ANNEX 83

EBC

Energy in Building and Communities Programme

International Energy Agency

Project Summary Report

Positive Energy Districts (Annex 83)

Energy in Buildings and Communities Technology Collaboration Programme

November 2025

Technology Collaboration Programme by iea

ANNEX **83**

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Preface

The International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster international co-operation among the 30 IEA participating countries and to increase energy security through energy research, development and demonstration in the fields of technologies for energy efficiency and renewable energy sources.

The IEA Energy in Buildings and Communities Programme

The IEA co-ordinates international energy research and development (R&D) activities through a comprehensive portfolio of Technology Collaboration Programmes (TCPs). The mission of the IEA Energy in Buildings and Communities (IEA EBC) TCP is to support the acceleration of the transformation of the built environment towards more energy efficient and sustainable buildings and communities, by the development and dissemination of knowledge, technologies and processes and other solutions through international collaborative research and open innovation. (Until 2013, the IEA EBC Programme was known as the IEA Energy Conservation in Buildings and Community Systems Programme, ECBCS.)

The high priority research themes in the EBC Strategic Plan 2019-2024 are based on research drivers, national programmes within the EBC participating countries, the Future Buildings Forum (FBF) Think Tank Workshop held in Singapore in October 2017, and a Strategy Planning Workshop held at the EBC Executive Committee Meeting in November 2017. The research themes represent a collective input of the Executive Committee members and Operating Agents to exploit technological and other opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy technologies, systems and processes. Future EBC collaborative research and innovation work should have its focus on these themes.

At the Strategy Planning Workshop in 2017, some 40 research themes were developed. From those 40 themes, 10 themes of special high priority have been extracted, taking into consideration a score that was given to each theme at the workshop. The 10 high priority themes can be separated in two types namely 'Objectives' and 'Means'. These two groups are distinguished for a better understanding of the different themes.

Objectives - The strategic objectives of the EBC TCP are as follows:

- Reinforcing the technical and economic basis for refurbishment of existing buildings, including financing, engagement of stakeholders and promotion of co-benefits;
- Improvement of planning, construction and management processes to reduce the performance gap between design stage assessments and real-world operation;
- The creation of 'low tech', robust and affordable technologies;
- The further development of energy efficient cooling in hot and humid, or dry climates, avoiding mechanical cooling if possible;
- The creation of holistic solution sets for district level systems taking into account energy grids, overall performance, business models, engagement of stakeholders, and transport energy system implications.

Means - The strategic objectives of the EBC TCP will be achieved by the means listed below:

- The creation of tools for supporting design and construction through to operations and maintenance, including building energy standards and life cycle analysis (LCA);
- Benefitting from 'living labs' to provide experience of and overcome barriers to adoption of energy efficiency measures;
- Improving smart control of building services technical installations, including occupant and operator interfaces;
- Addressing data issues in buildings, including non-intrusive and secure data collection;
- The development of building information modelling (BIM) as a game changer, from design and construction through to operations and maintenance.

The themes in both groups can be the subject for new Annexes, but what distinguishes them is that the 'objectives' themes are final goals or solutions (or part of) for an energy efficient built environment, while the 'means' themes are instruments or enablers to reach such a goal. These themes are explained in more detail in the EBC Strategic Plan 2019-2024.

The Executive Committee

Overall control of the IEA EBC Programme is maintained by an Executive Committee, which not only monitors existing projects, but also identifies new strategic areas in which collaborative efforts may be beneficial. As the Programme is based on a contract with the IEA, the projects are legally established as Annexes to the IEA EBC Implementing Agreement. At the present time, the following projects have been initiated by the IEA EBC Executive Committee, with completed projects identified by (*) and joint projects with the IEA Solar Heating and Cooling Technology Collaboration Programme by (☼):

Annex 1: Load Energy Determination of Buildings (*)
Annex 2: Ekistics and Advanced Community Energy Systems (*)
Annex 3: Energy Conservation in Residential Buildings (*)
Annex 4: Glasgow Commercial Building Monitoring (*)
Annex 5: Air Infiltration and Ventilation Centre
Annex 6: Energy Systems and Design of Communities (*)
Annex 7: Local Government Energy Planning (*)
Annex 8: Inhabitants Behaviour with Regard to Ventilation (*)
Annex 9: Minimum Ventilation Rates (*)
Annex 10: Building HVAC System Simulation (*)
Annex 11: Energy Auditing (*)
Annex 12: Windows and Fenestration (*)
Annex 13: Energy Management in Hospitals (*)
Annex 14: Condensation and Energy (*)
Annex 15: Energy Efficiency in Schools (*)
Annex 16: BEMS 1- User Interfaces and System Integration (*)
Annex 17: BEMS 2- Evaluation and Emulation Techniques (*)
Annex 18: Demand Controlled Ventilation Systems (*)
Annex 19: Low Slope Roof Systems (*)
Annex 20: Air Flow Patterns within Buildings (*)
Annex 21: Thermal Modelling (*)
Annex 22: Energy Efficient Communities (*)
Annex 23: Multi Zone Air Flow Modelling (COMIS) (*)
Annex 24: Heat, Air and Moisture Transfer in Envelopes (*)
Annex 25: Real time HVAC Simulation (*)
Annex 26: Energy Efficient Ventilation of Large Enclosures (*)
Annex 27: Evaluation and Demonstration of Domestic Ventilation Systems (*)
Annex 28: Low Energy Cooling Systems (*)
Annex 29: ☼ Daylight in Buildings (*)
Annex 30: Bringing Simulation to Application (*)
Annex 31: Energy-Related Environmental Impact of Buildings (*)
Annex 32: Integral Building Envelope Performance Assessment (*)
Annex 33: Advanced Local Energy Planning (*)
Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)
Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT) (*)
Annex 36: Retrofitting of Educational Buildings (*)
Annex 37: Low Exergy Systems for Heating and Cooling of Buildings (LowEx) (*)
Annex 38: ☼ Solar Sustainable Housing (*)
Annex 39: High Performance Insulation Systems (*)
Annex 40: Building Commissioning to Improve Energy Performance (*)
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG) (*)

Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM) (*)
Annex 43: ☼ Testing and Validation of Building Energy Simulation Tools (*)
Annex 44: Integrating Environmentally Responsive Elements in Buildings (*)
Annex 45: Energy Efficient Electric Lighting for Buildings (*)
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo) (*)
Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings (*)
Annex 48: Heat Pumping and Reversible Air Conditioning (*)
Annex 49: Low Exergy Systems for High Performance Buildings and Communities (*)
Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings (*)
Annex 51: Energy Efficient Communities (*)
Annex 52: ☼ Towards Net Zero Energy Solar Buildings (*)
Annex 53: Total Energy Use in Buildings: Analysis and Evaluation Methods (*)
Annex 54: Integration of Micro-Generation and Related Energy Technologies in Buildings (*)
Annex 55: Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance and Cost (RAP-RETRO) (*)
Annex 56: Cost Effective Energy and CO2 Emissions Optimization in Building Renovation (*)
Annex 57: Evaluation of Embodied Energy and CO2 Equivalent Emissions for Building Construction (*)
Annex 58: Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements (*)
Annex 59: High Temperature Cooling and Low Temperature Heating in Buildings (*)
Annex 60: New Generation Computational Tools for Building and Community Energy Systems (*)
Annex 61: Business and Technical Concepts for Deep Energy Retrofit of Public Buildings (*)
Annex 62: Ventilative Cooling (*)
Annex 63: Implementation of Energy Strategies in Communities (*)
Annex 64: LowEx Communities - Optimised Performance of Energy Supply Systems with Exergy Principles (*)
Annex 65: Long-Term Performance of Super-Insulating Materials in Building Components and Systems (*)
Annex 66: Definition and Simulation of Occupant Behavior in Buildings (*)
Annex 67: Energy Flexible Buildings (*)
Annex 68: Indoor Air Quality Design and Control in Low Energy Residential Buildings (*)
Annex 69: Strategy and Practice of Adaptive Thermal Comfort in Low Energy Buildings
Annex 70: Energy Epidemiology: Analysis of Real Building Energy Use at Scale
Annex 71: Building Energy Performance Assessment Based on In-situ Measurements
Annex 72: Assessing Life Cycle Related Environmental Impacts Caused by Buildings
Annex 73: Towards Net Zero Energy Resilient Public Communities
Annex 74: Competition and Living Lab Platform
Annex 75: Cost-effective Building Renovation at District Level Combining Energy Efficiency and Renewables
Annex 76: ☼ Deep Renovation of Historic Buildings Towards Lowest Possible Energy Demand and CO_2 Emissions
Annex 77: ☼ Integrated Solutions for Daylight and Electric Lighting
Annex 78: Supplementing Ventilation with Gas-phase Air Cleaning, Implementation and Energy Implications
Annex 79: Occupant-Centric Building Design and Operation
Annex 80: Resilient Cooling
Annex 81: Data-Driven Smart Buildings
Annex 82: Energy Flexible Buildings Towards Resilient Low Carbon Energy Systems
Annex 83: Positive Energy Districts
Annex 84: Demand Management of Buildings in Thermal Networks
Annex 85: Indirect Evaporative Cooling
Annex 86: Energy Efficient Indoor Air Quality Management in Residential Buildings

Annex 87: Energy and Indoor Environmental Quality Performance of Personalised Environmental Control Systems
Annex 88: Evaluation and Demonstration of Actual Energy Efficiency of Heat Pump Systems in Buildings
Annex 89: Ways to Implement Net-zero Whole Life Carbon Buildings
Annex 90: Low Carbon, High Comfort Integrated Lighting (EBC Annex 90 / SHC Task 70)
Annex 91: Open BIM for Energy Efficient Buildings
Annex 92: Smart Materials for Energy-Efficient Heating, Cooling and IAQ Control in Residential Buildings
Annex 93: Energy Resilience of the Buildings in Remote Cold Regions
Annex 94: Validation and Verification of In-situ Building Energy Performance Measurement Techniques
Annex 95: Human-centric Building Design and Operation for a Changing Climate
Annex 96: Grid Integrated Control of Buildings
Annex 97: Sustainable Cooling in Cities
Annex 98: Flexibilization and Optimization of Heat Pump Systems in Existing Buildings through Secondary-Side Digitalization
Annex 99: Air Cleaning for Sustainable and Resilient Buildings

Working Group - Energy Efficiency in Educational Buildings (*)
Working Group - Indicators of Energy Efficiency in Cold Climate Buildings (*)
Working Group - Annex 36 Extension: The Energy Concept Adviser (*)
Working Group - HVAC Energy Calculation Methodologies for Non-residential Buildings (*)
Working Group - Cities and Communities
Working Group - Building Energy Codes

Abbreviations

Abbreviation	Full Term / Definition
ATES	Aquifer Thermal Energy Storage
CBA	Cost–Benefit Analysis
Cfb / Dfb	Köppen Climate Classification Codes (Temperate / Cold Continental)
DHN	District Heating Network
DUT	Driving Urban Transitions Partnership
EBC	Energy in Buildings and Communities (IEA Programme)
EIA	Environmental Impact Assessment
ES	Energy Storage
EU	European Union
GHG	Greenhouse Gas
HP	Heat Pump
IEA	International Energy Agency
ISO	International Organization for Standardization
KPI	Key Performance Indicator
MCDA	Multi-Criteria Decision Analysis
PED	Positive Energy District
PV	Photovoltaics
R&D	Research and Development
SAREF4CITY	Smart Applications REFerence Ontology for Cities
SDG	Sustainable Development Goal
ST	Smart Technologies
STA	Subtask A (Strategic Framework Development)
STB	Subtask B (Technological and Modeling Frameworks)
TRNSYS	Transient System Simulation Tool
V2G	Vehicle-to-Grid
WRI	World Resources Institute

Contents

1. Introduction

1.1 General Context

The Positive Energy District (PED) concept evolved from earlier concepts such as Nearly/Net/Zero/Positive Energy Buildings. It shifts the focus from individual structures to the district scale, aiming to leverage energy mutuality between buildings and drive urban decarbonization (Leone et al., 2023).

