. This KPI will entail two elements: 1-Investment triggered in the district during the project. This includes all incurred expenditures related to the project interventions covering: • Investment in energy solutions • Investment in construction (building, infrastructure) solutions • Investment in mobility solutions • Investment in ICT solutions 2-Investment needed to transfer the results to the city level to X Districts beyond the project (qualitative: describing the actions, quantitative: measuring roughly the investment per targeted district) – This will entail a qualitative assessment methodology that is to be described in Deliverble XY				
KPI calculation					
Monitoring framework	Monitoring infrastructure	No additional specific monitoring infrastructures needed			
	Data collection process	Survey: Periodical interview with cities to monitor which investments have been planned, officially presented, and approved.			
	Data monitoring interval	Annual			
	Baseline comparison	No			
	Physical scope	District			

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	Solutions included	SP2, SP3, SP4
Input Parameters	- Economic reports on implemented solutions. • Investment cost for district solutions of energy (en), construction (con), mobility (mob), ICT, others. I_{tot} (€): total investment of all project interventions I_{en} (€): sum of investment related to all energy solutions. I_{con} (€): sum of investment related to construction solutions (building, infrastructure). I_{mob} (€): sum of investment related to mobility solutions. I_{ICT} (€): sum of investment related to ICT solutions. I_{oth} (€): sum of investment related to other interventions not included above. Note: Since the costs will occur in different years during the project implementation (2023–2027), they should be discounted to 2023 to become comparable in real term. I_{en} $\left(\frac{€}{m^2}\right)$: can be related to the total floor area of the considered building or building cluster under consideration.	
Calculation formula	$I_{tot} = I_{en} + I_{con} + I_{mob} + I_{ICT} + I_{oth}$	

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KPI description					
Abbreviation	D7ECC2	**Dimension**	D7 Economic	**Category**	Financial performance
Name	**Total amount of (non-public) investment attracted**				
Definition	External investments triggered by the project excluding public partners grants.				
Unit	€				
Description	Different external stakeholders will be engaged to test the interest in financing PCEDs. This KPI will reflect the financing provided by stakeholders that are external to the project excluding all public investors like public grants form EU Commission, Governmental Bodies, etc. The calculation will rely upon survey for each LHC. The goal is to track the attraction of non-public investors to support the replication and upscaling of PCED and the realized SPs.				
KPI calculation					
Monitoring framework	Monitoring infrastructure	No additional specific monitoring infrastructures needed			
	Data collection process	Survey Provided by partners or estimated based on the exchanges with external financial providers involved in the project			
	Data monitoring interval	Project period (2023–2027)			
	Baseline comparison	No			
	Physical scope	District			
	Solutions included	SP2, SP3, SP4			
Input Parameters	Financial reports on implemented solutions				
Calculation formula	NA				

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KPI description					
Abbreviation	D7ECC3	**Dimension**	D7 Economic	**Category**	Financial performance
Name	**NPV, PBT, IRR**				
Definition	• NPV: Net Present Value is the difference between the present value of cash inflows and the present value of cash outflows over a period of time. • PBT: the Payback Time is the amount of time necessary to recover/get back the initial investment. - IRR: the Internal Rate of Return is the discount rate that makes the NPV of the project cash flows equal to zero in a discounted cash flow analysis				
Unit	NPV: € (in constant price of 2023) PBT: years IRR: %				
Description	These KPIs (PBT/NPV/IRR) express the economic performance of an implemented solution. It considers all the cash flows required to install and operate this solution over its technical lifetime.				

KPI calculation		
Monitoring framework	Monitoring infrastructure	No additional specific monitoring infrastructures needed
	Data collection process	Calculation based on technical specification and performance of district energy assets (+D7ECC1)
	Data monitoring interval	Project period
	Baseline comparison	No
	Physical scope	District
	Solutions included	SP2, SP3, SP4
Input Parameters	I_0 (€): Initial investment cost t (year): number of periods T (year): technical lifetime of the solution (e.g., 10, 20, 30).	

