PED-ID

Holistic assessment and innovative stakeholder involvement process
for identification of Positive-Energy-Districts

D3.1 Holistic assessment method in early development phase of potential PED areas

Deliverable no.	D3.1
Deliverable Name	Holistic assessment method in early development phase of potential PED areas
Version	V5
Release date	15/04/2022
Dissemination level	Public
Status	Final
Authors	Jiří Karásek (SEVEn) Václav Šebek (SEVEn) Ladislav Kaločai (SEVEn) Jan Pojar (SEVEn) Jakub Kvasnica (SEVEn) Kateřina Válková (ČVUT) Camilla Rampinelli (e7) Gerhard Hofer (e7)

Document history:

Version	Date of issue	Content and changes	Edited by
V1	13/09/2021	First version	SEVEn
V2	22/12/2021	Second version	SEVEn
V3	03/01/2022	Third version	e7
V4	15/03/2022	Fourth version	SEVEn
V5	15/04/2022	Format & text	e7

Peer reviewed by:

Partner	Reviewer
e7	Camilla Rampinelli
e7	Gerhard Hofer
SEVEn	Jakub Kvasnica

This project has received funding from the JPI Urban Europe programme.

Table of contents

List of Figures

List of Tables

Acronyms table

BIPV	Building-integrated photovoltaics
CEA	City Energy Analyst
EM	Energy management
EPBD II	Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings
GDP	Gross domestic product
GHG	Greenhouse gas
GIS	Geographic information system
ICT	Information and communication technology
IEA	International Energy Agency
IRR	Internal rate of return (economic indicator)
LCA	Life-cycle Assessment
MCDA	Multi-Criteria Decision Analysis
NPV	Net present value (economic indicator)
NZEB	Nearly zero-energy building
PEB	Positive energy blocks (similar concept to PED)
PED	Positive energy district
PED-ID	Project "Holistic assessment and innovative stakeholder involvement process for identification of Positive-Energy-Districts" *(this document is part of it)*
PEN	Positive energy neighbourhood (similar concept to PED)
PV	Photovoltaics
RED II	Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources
RES	Renewable energy sources
SET plan	Strategic energy technology plan
ZED	Zero energy district

1 Executive summary

PED-ID creates a knowledge-based participation process where decision-makers are provided at an early stage **with guidance on how to achieve Positive Energy District (PED) status**, the options and the impacts. Data will be collected and processed using existing methodologies adapted for appropriate stakeholders, who may then actively initiate a data-driven participation process, consolidate their opinions and make qualified decisions.

This **process will be tried and tested in three real EU Living Labs**, all potential PED initiatives, focusing on the participation process and the identification of necessary data. By applying devised methodology, the objective is to accelerate the development of Positive Energy Districts and accomplish the goal of 100 PED sites in Europe by 2025.

The objective of the "Holistic assessment method in early development phase of potential PED areas" (Deliverable 3.1) in this context is to develop a holistic method(s) for technological, environmental and economic assessment and define data requirements for the early development phase. Data requirement plan is specified to existing data from municipal and national administrations, tailored to the national and regional specification of stored data in administration. The holistic assessment consists of **three main interconnected aspects**:

- technological;
- environmental and;
- economic.

The **"Holistic assessment method in early development phase of potential PED areas" contains the handbook with tasks necessary for creating a holistic technological, environmental and economic assessment of an area selected for PED development**. This handbook will become a part of the "PED criteria catalogue". The catalogue will combine the technological, environmental and economic and social and legal assessment for Positive Energy Districts, creating a comprehensive guide for the overall PED assessment.

The guideline shows that on the one hand, it is necessary to consider the lack of data, on the other hand, for the quality assessment of the PED design, it is essential to obtain as much data as possible.

2 Introduction

The PED-ID project **provides decision-makers comprehensive information about PED options and impacts and facilitates a corresponding knowledge-based participation process**. The data will be collected and processed with the help of a methodology and prepared for the appropriate target group. The target groups can actively use these in the data-driven participation process, consolidate their opinions and make decisions based on data.

It is an innovative approach to reach a climate-neutral future. It takes the concept of near-zero energy buildings (NZEBs) to a higher level by optimising technical and financial aspects, thus promoting collective energy production, flexibility and storage. Additionally, it allows involving in the process social and other environmental aspects in a holistic manner.

This **process will be tested using real Living Labs of potential PED projects**. This concerns the participation process and the development of the necessary data. With the help of this method, the decision on PED sites will be accelerated to reach the goal of 100 PED sites in Europe.

This document aspires to become a handbook with tasks necessary for creating a holistic technological, environmental and economic assessment of the selected area in terms of Positive Energy Districts development. The handbook covers all steps from the PED definition through the initial idea, data collection, assessment methods, and model scenarios. It is decided on the implementation of the project along with the selection of a suitable solution.

2.1 Scope of this document

First, the early stage of the development project is described. An early-stage offers the greatest opportunity to influence the form and quality of a PED. It is also when holistic assessment should be performed to achieve the best possible results.

Then, the PED definition is discussed. Although one broad definition is not yet clearly defined and it varies between different sources, understanding the nature of PEDs is critical for their correct design.

Chapter 5, the main and most voluminous, deals with the preparation of PEDs. The chapter addresses the steps necessary for creating a comprehensive PED area assessment. Chapter includes:

- **First idea** – pre-selection of the area where the PED could be implemented.
- **Data collection** – obtaining a sufficient area overview and underlying data for subsequent holistic assessment.
- **Holistic assessment** – assessment of possible technical concepts, energy needs, available resources and other aspects of individual solutions in the selected area.
- **Model, scenarios** – creation of the scenarios based on the data obtained in previous subchapters.
- **Solution selection** – presents a set of possible indicators for the selection of the final solution.

In chapter 6, appropriate tools and methods for energy assessment (covering energy need, renewable energy and overall integration – energy balance) are discussed.

Finally, the most important and relevant conclusions underlying the PED design and implementation principle are presented.

3 PED Definition

Positive energy district is a comprehensive system focused on the management of both energy consumption and production and on the overall sustainability of the system. The PED system is applied to urban areas. However, due to the diversity of urban areas across Europe and worldwide, it is necessary to understand PEDs holistically and define them correctly in terms of their goals, functionality, and requirements.

The concepts of Positive Energy Blocks (PEBs)[1] and Positive Energy Districts (PEDs) have initially emerged from the EU Horizon 2020 Smart Cities and Communities project calls[2] and from the Strategic Energy Technology Plan followed up by The EU Green Deal as the latest policy roadmap.

3.1 Various sources of definition

The PED definition is not yet clear and comprehensive. The following text introduces various approaches dealing with and defining the PED concept. Subsequently, based on their analysis, a summary of the main features of PED is presented.

3.1.1 PED definition by Strategic Energy Technology Plan

Within the SET plan[3], the smart cities and communities' focal area addresses the decarbonisation of the city energy system as a whole and, more specifically, promotes positive energy blocks and districts as a next step of smart cities. According to SET plan, the positive energy blocks and districts:

> "consist of buildings that actively manage the energy flow between them and the broader energy (electricity, heating and cooling) and mobility systems by making optimal use of advanced materials, local renewables, storage, demand response, electric vehicle smart-charging and ICT"

Key elements of the definition:

- energy management and energy use optimization;
- use of advanced materials;
- use of local renewables and energy storage systems;
- system integration and Information and Communication Technologies.

[1] Cartuyvels, P. et Bartholmes, J. Positive Energy Blocks. Smart Cities Marketplace, 2016. Available from https://smart-cities-marketplace.ec.europa.eu/action-clusters-and-initiatives/action-clusters/sustainable-built-environment/positive-energy#management

[2] Positive Energy Districts Solution Booklet. EU Smart Cities Information Systém, 2020. Available from: https://smart-cities-marketplace.ec.europa.eu/insights/solutions/solution-booklet-positive-energy-districts

[3] European Commission. The Strategic Energy Technology Plan – at the heart of energy research and innovation in Europe. 2018. Available from: https://op.europa.eu/en/publication-detail/-/publication/064a025d-0703-11e8-b8f5-01aa75ed71a1

3.1.2 PED definition by JRC technical report

The publication[4] presents and introduces concepts of zero-energy districts and positive energy districts and outlines the complexity of their definition. Publication offers several approaches to ZEDs/PEDs definition. The first one is based on the definition of nZEB according to the directive 2010/31/EU on the energy efficiency of building (EBPD II), which says that NZEB is:

> *"a building that has a very high energy performance, as determined in accordance with Annex I. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby."*

This definition could include the same concepts when applied to a district scale (more suitable for ZED than PED):

- *"Nearly Zero Energy Districts: have a very high-energy performance but do not always reach a zero-energy target over a year, almost all of the remaining energy demand is provided by onsite or nearby renewable energy."*

The definition for Zero-energy concepts is further addressed and can be used as a baseline for the PED definition:

- *"Plus Energy Districts: deliver more renewable energy to the grid than they use, producing more renewable energy than they consume*
- *Net Zero Energy Districts: deliver the same amount of energy to the supply grids as they use from the grids, and do not require any fossil fuel for heating, cooling and lighting. These districts are connected to the national grid for backup and energy exchange.*
- *Zero Stand Alone Districts: are not connected to the grid and are independent in generating their own renewable energy supply with the capacity to store energy in storage systems such as batteries.*
- *Zero Carbon Districts: do not use energy from carbon dioxide emitting sources (e.g. biomass, biogas excluded) and over the year will either be carbon neutral or positive energy, therefore they produce enough energy to ensure their energy demand is always at most zero."*

The publication concludes that taking into account the above definitions, definition for "renewable energy community" from the directive 2018/2001 (RED II) and definition of long-term renovation strategy based on the EPBD II, parameters of ZED / PED can be set as follows:

- Is based on open and voluntary participation, is autonomous, and is effectively controlled by its citizens.
- Whose primary purpose is to provide environmental, economic or social community benefits.
- Has a yearly based energy balance of *zero or positive, meaning a surplus on the energy production*.