This broader perspective is motivated by several key advantages over the single-building approach. District-level strategies offer benefits for energy-system design, integration and the optimization of urban morphology (Cellura et al., 2025; Volpe et al., 2025). Furthermore, district-scale energy systems can deliver economies of scale in both cost and technical performance, rather than simply aggregating individual building systems (Marrasso et al., 2024). They do so by facilitating local energy exchanges between different buildings, integrating electric mobility applications that exploit surplus renewable generation and enabling district-level energy storage (Kozlowska et al., 2024). PEDs also provide a practical framework for implementing the directive on renewable energy communities, as they encourage broad participation of locally based stakeholders in the energy system (Cabeza et al., 2024).

The concept of a “Positive Energy Block” (PEB) was also introduced for adoption within the European Innovation Partnership on Smart Cities and Communities Marketplace (now the Smart Cities Marketplace). Building on this initiative, a refined "Positive Energy District" (PED) concept was subsequently defined in 2018 by the European Commission's SET-Plan Action 3.2 "Smart Cities and Communities" (Volpe et al., 2024). In this framework, a PED is characterized as “a district with annual net zero energy import and net zero CO_2 emissions, working towards an annual local surplus production of renewable energy (Volpatti et al., 2024). Beyond the primary balance requirements (Guarino et al., 2023), this definition underscores three key features: energy efficiency, local renewable energy supply and demand-side flexibility (Natanian et al., 2024).

Subsequently, the Joint Programming Initiative (JPI) Urban Europe broadened this definition to include inclusiveness, human-centricity and resilience with respect to the distribution grid. The most widely acknowledged definition is as follows:

“Positive Energy Districts are energy-efficient and energy-flexible urban areas or groups of connected buildings which produce net zero greenhouse gas emissions and actively manage an annual local or regional surplus production of renewable energy. They require integration of different systems and infrastructures and interaction between buildings, 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.”

This comprehensive definition places specific emphasis on multiple energy-use sectors and infrastructures. It also highlights the pivotal role of interactions between buildings, including peer-to-peer solutions and energy communities. Crucially, it stresses the importance of ensuring a "good life" for all occupants in line with sustainability goals and going beyond purely mathematical performance targets.

In 2018, the European Commission also formally integrated requirements related to PEBs and PEDs into the Horizon 2020 calls for Smart Cities and Communities Lighthouse projects, using a slightly modified definition. As a result, several EU-funded projects are now conducting research and development activities on Positive Energy Districts, increasing scientific interest in the concept.

In this context, the International Energy Agency (IEA) Energy in Buildings and Communities (EBC) Annex 83, titled "Positive Energy Districts," provides a framework for further research. Its work focuses on stakeholder involvement, refining the PED definition, identifying technical solutions, developing modelling tools and assessing sustainability impacts. It also broadened the scope of the PED concept from a purely European to an international perspective.

The Annex has been active since November 2019 and its work is organised into the following four subtasks:

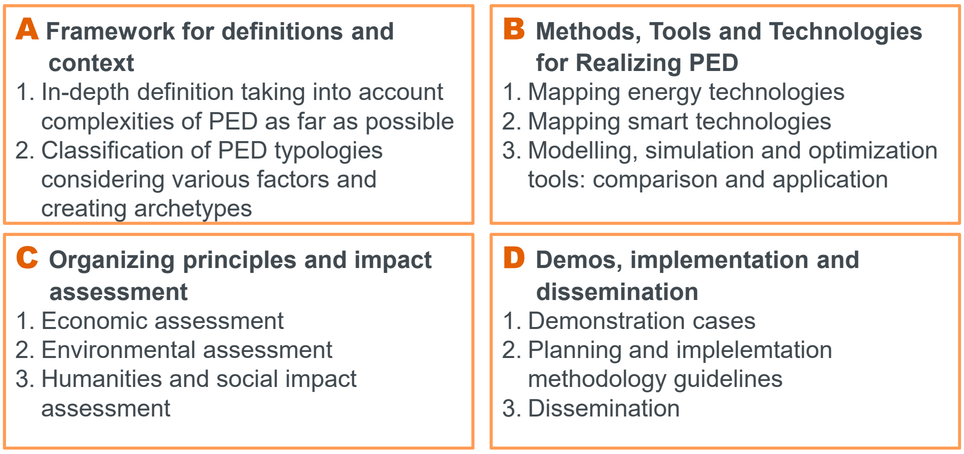

Figure 1. Annex 83 Subtasks objective definitions

Target audiences for each objective (see Fig.1 for Objective definitions) are the following:

- Objective 1. Map stakeholders, their needs and roles: building owners and users, city planners, service providers, developers, investors, R&D organizations, policymakers, technology providers, local authorities, etc.
- Objective 2. Develop in-depth definitions for policymakers, local authorities, R&D organizations, energy utilities, etc.
- Objective 3. Identify emerging technical solutions and a taxonomy of technologies: energy utilities, service providers, developers, designers and planners, technology providers, R&D organizations, energy entrepreneurs and prosumers, etc.
- Objective 4. Monitor solutions and data-driven technical and service opportunities: energy utilities, grid operators, service providers, developers, designers and planners, technology providers, R&D organizations, energy entrepreneurs and prosumers, etc.
- Objective 5. Provide a planning and implementation methodology for local authorities, designers, grid operators and planners, developers, etc.

Each Subtask will produce a deliverable presenting its results:

- Subtask A, Deliverable 1: Framework of Definitions and Key Concepts on Positive Energy Districts;
- Subtask B, Deliverable 2: Methods, Tools and Technologies for Realizing Positive Energy Districts;
- Subtask C, Deliverable 3: Governance Principles and Impact Assessment for Positive Energy Districts;
- Subtask D, Deliverable 4: Demo Cases on Positive Energy districts and Related Technologies.

The following sections provide a more detailed description of the scope and contents of each deliverable.

2. Subtask A: framework for definitions and context

Summary

Subtask A (STA) focuses on developing frameworks to support the strategic definition and design/planning of PEDs in diverse urban contexts. Within the Annex, it plays a key analytical and comparative role, bridging research, practice and policy dimensions and facilitating learning across national and local projects. STA synthesizes results from participating cities and research partners, addressing PED development from a systemic, cross-sectoral and multi-level governance perspective. It thereby complements the technical, spatial and social subtasks of Annex 83 by focusing on strategic definition assessment, replicability and stakeholder engagement frameworks.