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	i (%): Discount rate E_t (€): net cash inflow A_t (€): net cash outflows during a single period t $C_{Ft}(€) = E_t - A_t : net\ cash\ flow$ • Achieved energy savings related to the solution. • Energy prices and their projection over the technical lifetime of the solution. **Cash Inflow**: Cash inflow refers to the money that comes into a business. It includes all sources of funds received, such as revenue, investments, loans, or any other source that increases the available cash. Cash inflow represents the positive financial impact, indicating an increase in available funds, net of all liabilities. **Cash Outflow**: Cash outflow, on the other hand, is the money that flows out of a business. It includes all expenditures, payments, and expenses, such as operating costs, salaries, loan repayments, and any other expenses that reduce the available cash. Cash outflow represents the negative financial impact, indicating a decrease in available funds, net of all liabilities.
Calculation formula	$$NPV = I_0 + \sum_{t=1}^{T} \frac{E_t - A_t}{(1+i)^t} = \sum_{t=0}^{T} \frac{E_t - A_t}{(1+i)^t}$$ PBT, IRR **Payback Time = Initial Investment / Annual Net Cash Flow** $PBT = \frac{I_0}{(E_t - A_t)}$ The “Payback Time” represents the period of time required to recover the initial investment. The formula calculates this period by dividing the initial investment by the annual net cash flow. **Internal Rate of Return (IRR):** $$NPV = 0 = \sum_{t=0}^{T} \frac{E_t - A_t}{(1+i)^t} = \sum_{t=0}^{T} \frac{E_t - A_t}{(1+IRR)^t}$$ The “Internal Rate of Return” (IRR) is the discount rate that makes the net present value (NPV) of cash flows equal to zero. This formula is used to calculate the IRR and involves a summation of future cash flows (C_{Ft}) discounted at the rate IRR for each period (t).

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<table>
<tr><th colspan="6">KPI description</th></tr>
<tr><td>Abbreviation</td><td>D7ECC4</td><td>Dimension</td><td>D7 Economic</td><td>Category</td><td>Economic impact</td></tr>
<tr><td>Name</td><td colspan="5">Economic value of saved energy and reduced CO_2-emission</td></tr>
<tr><td>Definition</td><td colspan="5">The ratio of capital investment in an intervention to the achieved energy saving (€/kWh) and/or CO_2 emission reduction (€/tCO_2)</td></tr>
<tr><td>Unit</td><td colspan="5">€/kWh, €/tCO_2</td></tr>
<tr><td>Description</td><td colspan="5">This KPI refers to the sustainable project impact in economic sense. It measures the effectiveness of activated investment in an energy related solution (refurbishment, RES) in terms of investment spent (in €) per energy saved and/or CO_2 reduced.</td></tr>
<tr><th colspan="6">KPI calculation</th></tr>
<tr><td rowspan="6">Monitoring framework</td><td colspan="3">Monitoring infrastructure</td><td colspan="2">Refers to the energy solution of energy saving and RES and related investment</td></tr>
<tr><td colspan="3">Data collection process</td><td colspan="2">See D1, D2 and D7ECC1</td></tr>
<tr><td colspan="3">Data monitoring interval</td><td colspan="2">Annual</td></tr>
<tr><td colspan="3">Baseline comparison</td><td colspan="2">Yes</td></tr>
<tr><td colspan="3">Physical scope</td><td colspan="2">Solution, building, district</td></tr>
<tr><td colspan="3">Solutions included</td><td colspan="2">SP1, SP2, SP3, SP4</td></tr>
<tr><td>Input Parameters</td><td colspan="5">C_I: discounted annual capital investment cost (€/a).
T (year): number of periods (plant lifetime)
I_0 (€): Initial investment cost
i (%): discount rate
E_b: energy consumption before the intervention (kWh)
E_a: energy consumption after the intervention (kWh)
M_b: CO2-emission before the intervention (tCO2-eq)
M_a: CO2-emission after the intervention (tCO2-eq)
DE: annual energy saving (kWh/a)
DM: annual CO2-emission reduction (tCO2/a)
V_{E}: Value of energy saving (€/kWh)</td></tr>
</table>