[4] Shnapp, S., Paci, D. and Bertoldi, P., Enabling Positive Energy Districts across Europe: energy efficiency couples renewable energy, EUR 30280 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-21043-6, doi:10.2760/452028, JRC121405.

- Has buildings with very high energy performance, complying with applicable minimum energy performance requirements and local building codes.
- Has buildings with a nearly zero or very low amount of energy demand.
- Has its building demand covered to a very significant extent, or more, by renewable energy sources.
- Where renewable sources are produced on-site or nearby.

3.1.3 PED definition by Urban Europe

Definition from the White Paper[5] – Reference Framework for Positive Energy Districts and Neighbourhoods by Urban Europe:

"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, 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."

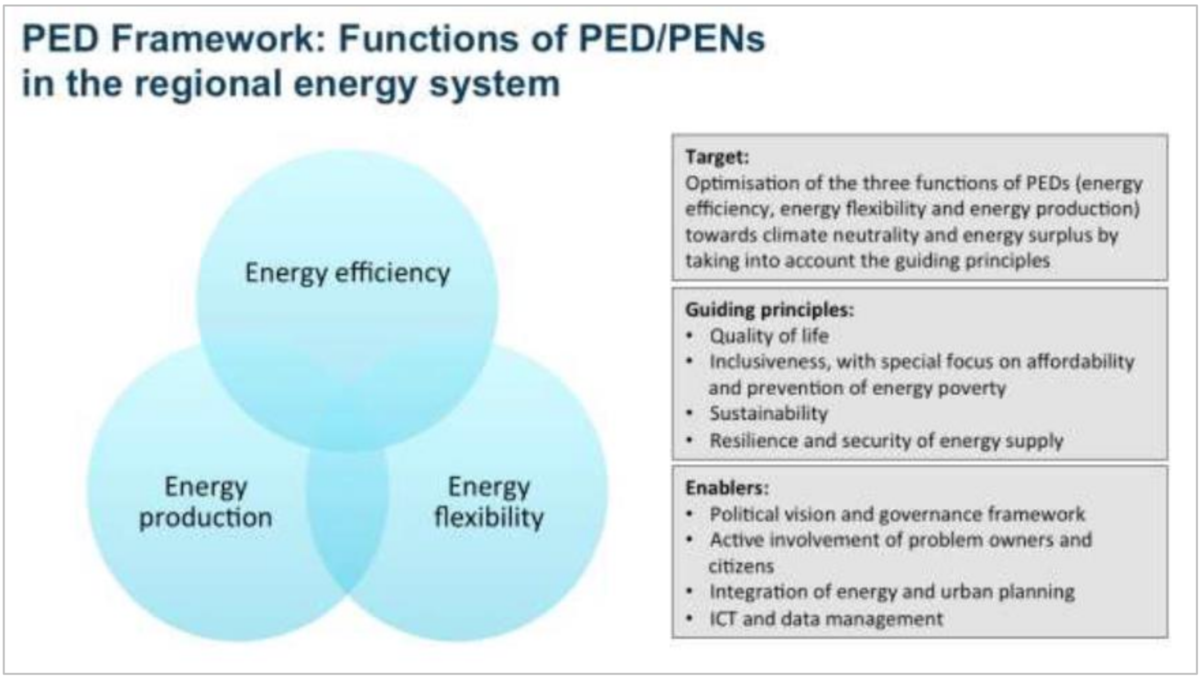


Figure 1 PED Definition from JPI Urban Europe[5]

Key elements of the definition:

- groups of buildings or urban area;
- net-zero greenhouse gas emissions;
- actively manage an annual local or regional surplus production of renewable energy;

[5] JPI Urban Europe / SET Plan Action 3.2 (2020). White Paper on PED Reference Framework for Positive Energy Districts and Neighbourhoods. https://jpi-urbaneurope.eu/ped/

- system integration;
- interconnection of several sectors;
- sustainability.

Further from the text:

- PEDs should ultimately rely on renewable energy only (energy production function).
- PEDs should make energy efficiency one of their priorities to best utilise the renewable energies available (energy efficiency function).
- PEDs should act in a way that is optimally beneficial for the energy system (energy flexibility function).

It means that **multiple areas** (economic, social, environment) **and sectors** (buildings, transport, infrastructure) **should be optimised in order to find balance** concerning the renewable energy resources available, the specific situation of the PED (municipality) and specific ambitions and needs of the PED (municipality). Another document by Urban Europe[6] – describes PEDs as:

> *"an integral part of comprehensive approaches towards sustainable urbanisation including technology, spatial, regulatory, financial, legal, social and economic perspectives while optimizing energy efficiency, energy flexibility and energy production towards climate neutrality and energy surplus."*

Key elements of the definition:

- interconnection of several sectors;
- energy efficiency and flexibility;
- climate neutrality.

A new white paper is being developed and intends to detail more the technical aspects of the PED definition. For such, there is a differentiation between primary and final energy:

- **Primary energy**: Energy embodied in resources that have not been transformed yet, like solar radiation, wind flow, water flow and other sources.

- **Final energy:** Energy consumed in the form of electricity and heat. The primary energy is transformed into final energy by different conversion, transport and processing processes, which means that energy is lost along the way. To account for these losses, primary energy factors are considered in the calculations, transforming the final energy (the one delivered to users) into primary energy.

This means that for PEDs, the annual **positive primary energy balance must be positive to account for those transformation losses also**. The balancing period and specific methods for its detailed calculation are still discussed among researchers, policymakers, and market actors. But overall, the most acceptable method is the annual energy balance. A general formulation **expressed in terms of primary energy** for the PED energy balance can be as follows:

[6] JPI Urban Europe. Towards 100 Positive Energy Districts and Neighbourhoods (Leaflet). 2019. Available from: https://jpi-urbaneurope.eu/wp-content/uploads/2019/09/PEN-Leaflet-190924.pdf

Energy consumed inside the PED boundaries
= RES generated inside the PED + Energy Imported – Energy exported