Main Activities and Methodological Approach

STA adopts a structured multi-phase methodology that combines literature review, expert workshops, case study analysis and synthesis of empirical data from pilot PEDs. Its main activities include:

- Development of a PED Typology Framework that categorises districts by energy balance, spatial configuration and implementation pathway.
- Design of a Strategic Planning Framework for PEDs that integrates governance structures, regulatory settings and stakeholder roles.
- Comparative analysis of case studies across participating countries to identify success patterns, barriers and enabling conditions.
- Organisation of stakeholder co-creation activities and cross-national workshops to foster exchange between researchers, municipalities and industry representatives.

The work of STA combines qualitative case study research with multi-criteria assessment tools and participatory analysis. A significant innovation lies in the integration of spatial, technological and governance dimensions of PED development within a single analytical model. STA also applies systems mapping and transition management principles to understand how PEDs evolve over time within different urban planning frameworks.

Case Studies and Empirical Basis

STA draws on case studies from a variety of urban contexts, representing both mature and emerging PED initiatives. Examples include Nordic, Central European and Mediterranean cases, covering diverse climatic, institutional and socio-economic settings. The case studies collectively address the design and planning of PEDs, with a particular focus on:

- Urban regeneration and densification processes.
- Integration of renewable energy systems and smart grids.
- Governance models for public-private collaboration.
- Socio-technical co-design and citizen participation mechanisms.

Each case was analysed using a common template aligned with the Annex 83 framework, enabling cross-comparison. The resulting insights highlight how local context (especially governance capacity, data availability and institutional culture) strongly shapes PED outcomes.

Main Results

STA has produced a set of consolidated results across various dimensions:

1. <u>Conceptual Clarification</u>: the work classified distinction between *Positive Energy Districts* (urban districts that aim for an annual net positive renewable energy balance), *Carbon-Neutral Districts*

(districts targeting net-zero GHG emissions over the year) and *Smart Energy Communities* (collective, citizen-centred renewable energy initiatives), providing guidance on consistent terminology and boundary conditions. This supports better integration of PED concepts into policy and planning instruments.

2. Strategic Frameworks: the PED Planning Framework defined stages from visioning and pre-feasibility to implementation and monitoring. It emphasizes the need for iterative and adaptive governance, rather than linear project delivery.
3. PED Typologies: three dominant types were identified, namely *Technology-driven PEDs*, *Urban regeneration-based PEDs* and *Community-oriented PEDs*, each with distinct priorities and challenges. This typological distinction helps stakeholders to align approaches with local capacities and objectives.
4. Barriers and Enablers: institutional fragmentation, lack of clear ownership models and misalignment between energy and urban planning policies remain major barriers. Conversely, strong local leadership, integrated planning tools and multi-actor collaboration emerge as key enablers.
5. Monitoring and Evaluation: STA developed metrics and indicators to assess PED performance, including energy balance, carbon footprint and social co-benefits, while emphasising continuous monitoring and open data practices for transparency and learning.

Key Lessons Learned

Several overarching lessons were derived from the synthesis:

- Integration across scales. Successful PEDs require alignment of city-scale strategies with neighbourhood-level design and building-scale technologies.
- Governance innovation. Institutional arrangements must evolve towards more flexible, cross-departmental collaboration between planning, energy, housing and mobility sectors.
- Stakeholder engagement. Co-creation and participation are not just social add-ons, but critical components for system acceptance, behavioural change and data co-production.
- Contextualization. There is no universal PED model: solutions must be adapted to context, respecting local resources, policy frameworks and community aspirations.
- Long-term thinking. PED development is a transitional process that extends beyond project cycles and requires stable frameworks for learning and scaling over time.

Recommendations for Stakeholders

Drawing on the evidence gathered, the research outputs from STA outline several recommendations for:

- Municipalities: embedding PED strategies in existing urban planning frameworks, ensuring continuity beyond political terms and developing capacity-building programs for municipal staff on energy-positive urban design.
- Policymakers: harmonising national regulations to enable district-level energy balancing and flexible market participation for local actors.
- Developers and Industry: taking part in co-design processes from the earliest project stages and adopting open-innovation practices to align technological solutions with community goals.
- Researchers: strengthening longitudinal studies and data-sharing infrastructures to track PED performance and facilitate cross-case learning.

Conclusion

STA substantially contributes to the operationalisation of the PED concept by linking theory and practice through comparative analysis and strategic frameworks.
It shows that PEDs are not merely technological demonstrations, but complex socio-technical transitions that require adaptive governance, integrated planning and sustained collaboration.
The findings provide an evidence-base for policy recommendations and practical tools to support cities in moving towards carbon neutrality and climate resilience, within the broader context of *Annex 83*.