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	V_M: Value of CO2-emission reduction (€/tCO_2)
Calculation formula	$$C_I = I_0 \cdot \frac{i \cdot (1+i)^T}{(1+i)^T - 1}$$ $DE = E_b - E_a$, $DM = M_b - M_a$ $$V_E = \frac{C_I}{D_E} \quad V_M = \frac{C_I}{D_M}$$
Reference	

KPI description					
Abbreviation	D7ECC5	**Dimension**	D7 Economic	**Category**	Economic impact
Name	**District climate (carbon) dividend**				
Definition	Carbon fee and dividend: The basic definition of carbon dividend (CD) refers to *"returning all net revenues received from the carbon tax – usually imposed on fossil fuel burning – to citizens in the form of a monthly/yearly dividend"***.** redistribution of the CO2-taxes imposed on fossil fuel burning equally to the citizen in a country. Within ASCEND, it will be used as reference to an economic valorisation of the value of the avoided carbon emission triggered by the project (at district level).				
Unit	€, % p.a.				
Description	Dividend calculation: Valorisation by multiplying the amount of CO2-emission reduced with the price in € per metric ton CO2 (according to EU-ETS allowance prices-average annual price-). *This parameter can also be calculated as ratio to the investment cost per tCO2-reduction clauclated in D7EC_C4. Additional, bringing the calculated dividend in relation to the district population provides the "Per capita carbon dividends" which has solid mean in terms of **clean PCED**.				
KPI calculation					
Monitoring framework	Monitoring infrastructure	No additional specific monitoring infrastructures needed			
	Data collection process	Sum of all avoided annual CO2 emissions in the PCED. These savings are subsequently multiplied with applicable CO2 prices. * CO2-emission reduction achieved by all measures at district scale.			

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	Data monitoring interval	Project duration
	Baseline comparison	No
	Physical scope	PCED as a district
	Solutions included	SP2, SP3, SP4
Input Parameters	$A_{V\text{-}CO2}$: Avoided annual CO2 emissions triggered by the project over all interventions (tCO_2/a). $Tax_{\text{-}CO2}$: Applicable CO2 prices (national/EU carbon tax, ETS etc.) (€/tCO_2) CD: annual carbon dividend (€/a).	
Calculation formula	$CD = A_{V\text{-}CO2} \,.\, Tax_{\text{-}CO2}$	
Reference	Carbon Fee and Dividend in the European Union Carbon Taxes in Europe 2023	

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D8 Governance Dimension

KPI description						
Abbreviation	D8GVC1	**Dimension**	D8 Governance	**Category**	**Local governance**	
Name	**Number of Key Stakeholders involved**					
Definition	Key stakeholders are defined as local organizations or representatives of residents that are directly involved in the development and realisation of the PCED and have direct links to the local context. This involvement can reach from participation in project meetings, the implementation of solutions, provision of feedback etc.					
Unit	#					
Description	This KPI expresses how many stakeholders were involved in the planning and realisation of the PED and provides insights into how the project reached local stakeholders.					
KPI calculation						
Monitoring framework	Monitoring infrastructure	No specific monitoring infrastructure required				
	Data collection process	Survey				
	Data monitoring interval	Project duration				
	Baseline comparison	No				
	Physical scope	PCED				
	Solutions included	SP6				
Input Parameters	Documentation on solution and project development and implementation					
Calculation formula	NA					

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KPI description					
Abbreviation	D8GVC2	**Dimension**	D8 Governance	**Category**	**Local governance**
Name	**Involvement of city administration**				
Definition	Evaluation of the level of local authority involvement.				
Unit	Likert scale				
Description	This KPI provides insight the involvement of local authority in the development of the project. The level of involvement is estimated based on a Likert scale.				
KPI calculation					
Monitoring framework	Monitoring infrastructure		No specific monitoring infrastructure required		
	Data collection process		Survey		
	Data monitoring interval		Project duration		
	Baseline comparison		No		
	Physical scope		PCED		
	Solutions included		SP6		
Input Parameters	Documentation on solution and project development and implementation				
Calculation formula	NA				

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10. Annexes-B Optional KPIs

List of recommended (optional) KPIs for Monitoring & Evaluation for ASCEND.