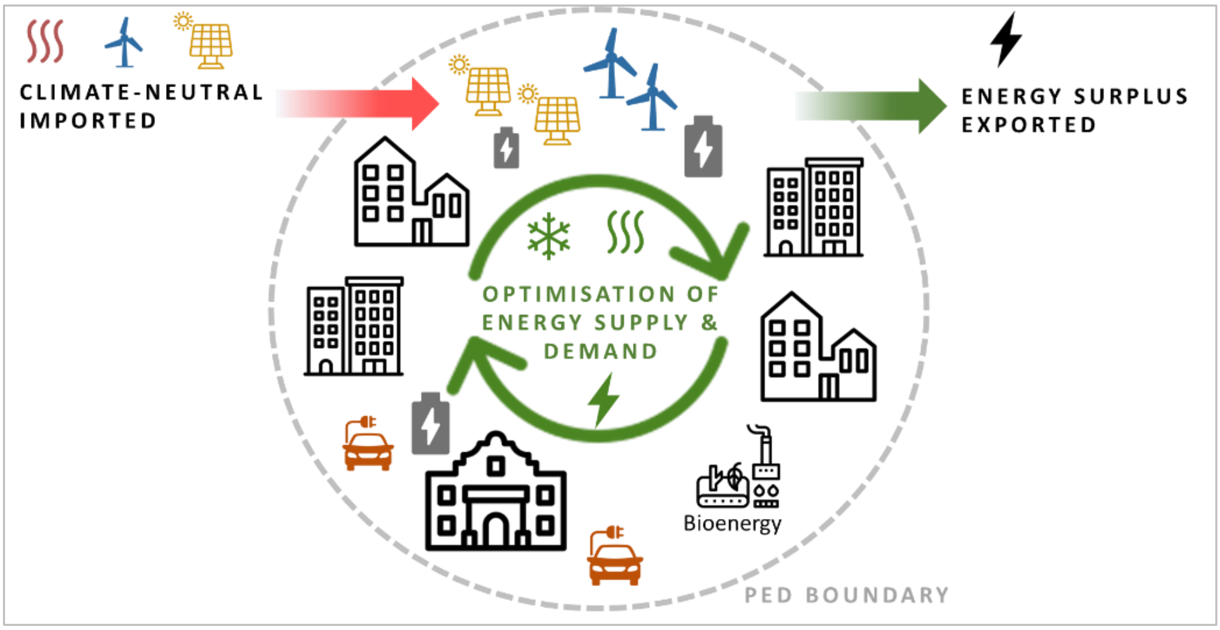


Figure 2 General Energy Balance diagram of a PED

There is also the possibility to analyse the **energy balance from a seasonal perspective**, which indicates how to conciliate the energy supply and demand better. However, this is a more challenging approach, especially for achieving zero energy balance. Another analysis that could be followed is the **life cycle balance**, specifically for buildings[7]. This method also accounts for the life cycle of the building, considering not only the operating energy demand but also the energy embodied in the materials used, work done (construction, retrofit) and installations. It is a complementary method that assists in evaluating environmental impacts and sustainability levels of the PED interventions, accounting for embedded carbon and emissions and energy consumption.

3.1.4 Definition of Positive Energy Blocks

Positive Energy Blocks[1] (PEBs) is supported by the European Commission dealing with a concept similar to Positive Energy District. PEBs are defined as follows:

> *"A Positive Energy Block (PEB) is a group of at least three connected neighbouring buildings producing on a yearly basis more primary energy than what they use. These buildings must serve different purposes (housing, offices, commercial spaces...) to take advantage of complementary energy consumption curves and optimise local renewable energy production, consumption and storage."*

Key elements of the definition:

[7] Hernandez, P. et Kenny, P. From net energy to zero energy buildings: Defining life cycle zero energy buildings (LC-ZEB). Energy Build, 2010. https://doi.org/10.1016/j.enbuild.2009.12.001

- group of neighbouring buildings;
- positive energy balance over the year;
- renewable energy sources, storage systems.

Four more features can be pointed out from the project documents:

- smart grids;
- use of advanced materials;
- connection to electro-mobility solutions;
- circular economy.

3.1.5 Other definitions or PED descriptions

Within the article Positive Energy District: A Model for Historic Districts to Address Energy Poverty[8], the PEDs are referred to as:

"an energy-efficient and flexible urban area with net-zero energy import and greenhouse gas emissions, aiming toward an annual local surplus of renewable energy."

Key elements of the definition:

- energy efficiency and flexibility;
- net-zero energy import and greenhouse gas emissions;
- use of renewable energy.

Based on a hierarchy in the complexity of energy management and stakeholder engagement, PEDs can be defined as the following figure below.

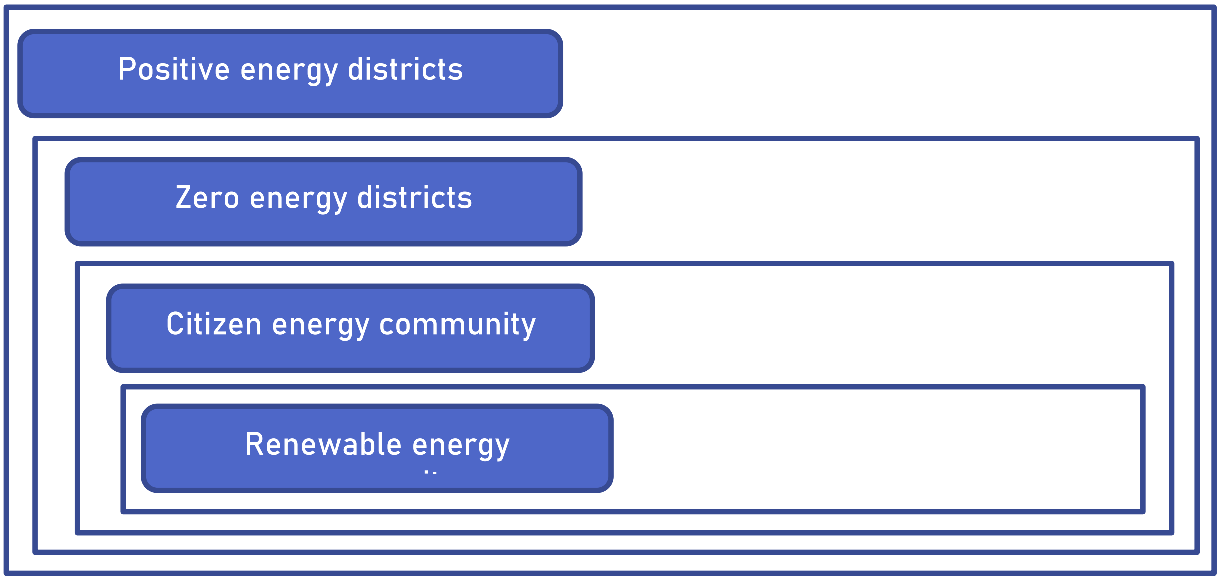


Figure 3 Layers included in a PED project

[8] Gouveia, P. J et al. Positive Energy District: A Model for Historic Districts to Address Energy Poverty. Frontiers in Sustainable Cities, 2021. https://doi.org/10.3389/frsc.2021.648473

The last definition or description of PEDs is based on the energy management approach. Energy management aims to ensure data management on the amount of energy and its consumption over time. Another similarity is the continuous optimization and improvement of the energy performance of buildings, especially consumption reduction through increasing energy efficiency.

While basic energy management addresses mainly consumption management and energy savings, **in the case of PEDs we speak about a higher level of energy management (EM) implementation**, where the task is covering all the energy consumption with local renewable energy sources and striving for a positive energy balance. This requires **comprehensive energy management both at the level of individual buildings and on the whole area level**, i.e. other related sectors such as transport and infrastructure, all of which must be interconnected and balanced in order to reach goals or principles of PEDs.

3.1.6 IEA Annex 83 Positive Energy Districts

Currently, further developments are underway to clarify the definition of PEDs. Definitions are being developed within the framework of the IEA Annex 83 Positive Energy Districts[9]. This annexe started in 2020 and has "Definitions and context" as Subtask A. The planned end of this project is in 2024 and should give an international definition on PED.

3.2 Summary of the definitions

Based on the definitions and descriptions of Positive Energy Districts, the following elements and parameters of the PEDs were identified:

- → **PEDs are composed of groups of buildings or an urban area.**
- → **PEDs require interconnection and interaction of several sectors along with a high degree of system and communication integration.**
- → **PEDs use comprehensive energy management.**
- → **PEDs focus on the energy efficiency of buildings and energy balance of all sectors involved.**
- → **PEDs reach at least net-zero energy import and greenhouse gas emissions balances per year with the goal or producing surplus energy.**
- → **PEDs rely exclusively on the (local) renewable energy sources and energy storage systems.**
- → **PEDs are not limited by social, material, technical or technological solutions.**

The seven points represent the main elements in the implementation of PEDs but also the risks and challenges as Positive Energy Districts form a very comprehensive system. PEDs aim to create an emission-neutral, energy self-sufficient and sustainable local economy. However, due to the diversity of urban areas, a holistic approach is needed in the development and implementation of PEDs, which needs to be adjusted to specific local conditions.

---

[9] IEA EBC. Annex 83 - Positive Energy Districts. Available from https://annex83.iea-ebc.org/

Graphic summary of the PED definition

Group of buildings or urban area

- Defining the area.
- Minimum 3 buildings in respect of positive energy blocks (PEBs).

High degree of system and communication integration

- Requires interconnection and interaction of several sectors (private buildings, public buildings, transport and mobility, infrastructure…).

Energy management

- A shift from the basic level of EM implementation to the advanced level of EM implementation.
- Utilization of the energy flexibility concept and demand-response principle.

Energy-efficient buildings

- Plus energy standard.
- Zero energy standard.
- Passive energy standard.

Local RES and energy storage

- PEDs rely exclusively on the (local) renewable energy sources and energy storage systems.
- PEDs should achieve energy surplus.

Net-zero energy import and GHG emissions

- PEDs represent the path to the (local) carbon neutrality.
- PEDs strive for zero GHG emissions balance.

Innovative social, technology, material or technical solutions

- PEDs are not limited by the chosen solutions. Modern and innovative technologies and approaches will be essential for the PED implementation.