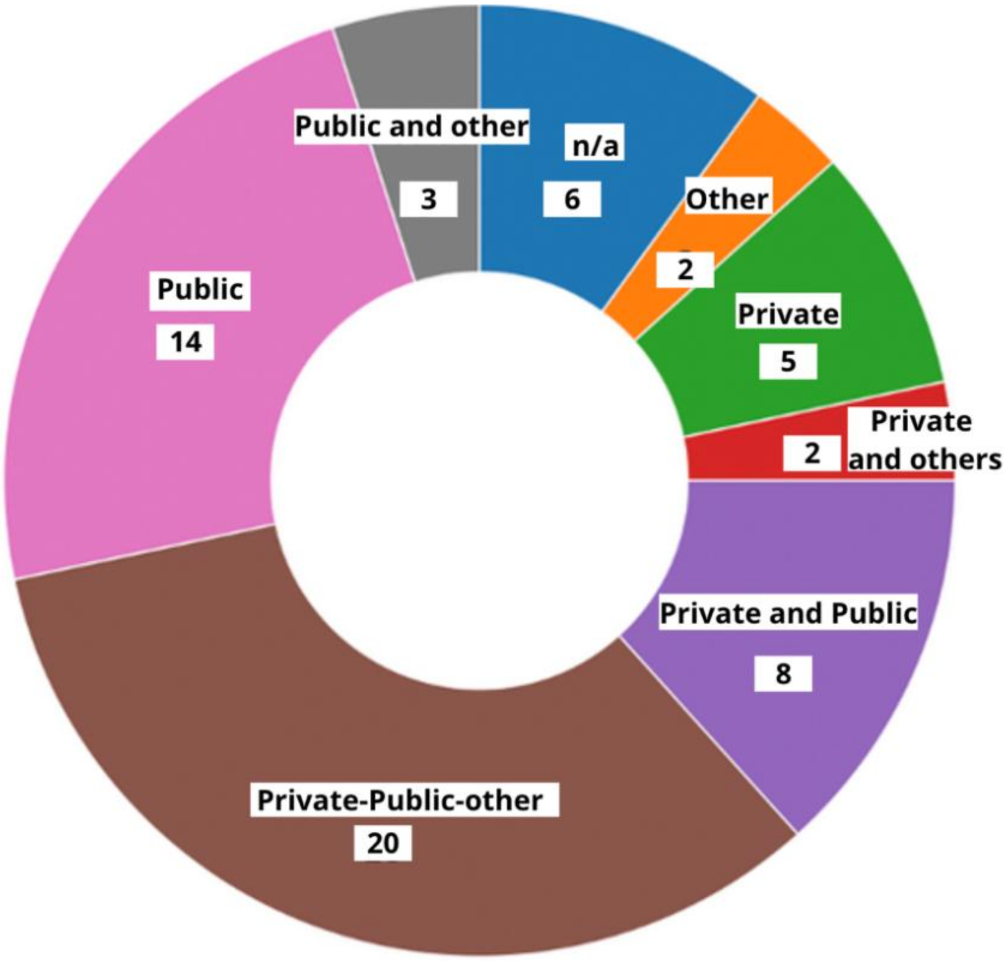

Figure 2. Commonly used type of finance models

3. Subtask B: methods, tools and technologies for realizing PEDs

Summary

Subtask B has focused on reviewing the technologies, tools and modelling frameworks that enable PED implementation. Its objectives are the following.

1. To map relevant technologies at building and district scales.
2. To assess smart control and flexibility solutions.
3. To review modelling tools and data requirements for PED analysis. Subtask B supports Annex 83 objectives O3 (technologies) and O4 (digital enablers).

Main Activities and Methodological Approach

PEDs integrate buildings, mobility and ICT infrastructures to achieve net-positive annual energy balances. Three main PED configurations are defined: autonomous, dynamic and virtual. Most operational PEDs in Europe are dynamic, with autonomous systems being rarer and virtual PEDs mainly suited to northern climates.

PEDs integrate a wide range of technologies. Photovoltaics (PV) are the dominant renewable energy source due to their cost-effectiveness, scalability, and ease of installation. A second key technology in PEDs is the use of heat pumps, powered by low-emission electricity and crucial for decarbonising heating and cooling, while district heating networks may use not only heat pumps, but also waste heat from data centres, supermarkets, or geothermal sources. To enable flexibility and a better match between supply and demand, PEDs typically rely on energy sharing, as well as on thermal and electrical storage.

Case Studies and Empirical Basis

A review of more than 39 European case studies shows that PEDs combining PV and heat pumps, together with highly efficient building envelopes, achieve the best results. For instance, in Innsbruck, integrating heat pumps and PV reduced seasonal imbalances (page 23 of subtask B deliverable). Similarly, the Buiksloterham PED in Amsterdam demonstrates how PV, aquifer thermal storage (ATES) and flexibility mechanisms can coexist in dense urban environments despite space limitations. Its governance model, which allows peer-to-peer energy exchanges, highlights that technical success must be coupled with supportive legal and regulatory frameworks to unlock the full potential of PEDs.

Main Results

For flexibility, different strategies are adopted, including smart demand control and load shifting, integration of energy storage, Vehicle-to-Grid (V2G) schemes and community-level energy management systems. Several PED cases integrate software platforms to form Virtual Power Plants (VPPs), aggregating flexibility from EVs, batteries and PV, thereby reducing grid congestion. In Oulu a Model Predictive Controller (MPC) is applied for load planning and flexibility management via a Building Energy Management System (BEMS). The Syn.ikia pilots in Uden and Santa Coloma deploy digital twins (DigiTwinN, SirinE) and Economic MPC to cut energy costs by around 5.6 % through adaptive control and occupant-behaviour modelling (pages 47-49 of subtask B deliverable). These examples confirm that digitalisation, predictive modelling and control technologies are indispensable for delivering cost-effective and stable PEDs.

When it comes to modelling, PED analysis requires the integration of multiple energy carriers, sectors and domains (social, technical and spatial). Key modelling elements include energy demand profiles, generation technologies, spatio-temporal scales and optimization objectives. A comparative review of tools such as TRNSYS, City Energy Analyst (CEA), Oemof, CERC Hub and EnergyPlus, reveals limited interoperability and weak coupling with GIS and control models. Challenges include complex data collection and harmonisation, poor integration of meteorological and microclimate data, oversimplified building geometries (LOD1), poor interoperability and the high cost of fine-resolution simulations.

To illustrate these issues, the Lachine Eco-District in Canada was modelled using the CERC Hub workflow to evaluate different scenarios combining PV, heat pumps and district heating. The modelling revealed that integrating a low-temperature district-heating network with canal-water heat pumps reduced grid dependency by more than 50 % and increased annual self-sufficiency to 37 %. However, the study also showed that improving building efficiency alone yields limited gains, underscoring that PED design must combine energy-efficiency measures with renewable integration and flexibility strategies.

Key Lessons Learned

To tackle the challenge of fragmented data, STB recommends the use of ontology-based frameworks, such as the BIGG Ontology, to harmonise datasets and ensure interoperability among modelling tools. Ontologies formally define the relationships between concepts such as Building, Energy System, Sensor and TimeSeries, enabling machines and humans to share a common understanding of information. This semantic layer allows automated data mapping between heterogeneous systems, for instance transferring building geometry from BIM to TRNSYS, or energy profiles from CEA to Hub models, without manual re-entry. Once data are standardized and instantiated into an ontology-based framework, workflow pipelines (such as energy balance calculations or KPI assessments) can be reused across projects, substantially reducing time and cost. The ontology approach also underpins semantic co-simulation, where multiple domain-specific tools interact through a shared knowledge graph. For example, a building model in EnergyPlus can communicate occupancy data to an urban mobility simulation or receive real-time weather updates from an external service. This interoperability enhances accuracy and enables multi-domain assessments, combining building performance, transport energy use and microclimatic effects within a unified PED model.
The BIGG Ontology integrates standards such as SAREF4CITY and GeoSPARQL to capture spatial, temporal and technical dimensions, thereby supporting automated reasoning, KPI evaluation and benchmarking of districts under different climate or policy scenarios.