Abbreviation	KPI Name	Unit
D1 – Integrated energy solutions at building level		
D1EBC2	Energy savings by building efficiency measures (measured)	
D1EBC3	Energy savings induced by switching to new heating system	
D1EBO1	Energy savings by building efficiency measures (derived from D1EBC2)	
D1EBO2	Energy savings by building efficiency measures of demand side management (DSM)	
D1EBO3	Energy consumption shifted by building measures of demand side management (DSM)	
D1EBO4	Energy consumption shifted by building measures of demand side response (DSR)	
D1EBO5	Energy savings induced by sufficiency measures	
D1EBO6	On-site annual renewable energy production (simulated)	
D1EBC7	Building self-supply-ratio)	
D1EBO7	Building dynamic energy balance	
D2 – Integrated energy solutions at district level		
D2EDO1	Electrification rate of final energy demand (measured)	
D2EDO2	Maximum local PV generation to district electric peak demand	
D2EDO5	Local Power storage capacity to the electric peak demand	
D2EDO6	Number of buildings integrated in energy management systems	
D2EDO7	Accumulated time of electric grid reliance (seasonal, annual)	
D2EDO8	Reduction in energy curtailment (Annual)	
D2EDO9	Amount of energy shared	
D2EDO10	Ratio of EV electricity consumption to the local electricity production	
D2EDC11	PED dynamic energy balance	
D2EDO12	Used heat storage capacity	
D1EDO13	Efficiency of the heat storages	
D1EDO14	Available electricity storage capacity	
D1EDO15	Efficiency of the electricity storages	
D3 – Mobility and Transport		
D3MBO1	Average annual distance travelled with EV (per person)	
D3MBO2	Biking and walking transport infrastructure	
D3MBO3	Access point to public transport (metro, busses) within the district	
D3MBO4	Energy intensity improvement of freight transport	
D3MBO5	Total capacity of EV-Charging stations	
D3MBC4	Annual electricity provided by smart bidirectional charging	
D3MBO6	Electricity supplied for EV charging by local RES surpluses	
D3MBO7	Capacity of EV-Charging stations allowing smart bidirectional charging	
D3MBO8	Mobility points for Smart Urban Transport	
D3MBO9	Number of shared vehicles available in the district	
D3MBO10	Number of clients within the project area	

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D3MBO11	Number of bookings within the project period per year	
D3MBO12	Kilometers driven per EV and altogether	
D4 – ICT		
D4ITC1	Connected district assets	
D4ICO1	Amount of real-time data sets connected to the urban data platform.	
D4ITO2	Degree of Interoperability (IRL)	
D4ITO3	Citizen data sharing	
D4ITO4	Quality of open data	
D5 – Environmental sustainability		
D5ENO1	Outdoor air pollution reduction (PM10, NOx)	
D5ENO2	Energy from waste resources	
D5ENO3	Waste/Product recycling rate (proportion of reuse/recycling)	
D6- Social sustainability		
D6SOO1	Resident involved in energy communities or tenant electricity model (Mieterstrommodel). For non-residential building: may we use the operations staff of the building	
D6SOO2	Number of households/entities integrated in energy communities	
D6SOO3	Active/proactive citizens' behavior	
D6SOO4	Occupant comfort	
D6SOO5	Number of residents directly benefited from the energy/mobility project solutions	
D6SOC4	Financial benefit for the end-user (reduction in energy bill)	
D7 – Economic sustainability		
D7ECO1	N. of financial providers actively involved (*included in the above KPI on attracted investment)	
D7ECO2	Operation & Maintenance costs	
D7ECO3	Increase in the market price of the housing in the district	
D8 – Governance		
D8GVO1	Compatibility of existing regulations	
D8GVO2	Number of Regulations adapted due to the project	
D8GVO3	Local community participation in implementation	
D8GVC3	replication and deployment	
D8GVO5	Change in rules and regulations	
D8GVO6	Change in public procurement	
D8GVO7	Progressing in urban plans	
D8GVO8	New Governance models and policies (shifting from silo to interdisciplinary solutions, e.g., energy-water-mobility nexus; Energieraumplannung)	
D8GVO9	Capacity building	

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