4 Early-stage of the project

The earlier the stage of a project is, the more it possible to influence the outcomes. With such a comprehensive and multi-layered project as PED, involving many different stakeholders, cutting edge technologies and with a lifespan of decades, the importance of early stage preparation cannot be underestimated. This section defines the early phases of a project in the context of a project life cycle.

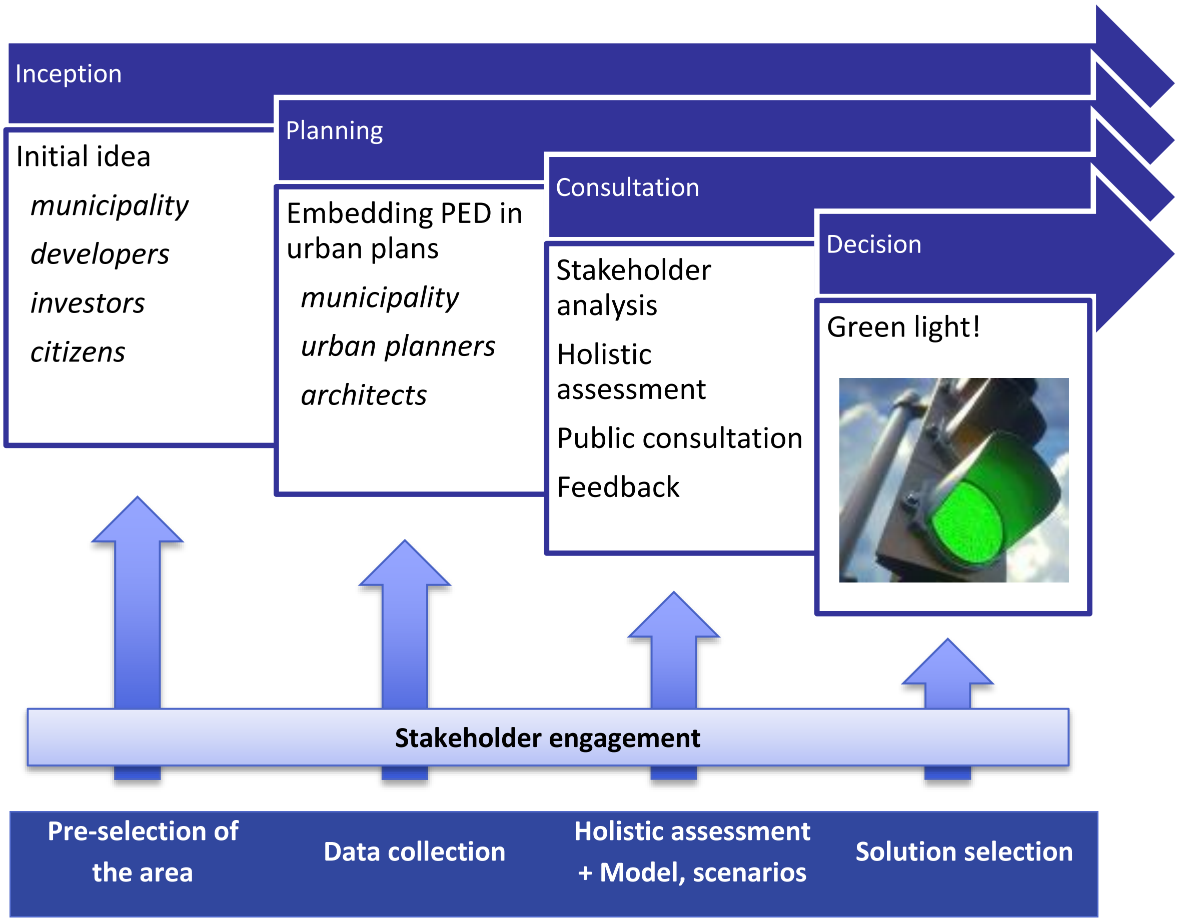


Figure 4 Early-stage steps of a PED project

PEDs differ in details. The specific solution depends on the local conditions of each place. They nonetheless share some features:

1. excellent availability of renewable energy sources in place;
2. high awareness and engagement of local citizens and the wider community;
3. financial support by national and international programmes;
4. the method of initiation.

A combination of common features as well as differences seems to confirm that every PED should be designed and developed individually concerning local conditions even. Some universal approaches may be used as well with just a little need for adjustment.

Stakeholder engagement is a parallel part of the PED inception and is an inseparable element. **Good public awareness is key to success.** To accept PED development costs, citizens must understand and acquire the benefits of energy efficiency and energy self-sufficiency. Informed and engaged users are invaluable for successfully building and operating a PED project in the long term.

When a PED location is being chosen and defined initially, it is important to keep the comparative advantage of the place in question**. An area suitable for PED development should have an appeal for investors and be economically sound**. It is a must to follow places with sufficient RES potential.

An overview of 28 PED projects from all over Europe[10] shows that **various stakeholders may initiate a PED project**: Developers, municipalities, building owners, companies or public institutions. Developers and investors are the most significant single group to initiate a PED project. They tend to develop a PED on their own property. Municipalities are the other significant PED initiator. It is less common for homeowners to engage in PED initiation. There are some substantial barriers for homeowners, such as coordinating many stakeholders or lack of expertise. On the other side, homeowners and inhabitants enjoy the most significant share of PED benefits.

PEDs are financed from both public and private sources and they often use research and other European and national grants. Regarding the type of buildings included in PEDs, residential buildings are the most common, followed by civil facilities such as schools, shops, and sports facilities. Buildings with high energy demand, such as industrial buildings, are scarcely included in a PED. They are usually not situated in the neighbourhood and their inclusion and it may prove difficult to include them in a PED and keep the positive energy balance simultaneously.

Although creating a PED is challenging, it follows the phases similar to other urban development projects. There should be a strategic phase, in which relevant data, connections and assessments are performed. Then at the planning phase the objectives and goals are turned into action plans and technical solutions. In the implementation phase, the physical interventions and construction takes place, making the PED project a reality. Lastly is the operation and verification phases, where it is assured that the planned results are being achieved, and if not, changes should be made.

[10] Urban Europe: EUROPE TOWARDS POSITIVE ENERGY DISTRICTS. In: Urban Europe. [online]. JPI, Urban Europe. Únor, 2020. [Accessed 11 January 2021] Available from: https://jpi-urbaneurope.eu/wp-content/uploads/2020/06/PED-Booklet-Update-Feb-2020_2.pdf

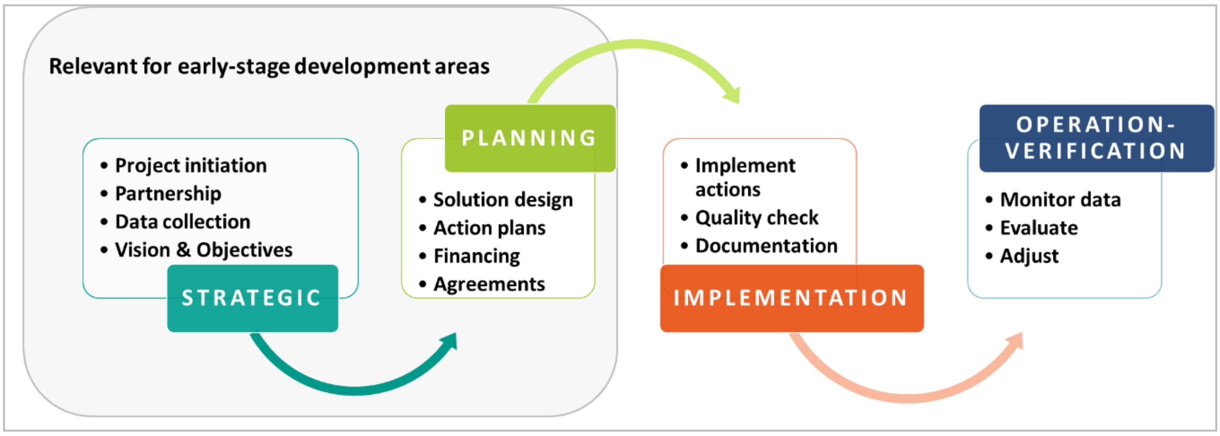


Figure 5 Phases of a PED project

This document and PED-ID project focus on the early stage of development of PEDs. That means that only the Strategic & Planning phases are tackled in following sections, describing technical themes, i.e. energy analysis, urban planning, financial analysis and project assessment. Questions of public awareness-raising and engagement are discussed in other project results.

5 PED preparation

In a PED project, **one of the main objectives is to achieve an energy balance that is positive** (or at least zero). As a result, the design should integrate the energy needs and analyse the district as a holistic urban system. Some factors that need to be addressed by planners are[4]:

- Geographical and urban morphology.
- Building characteristics and use.
- Energy demand & balance between the energy production and energy consumption.
- Natural resources available.