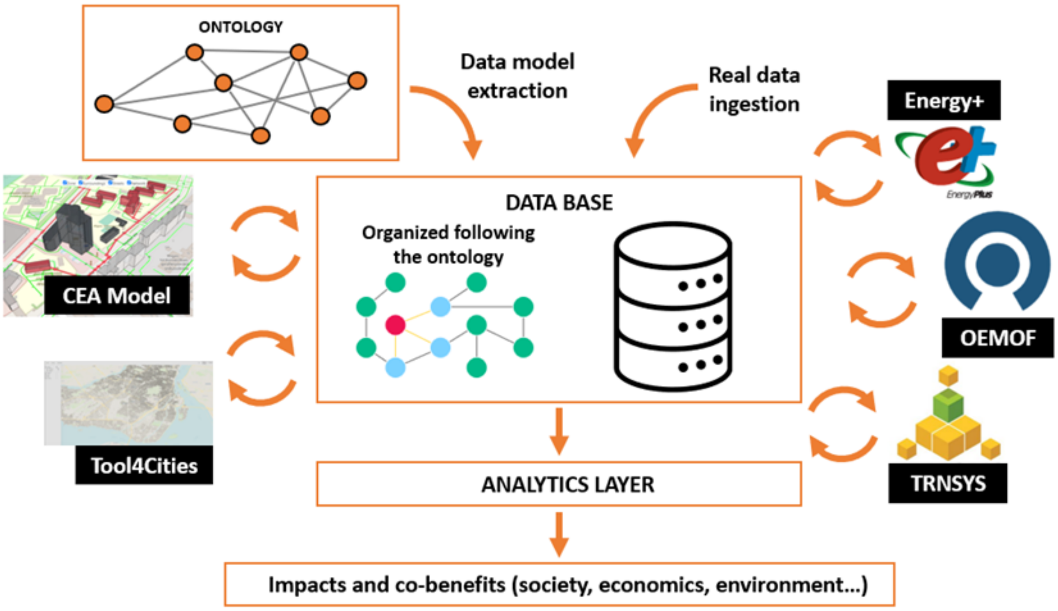

Figure 3. Scheme of ontology use in the PED context, integrating data from different systems to assess PED KPIs.

Conclusion

In summary, Subtask B provides a comprehensive technological and methodological foundation for PED development. It shows that coupling renewable technologies with flexibility mechanisms, smart control and robust digital modelling enables decarbonised, resilient and scalable urban districts. Case studies, from Amsterdam's circular redevelopment to Trondheim's ZEB Laboratory, illustrate that successful PEDs depend as much on governance, regulatory adaptation and citizen engagement, as on technology. The deliverable concludes that systemic integration, reliable data and open digital infrastructures are key enablers for realising the Positive Energy District vision and that ontology-driven interoperability will be fundamental for scaling PED implementation across Europe and beyond.

4. Subtask C: organizing principles and impact assessment

Summary

Within the IEA EBC Annex 83 Positive Energy Districts (PEDs), Subtask C focused on the conceptual, methodological and practical implications for assessing PED sustainability impacts across the economic, environmental and social pillars and on synthesising these into an integrated multi-benefit framework. Subtask C translated high-level PED ambitions, such as energy positivity, decarbonization and social inclusion, into measurable and comparable impact dimensions to guide city planners, policymakers and stakeholders in implementing and replicating PEDs.

Main Activities and Methodological Approach

Subtask C focused on the following activities.

- Systematic review of available state-of-the-art methods and indicators for assessing district-scale sustainability.
- Definition of methodological frameworks and key performance indicators tailored to the PED context.
- Testing of the developed frameworks in European case studies and projects.
- Integration of the findings into a multi-benefit toolbox that connects the economic, environmental and social dimensions within a coherent decision-support perspective.

The methods developed combine both quantitative modelling and qualitative analysis. Economic assessment relied on life-cycle costing, cost-benefit analysis and techno-economic evaluation to capture both investment feasibility and macro-economic effects. Environmental assessment employed life-cycle assessment (LCA) methods at district scale, linking operational and embodied impacts through dedicated indicators such as net CO_2 emissions, installed renewable energy capacity and material footprint. Social impact assessment was based on a Social Life-Cycle Assessment (S-LCA) structure integrating stakeholder analysis, surveys and qualitative scoring of social outcomes such as employment, equity and participation. Finally, the three pillars were merged into a multi-criteria decision analysis scheme, enabling cross-comparison of co-benefits and trade-offs.

Case Studies and Empirical Basis

Representative case studies were selected from European PED demonstration projects, namely EXCESS (economic evaluation), the University of Palermo Campus (environmental analysis) and ATELIER (social assessment). These living-lab contexts provided data for applying and validating the developed frameworks. The case studies covered diverse climates, technologies and governance settings, allowing cross-comparison of financial models, LCA boundaries and participatory approaches. Each case was analysed following a common protocol, including boundary definition, data collection, KPI calculation and interpretation of results with local stakeholders.

Main Results

The work carried out within Subtask C revealed significant methodological advances and practical findings. From an economic viewpoint, it emerged that PEDs require hybrid evaluation approaches that combine costing at both building and district scales. Traditional financial indicators (NPV, IRR, payback time) must be complemented with system-level metrics such as avoided grid investments, flexibility revenues and social return on investment (SROI).
Subtask C consolidated a library of more than 50 economic KPIs derived from EU projects (e.g., SCIS, CITYkeys, POCITYF, ATELIER).