When it comes to the implementation of PEDs, it is necessary to consider the goals as well as reasons and consequences of such implementation. This can be framed in four topics:

1. **Motivation**
2. **Barriers and challenges**
3. **Costs (both financial and non-financial costs)**
4. **Risks**

Motivation for developing PEDs stems from climate and energy policy. Developing PEDs is a way to achieve carbon-neutrality in a given area, which is in line with the long-term goals of climate protection and decarbonising the economy (and cities) by 2050 (note activities for example by Smart cities or Covenant of Mayors and support of the European Union in energy transformation).

PEDs have, nonetheless, many additional benefits. An intelligent interconnected local energy network is created within a PED. Refurbishing buildings improve the quality of life of the citizens. Environmental costs associated with importing energy into an area are diminished within the modern and self-sufficient area. For other details, see chapter 5.3.2.

Table 1 PED characteristics

PED Advantages	PED Challenges and barriers
Acceleration toward carbon neutrality	High demands on the complexity of the solution
Acceleration of the energy system transformation	Use of innovative solutions Energy flexibility exploitation
Improved quality of life	Stakeholder support
Improved local climate quality	Local regulations and laws
Reduction of energy poverty	High financial cost in the early stages

The third and fourth questions consist in holistic assessment dealing with the PED implementation's economical, technical, environmental, social and political/legal aspects, as described in Figure 6.

- **Economic area** answers mainly financial issues – how much will the PED implementation cost? What will be the revenues? How to secure funding?
- **Technical area** deals with the technical potential of the area considered for PED implementation (technical condition of buildings, possibilities of buildings in terms of energy saving measures, energy consumption, infrastructure of the territory, RES capacities in the territory, technical solutions to be used)
- **Environmental area** primary assesses the impact of measures on the environment – greenhouse gas emissions reduction, saving energy from non-renewable energy sources, assessment of other environmental impacts.

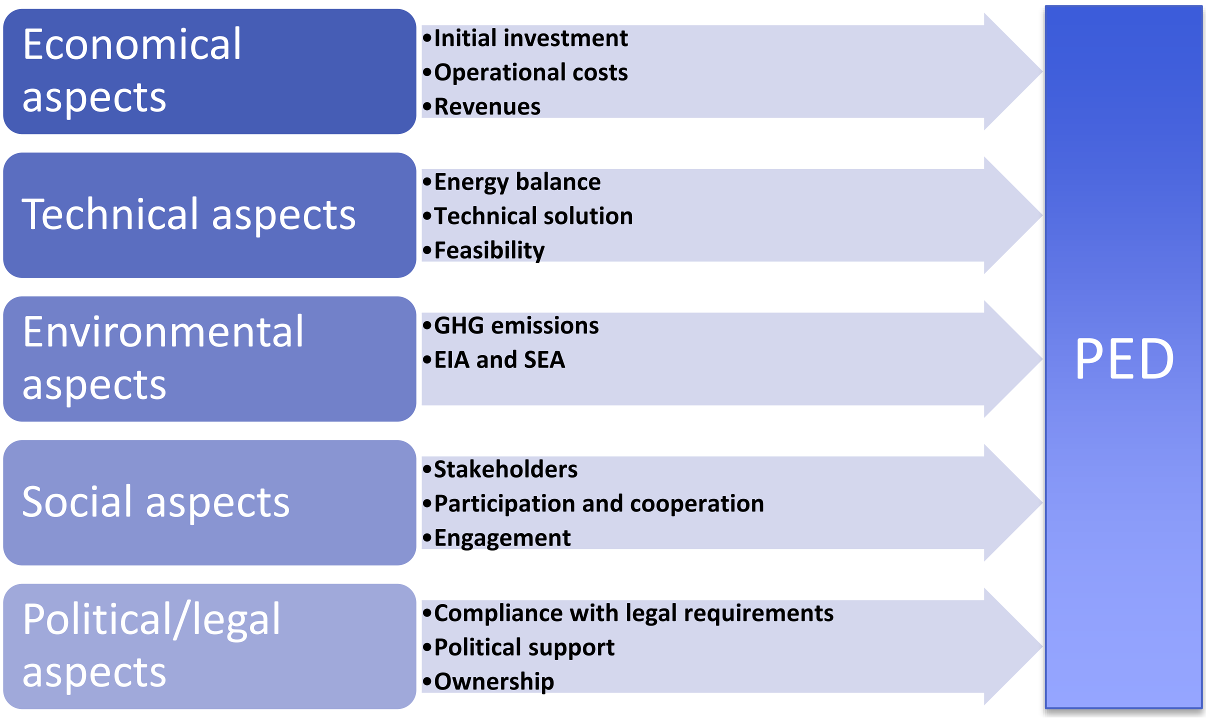


Figure 6 Aspects of a PED

It is necessary to realize that these five aspects do not represent five separate areas. The areas are interconnected and intertwined, and in many cases, they are addressed across several areas (for example financing) and affect one another. Therefore, it is necessary to address them as a whole complex cycle or mutual process.

Once the reasons for the implementation of Positive Energy Districts have been clarified, the basic aspects of the PED evaluation have been introduced and a basic risk analysis has been carried out, it can proceed to holistic PED assessment.

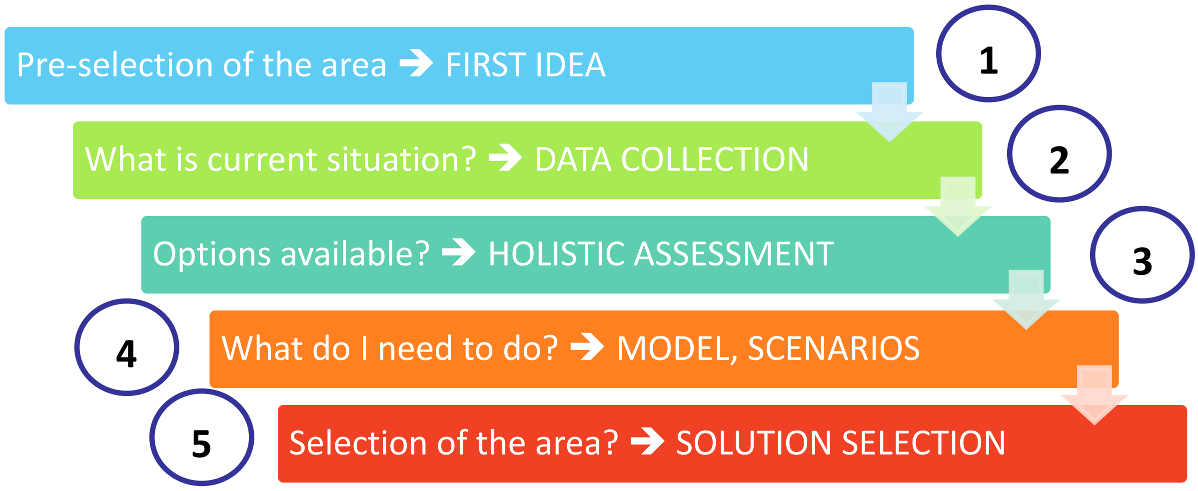


Figure 7 Assessment of PED solutions – phases

Holistic assessment of the Positive Energy Districts implementation consists of several key steps. First, there is a preselection of the area, where the PED in question could possibly be implemented. For this area, the data have to be collected on the basis of which the technical and technological solutions can be selected. The assessment of potential solutions leads to the development of possible implementation scenarios. The scenarios are assessed on the basis of indicators and benchmarks and then the final solution with the final area is selected.

5.1 Pre-selection of the area

The basis of the Positive Energy Districts is formed by the initial idea of their development which is followed by a core notion of the area where the Positive Energy District could be implemented. The main question is "**Where I would like to create PED**"? Positive Energy District can be part of both a rural and urban infrastructure. There are three options for pre-selection of the area type.

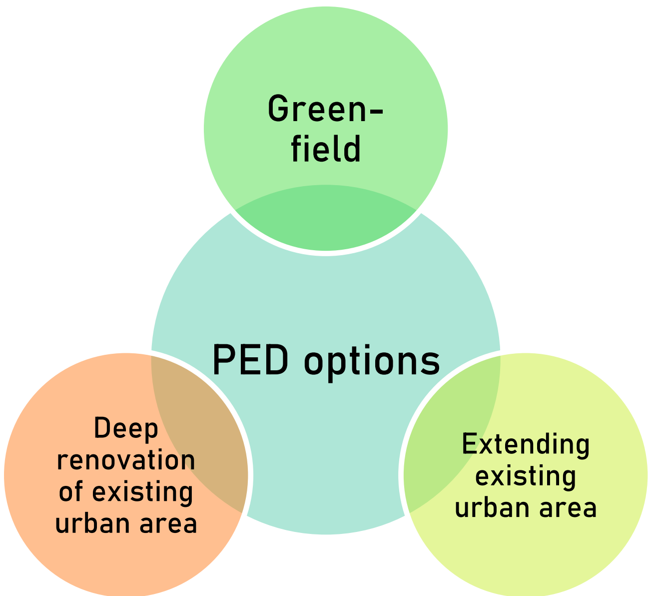


Figure 8 PED initiation options

The first option is to build a new district in a new undeveloped area, "on a **green field**". The construction of a Positive Energy District on a green field is advantageous for urban engineers, urban planners, architects, designers, developers and investors. Green field PED can be planned in various ways as the only limitation is the size of the selected area and available funding. In a green field setting, the fewest barriers arise to the future arrangement of the PED. At the same time, the municipality and the public can easily control private investors and developers[11]. A high proportion of energy-plus buildings and passive buildings can be expected from the construction of the Positive Energy District on a green field.

The second option is to implement the Positive Energy District in an **existing urban area** as its extension. This solution connects new energy-plus and passive buildings with existing buildings. In the case of existing buildings, it is appropriate to conduct a deep renovation to increase energy efficiency. Close cooperation between municipal officials, investors and property owners is necessary.[11]

The third option of Positive Energy District implementation is a comprehensive **reconstruction of a selected existing urban**. Existing buildings must be renovated so that, together with the production of energy from renewable sources, they sufficiently balance the final energy consumption of the area. In the case of the existing urban area, it is always better to carry out a deep renovation of a smaller number of buildings than a shallow or partial renovation of all buildings, which could result in a lock-in effect. However, it can be assumed that most buildings will need to be renovated anyway. Shallow renovations seldom decrease the consumption of a building enough to ensure a positive energy balance. They also are not economical, as they must often be renovated again to comply with stricter requirements or to achieve higher energy performance standard. The success of the third PED variant depends the most on the cooperation of property owners and the public concerned[11].

Table 2 Assessment of complexity of solutions and parameters of various PED types

	Green field	Extending existing urban area	Renovation of existing area
Implementation	**Low**	**Medium**	**High**
Data collection	**Low**	**Medium**	**High**
Citizen engagement	**Low**	**Medium**	**High**
Ownership/property	**Low**	**Medium**	**High**
Impact on climate protection	**Low**	**Medium**	**High**
Financing	**Low**	**Medium**	**High**

Note that new PEDs are areas with net-zero energy import by definition. They shouldn't add to the existing energy consumption and GHG production. On the other hand, existing buildings have real energy consumption and GHG production and therefore their transformation to PED (including an increase in energy efficiency) has a much more significant effect on climate protection.

All in all, green field development is the easiest way to create PEDs, while utilization of existing urban areas is the most difficult one. New buildings (districts) can be built as energy efficient as possible. On

[11] Alpagut, Beril, Akyürek, Ömer, Miguel Mitre, Emilio: Positive Energy Districts Methodology and Its Replication Potential. Researchgate [online]. 2019. https://doi.org/10.3390/proceedings2019020008

the other hand, given the average age of the building stock in Europe, most of the buildings have to undergo deep renovation in order to comply with increasingly stringent climate policies. **PEDs in built-up areas therefore represent a significant potential to boost the renovation rate** along with new renewable energy capacities.

5.1.1 Positive Energy District boundaries analysis

When selecting (preliminary) area for implementation of Positive Energy Districts, the boundaries of the area must be determined. We must consider the following points:

- *What do we include in the PED area?*
    - Built-up area
        - → Objects – buildings, other objects
        - → Infrastructure – technical (utility networks), transport network
    - Non-urban area

  → General identification of the objects and infrastructure. What we have for disposal? In this stage, there is no need to deal with the area in detail and collect data, but the main thing is to get an idea of what the area contains.

- *What are the boundaries of the PED area?* System, technical, topographic and geographical boundaries?
    - Compact units or blocks of buildings or premises/sites, complete districts. Do not divide natural units unnecessarily.
    - Entry and exit points of transport network.
    - Entry and exit points for utility networks – heat, electricity, water and sewage. It is appropriate that networks are considered in such a way that changes in supply can be assessed.
    - Natural borders (mountains and cliffs, valleys, rivers, expanses of water, forests, parks and public gardens).

- *What will be the scope of PED in terms of feasibility?*

  → Consider that a larger area is usually more difficult to assess. However it depends on the specifics of the area – if it consist of standardized or similar objects, the assessment can be easier.

- *Compactness of PED area?*
    - PED area should be as compact as it can be as it is easier for the overall assessment and ongoing management, although it can be possible to involve more separated or distance areas as well (primarily for the renewable energy sources utilization). However, keep in mind that the fragmentation of the PED area can cause problems when there are changes in its surroundings. The PED area is balanced to meet the PED parameters (energy and GHG balance), possible changes afterwards could be difficult.

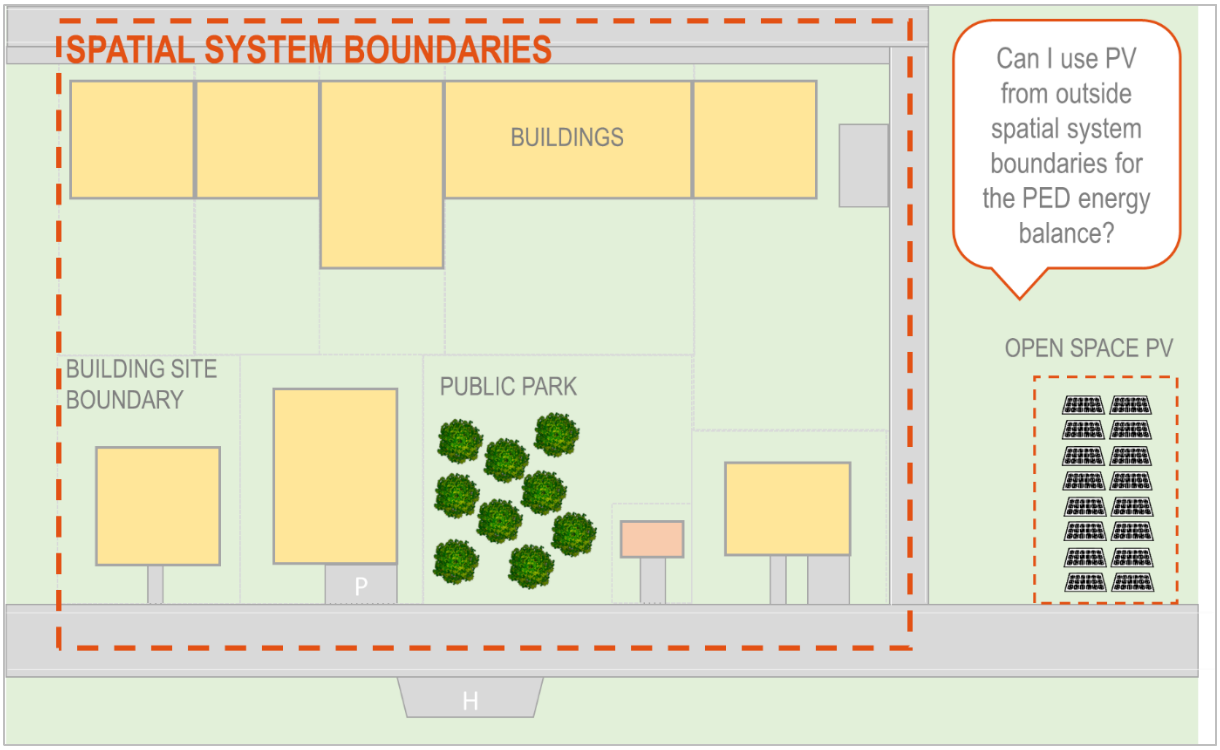


Figure 9 An example of PED boundaries

- *Specifics of the area?*
    - Adapt to the specific conditions of the area. Some areas will be sparsely built up, some will be heavily urbanized. Some areas will be located in the mountains, others on plains. All PEDs have the same goal and final parameters (GHG emissions neutrality, net-zero energy import, coverage of energy consumption by renewable sources), but each achieves this a little differently due to the specifics of the area. Therefore, it is necessary to consider the specifics – barriers and opportunities of the area.

Positive Energy Districts should ideally form a coherent area within of which all relevant parameters can be evaluated. This area cannot be selected immediately without prior analysis as it may not be entirely clear where the PED will be implemented. First, it is necessary to identify the potential of the area, i.e., its possibilities, barriers and limits (data collection). Then, a decision on the selection of the final area is made based on individual elements of the area (options available) and in relation to the implementation analysis (what can be achieved after the implementation of the selected measures).