As a final remark, it highlighted that long-term economic sustainability depends on adaptive business models and supportive regulatory frameworks.
Regarding the environmental dimension, the work showed that extending the assessment beyond operational energy is essential. The life-cycle perspective adopted in STC identified embodied emissions from materials and infrastructure as major contributors (up to 40 % of total impacts), calling for integrated renovation strategies.
The methodology developed and proposed by Subtask C combines operational KPIs (energy self-sufficiency, renewable fraction) with LCA-based metrics (Global Warming Potential, kg CO_2-eq/m²) to assess both annual performance and long-term neutrality. The case study in Palermo demonstrated how renovation and renewable integration scenarios could shift a district towards a net-positive energy and carbon balance within 30 years.
The social impact assessment confirmed that citizens' engagement, energy affordability and perceived fairness determine the long-term success of PEDs.
The S-LCA framework identified relevant impact categories, such as employment, health & safety, equity, participation and quality of life and linked them to measurable indicators (e.g., local jobs created per € 1 million invested, reduction in the energy poverty rate). Its application in the ATELIER project showed that early co-creation processes significantly improve acceptance of innovative technologies and foster behavioural change towards sustainable lifestyles.
As a final result, the multi-benefit toolbox developed within STC integrated the three sustainability pillars into a single analytical framework, enabling decision-makers to visualise synergies and conflicts among objectives. Structured around KPIs and qualitative descriptors, the toolbox supports cross-sector evaluation and stakeholder dialogue. It enables decision-makers to prioritise interventions not only on the basis of economic return, but also on their environmental and social value. This integrated perspective represents a key methodological step forward for future PED assessment and monitoring.

Key Lessons Learned

PED assessment must adopt a life-cycle and multi-scale approach, addressing both operational and embodied impacts from the building to district level. Economic viability cannot be separated from governance and regulatory contexts; social acceptance and equity are critical to success as well.
In this sense, involving diverse stakeholder groups from the planning phase reduces opposition and enhances the sense of ownership.

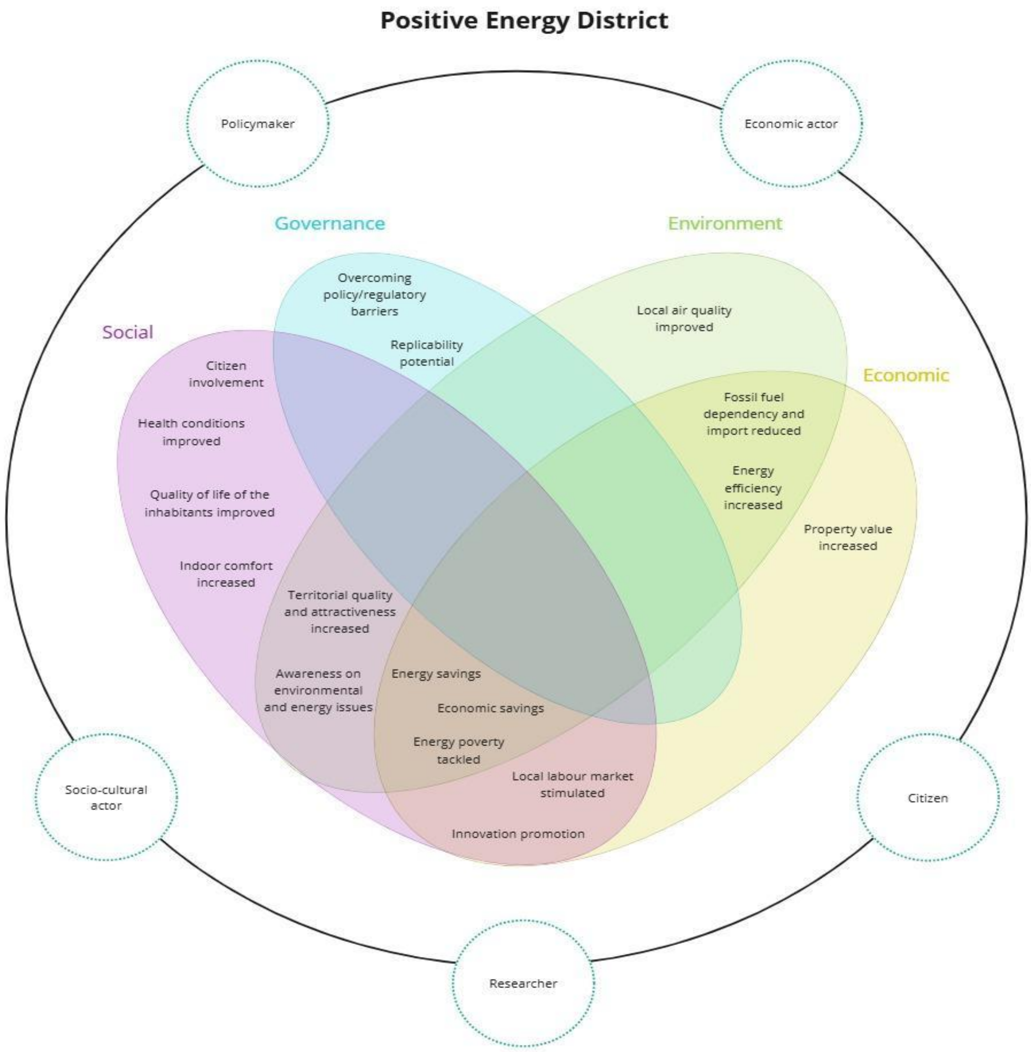

Figure 4. Most relevant multiple benefits in a PED according to the literature review

Recommendations for Stakeholders

In more detail, for city planners and local governments the results highlight the need to integrate PED principles into urban energy and climate strategies, ensuring alignment with national decarbonisation targets. Developers and investors should employ life-cycle costing, combined with social and environmental metrics, to design business models that are financially robust and socially inclusive. Policymakers and regulators are encouraged to foster enabling frameworks for collective energy actions, transparent tariff structures and public-private partnerships.

Conclusion

Finally, researchers and standardisation bodies should continue working towards harmonised assessment methodologies and interoperable data platforms, ensuring that future PED implementations can be evaluated on a comparable and replicable basis.

5. Subtask D: demos,implementation and dissemination

Summary – PED Database

The PED Database is a joint effort of COST Action “PED-EU-NET”, IEA EBC Annex 83 and JPI Urban Europe to provide a wealth of information about new and refurbished urban environments that aim to produce more energy than they consume. Deliverable D reports on the development of the PED-Database framework and its online implementation as an interoperable platform, designed in a modular way, so that the general survey can be divided into smaller, independent sections that facilitate data entry and subsequent processing. An internal peer-review process for data entry, carried out by the editors, ensures that the data in the database are sourced from reliable and verified information, supporting its overall accuracy and reliability.