5.1.2 Individual PED Definition

This section determines individual aspects of a Positive Energy definition separately. This concept is based on Schöfmann et al. 2019[12] and provides a good overview of the limits of the definition.

[12] Schöfmann, Petra, Thomas Zelger, Nadja Bartlmä, Simon Schneider, Daniel Bell, und Jens Leibold. 2019. „Zukunftsquartier, Weg zum Plus-Energie-Quartier in Wien". Berichte aus der Energie- und Umweltforschung 11/2020. Stadt der Zukunft. Wien: Bundesministerium für Klimaschutz, Umweld, Energie, Mobilität, Innovation und Technologie (BMK).

The definition of plus-energy districts is divided into the following aspects:

- Objective
- Indicator
- Period of balancing
- Spatial delimitation
- Energy uses

The descriptions are divided into options and choices of definition, supplementary explanations and definitions for the Plus-Energy areas in Melk.

5.1.3 Objectives

The following table describes options for objectives in terms of energy use and GHG emissions for urban area developments:

Objectives	Determination
Positive balance for energy	
Positive balance for GHG emission	
Zero-energy balance	
Zero-emission balance/carbon neutral	
Nearly zero energy balance	
Other objectives	

This determination is made with the neighbourhood developer or the municipality. This concerns the objective of the area development in terms of sustainability, energy use or climate impact. Depending on which priorities are set, different objectives can be defined.

5.1.4 Indicator

The following table shows options for indicators separated in energy use and energy supply.

Indicators	Energy Use	Energy Supply
Final Energy		
Primary Energy renewable		
Primary Energy non-renewable		
Primary Energy total		
CO_2 emissions		

In most literature sources on the topic of PEDs, the indicator for the achievement of the target is the total primary energy demand. Internationally, however, carbon-neutral neighbourhoods and cities are already being discussed. Here, the CO_2 equivalent is usually used as an indicator. In the case of areas where there is only one form of energy for supply (especially electricity), the assessment can also be based on final energy.

5.1.5 Accounting period

The following tables shows options for accounting period for PEDs.

Period Name	Accounting Period	Determination
Life cycle	-	
Annually	1 year	
Monthly	1 month	
Hourly	1 hour	
Instant	1 minute?	

The balancing period defines the period for which the target in section 3.2 is to be met. For example, with the objective "positive energy balance", a surplus of energy is to be provided in the balancing period "annually" over this period. This therefore does not take into account the seasonal imbalance, so that in summer there tends to be more energy in stock and in winter there tends to be an undersupply.

The shorter this period is, the more the balancing comes into the range of an "energy self-sufficient" neighbourhood. In the "current" period, there must be a positive energy balance at all times. This condition corresponds to an energy self-sufficient neighbourhood.

Monthly balancing cannot represent energy self-sufficient operation, but it can better account the seasonal imbalance.

5.1.6 Spatial system boundaries

The spatial system boundaries describe this spatial limits for renewable energy supply.

Spatial borders	Heat	Electricity
Development area of the building (e.g. PV on the roof)		
Property of the building (e.g. PV on the property)		•
Property with energy resources from outside the property (e.g. biomass boiler)		
Energy production outside the property, with direct supply (e.g. district heating)	•	
Energy supply outside the property (e.g. green electricity)		

The focus is on the use of renewable resources on one's own property. If renewable local/district heating is available, this can of course be taken into account. The use of renewable electricity production is considered within the boundaries of the site. However, it will also be examined whether there are possibilities to consider renewable electricity production from neighbouring areas.

5.1.7 Energy use

The following table gives possibilities of energy use for PEDs.

Category		Energy use	Determination
Operational energy	Building operation	Heating	

		Cooling	
		Humidification/dehumidification	
		Auxiliary energy	
		Lighting	
	User electricity	Domestic electricity	
		Operating current	
	Process energy	Process heat	
		Process cooling	
		Process electricity	
	Quarter	Lighting	
		Supply	
		Waste disposal	
Embedded energy	Production	Raw material procurement	
		Transport	
		Production	
	Construction	Transport	
		Construction / Installation	
	Use	Use	
		Maintenance	
		Repair	
		Replacement	
		Modernisation	
	Disposal	Deconstruction/demolition	
		Transport	
		Waste treatment	
		Disposal	
Mobility	Passenger mobility	Public transport	
		Sharing mobility	
		Motorised individual transport	
	Goods transport	Freight transport	

5.2 Data collection

Data collection is one of the crucial steps within the PED preparation as it forms the basis for a holistic PED assessment. It is also one of the most time-consuming steps because usually many data are missing or are not available at the moment. Therefore, a comprehensive survey must be carried out to obtain the data. However, it is often the case that data are not available at the early stage, and then an estimation has to be made based on the available benchmarks and other calculations.

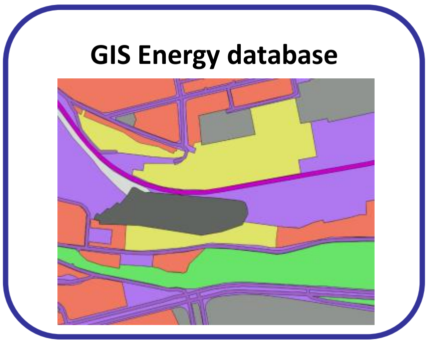
Better quality data facilitates subsequent assessment and design of suitable solutions for PED implementation. However, with larger PED (preliminary) area, the amount of data needed (and obtained) grows significantly, which makes the data processing more demanding. Therefore, data collection efforts must be optimised. Estimates based on similar or grouped parameters can also be used to simplify the process.

5.2.1 Spatial (energy) analysis

"Spatial analysis or spatial statistics includes any of the formal techniques which studies entities using their topological, geometric, or geographic properties"[13]. Spatial analysis answers where questions[14].

Spatial analysis is often associated with Geoprocessing, which uses Geographic information systems (GIS) and allows for definition, management, and analysis of information used to form decisions[14]. It includes two important subtypes:

- **Geovisulation** – combines scientific visualization with digital cartography to support the exploration and analysis of geographic data and information, including the results of spatial analysis or simulation[13]. Geovisulation outputs are usually presented via GIS maps.
- **Spatial decision support systems** – takes existing spatial data and use a variety of mathematical models to make projections into the future. This allows urban and regional planners to test intervention decisions prior to implementation[15].



Spatial analysis within the PEDs should focus primarily on energy sources – "where can I implement renewable energy sources"? However, within PED, the comprehensive approach is necessary, so it is also essential to answer where the energy consumption is and what is its value; identify potential areas for energy performance improvement or GHG emissions reduction and characterize the energy and environmental interconnection and interaction of various sectors in the PED area.

Overview of data to obtain

Spatial analysis within the PEDs should address the following topics:

1. **Buildings –** energy efficiency – type of building (residential, administrative, public…), ownership (city, public-benefit corporation, private,…), energy consumption, building usage (Load profiles, Temperature level, flexibility potential, etc.), technical and technological condition (energy sources – primary heat sources, energy performance, other information).
2. **Infrastructure –** current heating and electricity systems, other energy sources, existing utilities (heat pipes, MV networks, LV networks, water mains, sewers), wastewater treatment plants, incinerators.

[13] Wikipedia. 2021. Spatial analysis. Wikipedia [online]. Last modified August 17, 2021. Available from: https://en.wikipedia.org/wiki/Spatial_analysis#Spatial_data_analysis [Accessed 23 August 2021].
[14] Tulane Universities Libraries. Spatial Analysis. Last modified July 26, 2021 Available from: https://libguides.tulane.edu/geographicinformationsystems/spatialanalysis [Accessed 23 August 2021]
[15] González, Ainhoa; Donnelly, Alison; Jones, Mike; Chrysoulakis, Nektarios; Lopes, Myriam (2012). "A decision-support system for sustainable urban metabolism in Europe". Environmental Impact Assessment Review. 38: 109–119. https://doi:10.1016/j.eiar.2012.06.007

3. **Transport and mobility** – traffic intensity, traffic routes, energy consumption.
4. **Other municipality objects –** energy consumption parameters and energy savings potential.
5. **RES potential –** current production from RES, potential production from RES – Water energy (rivers, creeks, reservoirs, mere/pond, weirs, water canals, irrigation canals), geothermal energy (Near-surface geothermal energy potential), wind power, bio power (Production of unused biomass in the area or its surroundings, analysis of areas suitable for biomass production), solar energy (roofs, facades, windows, other – large water bodies, accessible unused areas, covered parking).
6. **Utilization of energy recovery –** Waste power (municipal waste, bio-waste and sorted waste – focus on unused biological and "combustible" waste in the area and its surroundings), heat recovery (significant heat sources in the area – not at the level of individual buildings).
7. **Greenery potential** – current state (Mature free-standing trees, alleys, parks, forests, grass areas), unused or underused areas for future potential (Grass areas, self-setting greenery, areas after demolition, other unused areas, flat roofs, covered car parks).
8. **Restrictions** – heritage protection, urban development plan, easements, other…