Main Results

The database was developed following a database life cycle (DDLC), starting with a scoping phase in which requirements were defined and settled through a statement of requirements with the aim of creating a framework for data collection from demo cases. Finally, a testing phase has been initiated; the main conclusion drawn from this first analysis is that there is no one-size-fits-all solution for PED implementation.
Overall PED framework definitions still require further detailing in the local context. The PED Database provides an overview not only of different implementation strategies, but also of the diverse conceptualisations and approaches to the PED concept. Thanks to the contributions collected, all inputs are stored in the Database and users of the platform can visualise and compare different PED scenarios by customising their selection. Before export, the selected data can be viewed in the user-friendly front end of the PED-EU NET Database, which displays each KPI derived from the information compiled by the database editors. The selected comparison can then be saved and exported as a .csv format. In this way, users can select and work with the information that best matches their expectations and goals and then use it to develop their own data-driven storytelling.

As shown in Figure 5, the PED EU NET Database structure consists of two main blocks, divided into six closely interrelated sections.

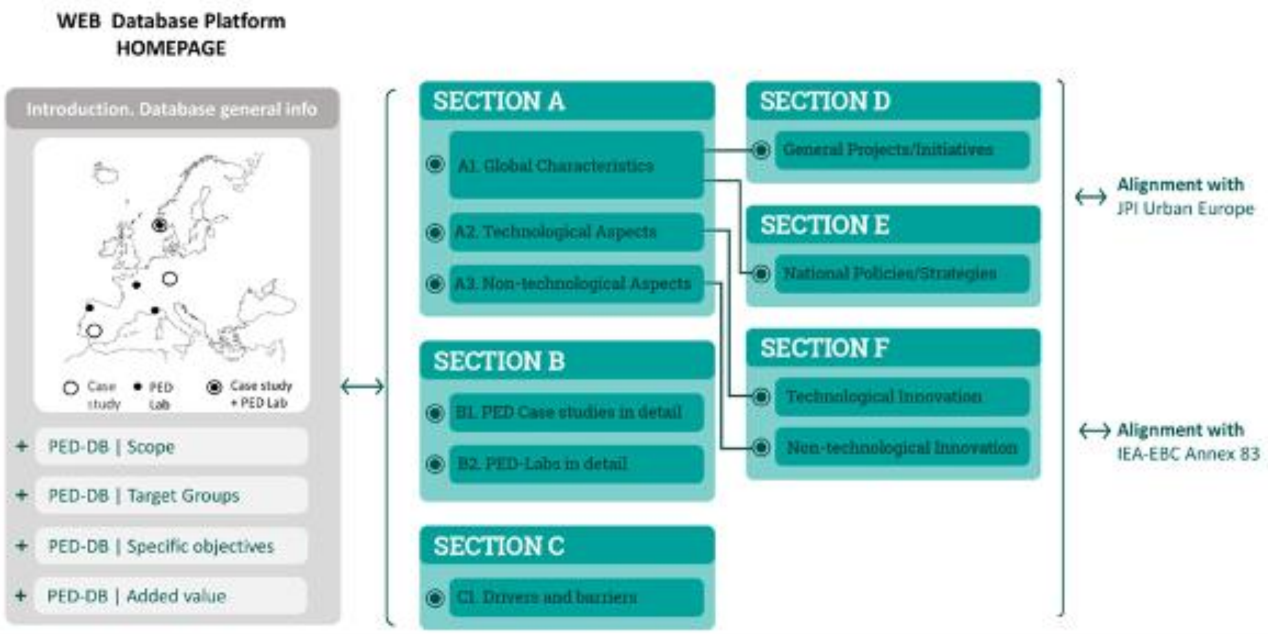

Figure 5. Sections of the PED EU NET Database

Key Lesson Learned

1. **PEDs are a crucial concept in the transition towards sustainable urban energy systems**, marking a shift from individual building-centric approaches to a district-scale perspective for integrated, efficient and sustainable urban development. Identified as a strategic priority by the European Commission (EC), the PED concept has evolved from Net Zero Energy Districts (NZEDs) and Positive Energy Blocks (PEBs), emphasising the systemic integration of renewable energy, smart grids and energy sharing at the urban level. The EC actively supports PED development through pilot projects funded under the Horizon 2020 programme.

2. **Various definitions of PEDs coexist across organisations and initiatives**; however, a single universally accepted definition is still lacking. This hinders project comparison, as different baseline assumptions are often applied. Nevertheless, the main definitions converge on annual net-zero energy imports and CO_2 emissions, while working towards a local surplus of renewable energy; they describe PEDs as energy-efficient and energy-flexible urban areas integrating energy, mobility and ICT systems and emphasise active management of energy flows and exchanges within the wider district/city energy system, typically across multiple connected buildings to achieve an annual positive energy balance.

Conclusion

Despite differing definitions, several common principles underpin the PED concept:

- Energy efficiency and flexibility of interconnected buildings and urban areas to optimise energy use.
- Active management of an annual surplus of locally or regionally produced renewable energy, aiming at net-zero GHG emissions over the year.
- Integration of urban systems, including buildings, mobility, energy and ICT.
- Priority to social, economic and environmental sustainability, with secure energy supply and inclusivity.
- Integration within urban and regional energy networks supplied by renewables.
- In many cases, the incorporation of net-zero direct carbon emissions as a target.

Key topics covered in the document include:

- Definitions and Frameworks.
- Energy-Balance Methodologies.
- Technological Solutions.
- Monitoring and Evaluation.
- Social Aspects.
- Financial and Business Models.
- Urban Planning and Spatial Integration.
- Governance and Legal Aspects.
- Implementation Processes.
- Alignment with wider Urban Sustainability Initiatives.

Definitions

Definitions of energy performance according to EN 15603:2008 (Official Journal of the EU, 19.4. 2012, p. C 115/9):

Energy source: source from which useful energy can be extracted or recovered either directly or by means of a conversion or transformation process.

Energy carrier: substance or phenomenon that can be used to produce mechanical work or heat or to operate chemical or physical processes.

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