Detailed building analysis

1. **Energy performance of buildings**
    - Based on the Energy performance certificates
    - Based on the Energy audit
    - Based on current energy consumption from metering/billing
2. **Structural, technical a technological condition**
    - Thermal characteristics of the building (current insulation of the facade and roof, condition of the windows)
    - Potential to carry out thermal insulation (facade, roof, windows)
    - Potential for renovation or replacement of the energy source
    - Potential for renovation/implementation of technologies for the indoor environment treatment
    - Restrictions on energy saving measures - construction restrictions, monument protection, other forms of protection or restrictions (e.g. sustainability period for subsidized measures)
    - Capacity of the building for the production of energy from RES (this is primarily addressed in RES potential topic, however, the RES potential may be assessed within an Energy audit or Energy performance certificate as one of the possible energy saving measures)

It is best to obtain values for each object, however, this presupposes high processing effort. Therefore it is possible to make estimates based on typical buildings and known values for sample of buildings (based on roofs, construction type, building category, number of floors or number of apartments, construction period). Note, that this estimation may not be accurate enough for PED implementation in larger areas.

Traffic analysis of the area

1. **Intensity of passenger road transport (vehicle-kilometres)**
    - Based on counters on the main roads
    - Based on survey among households and businesses
2. **Intensity of public road transport**
    - Based on counters on the main roads
    - Based on information from transport companies and transport operators (excluding "green" transport vehicles if they are fully powered by RES – note that electric vehicles charged from the electricity network must be counted if the electricity energy mix is also based on non-renewable energy sources)
3. **Intensity of road freight transport**
    - Based on counters on the main roads
4. **Intensity of other means of transport**
    - Water transport (Vehicle-kilometres, typical consumption)
    - Rail transport (vehicle-kilometres or passenger-kilometres within the PED area, typical consumption)
    - Cable railways (electricity consumption over the year)
    - Air transport – this one is questionable, but in the event that the airport is also included in the PED area, the impact of air traffic intensity should be also calculated (we recommend to calculate energy consumption and GHG emissions only from the take-off and landing phase (so-called LTO cycle))

Energy and GHG emissions are usually calculated based on the transport intensity, typical consumption and fuel type. Traffic analysis can be based on the development of simplified transport model of the area to predict traffic demand within the PED and between the PED and surrounding areas.

PV potential analysis of the area

The use of solar energy is one of the main elements of RES within the PEDs. Therefore, it is necessary to pay special attention and effort to assess the areas suitable for potential PV usage. Area assessment and its level of detail are closely related to the type of calculation of PV energy production. There are 3 suitable approaches for the estimation of the electricity generation potential for PV projects[16]:

a. Sample
b. Multivariate sampling
c. Complete census

Sample:

[16] Byrne, J., Taminiau J., Kurdgelashvili L. and Kim N. K. A review of the solar city concept and methods to assess rooftop solar electric potential, with an illustrative application to the city of Seoul. Renewable and Sustainable Energy Reviews, 2015. https://doi.org/10.1016/j.rser.2014.08.023

Fast calculation, good for calculating estimates, not much precise

1) Survey to obtain data on the available roof area
2) Determination of the average annual solar irradiation on inclined surfaces
3) Calculation of yearly PV production

Multivariate sampling

The calculation of some variables such as the shading is extremely difficult to conduct, but outputs are more precise

1) Geographical division of the region
2) Rooftop sampling
3) Extrapolation through the use of rooftop area and population relationships
4) Calculations of constraints and detriments (shading, orientation, etc.)
5) Conversion of data into power and energy outputs

Complete census

Relies on the computing of the entire available rooftop area, usually performed through the use of innovative cartographic data sets that offer a digital model of the study region, or through the use of existing statistical data sets containing building information.

Data collection by PED type

Implementing PEDs in Green-field areas requires less information than the implementation in the existing urban areas.

In the Green-field area, it is possible to **design individual buildings directly in a high energy-efficient standard** and use innovative energy-saving or energy-producing technologies within other objects. The area can more easily be adapted to meet the requirements of the PEDs. Moreover, as existing data for the area (for example for traffic or real building usage) will not be available, many parameters can be estimated which can speed up the spatial analysis.

However, PEDs can be implemented also in the areas with existing buildings and objects, which will generally not meet a high energy-efficient standard or will not use renewable energy sources. For the successful PED implementation, these **buildings and objects will need to be renovated**. This will require much more information to be obtained, at least for basic overview.

Data collection levels

Within the data collection, levels of data detail have been set. While the basic level is only sufficient to provide a comprehensive overview of the area and for some basic estimations, the advanced level can already be used for most calculations and evaluations. The expert level will enable an accurate assessment of all parameters, but it is also the most difficult to obtain and process all the required information. The following tables discuss the individual levels of data collection in more detail.

Table 3 Level of data collecting for Buildings

Basic level		Advanced level		Expert level	
Main section indicator/metrics	**Solution / data source**	**Subsection indicator / metrics**	**Solution / data source**	**Indicator / metrics**	**Solution / data source**
Buildings					
Building ownership	Cadastral register GIS				
Type of buildings (residential, administrative, public, etc.	Map survey GIS Urban plans Cadastral register				
		Building occupancy	Individual survey Building operating data		
		Structural, technical a technological condition			
		Year of construction	Individual survey Statistics Map survey		
		Type of construction (basic material)	Individual survey		
				Condition of construction	
				Current overall condition (emergency, worn, maintained, new)	Energy audit Individual survey
				Current thermal characteristics of the building	Energy audit Individual survey
				Year of last renovation	Individual survey Service records
				Potential for renovation (thermal insulation)	Energy audit Individual survey
		Type of technologies used (cooling, ventilation…)	Individual survey		
				Condition of technologies	
				Condition of technologies for the indoor environment treatment	Energy audit Individual survey

Basic level		Advanced level		Expert level	
Main section indicator/metrics	**Solution / data source**	**Subsection indicator / metrics**	**Solution / data source**	**Indicator / metrics**	**Solution / data source**
				Potential for renovation (technologies)	Energy audit Individual survey
Energy performance of building	Database of Energy performance certificates or Energy audits				
		Energy sources			
		Heat source	GIS Individual survey		
		Electricity sources	GIS Individual survey		
		Other sources	GIS Individual survey		
				Technical parameters of local energy source	Individual survey
				Potential for renovation (energy sources)	Energy audit Individual survey
		Energy consumption			
		Basic energy consumption	Energy performance certificate		
				Real consumption	Energy audit Energy bills
				Building usage parameters*	Individual survey
Development area (free area for future construction)	Map survey GIS Urban plans				

** Load profiles, Temperature level, flexibility potential, etc.*

Table 4 Level of data collecting for Infrastructure

Basic level		Advanced level		Expert level	
Main section indicator / metrics	Solution / data source	Subsection indicator / metrics	Solution / data source	Indicator / metrics	Solution / data source
Infrastructure					
Primary infrastructure areas	Map survey GIS Urban plans				
Main utility construction routes	Map survey GIS				
		Infrastructure objects (energy sources, wastewater treatment plants, incinerators)			
		Types	Map survey GIS Urban plans		
				Performance of the objects	Individual survey
		Utility constructions (heat pipes, MV networks, LV networks, water mains, sewers)			
		Types	Map survey GIS		
		Routes	Map survey GIS		
				Length	Map survey GIS
				Technical parameters	Individual survey

Table 5 Level of data collecting for Transport and mobility

Basic level		**Advanced level**		**Expert level**	
Main section indicator/metrics	**Solution / data source**	**Subsection indicator / metrics**	**Solution / data source**	**Indicator / metrics**	**Solution / data source**
Transport and mobility					
Traffic routes	Map survey GIS Urban plans				
		Traffic intensity			
		The number of vehicles that passed the checkpoint (daily)	Statistic survey Measurement from traffic counter		
		Type of vehicles (daily) (car, bus, lorry)	Statistic survey Measurement from traffic counter		

		Specific fuel consumption of vehicles	Individual survey (public) Carrier statistics		
				Vehicle-kilometres	Individual survey (public) Carrier statistics
				Fuel / electricity consumption	Individual survey (public) Carrier statistics
		Traffic routes			
		Lengths of the sections between checkpoints	Map survey GIS		
		Entry and exit points, other checkpoints	Map survey		
				Stations/stops	Map survey

Table 6 Level of data collecting for RES Potential

Basic level		**Advanced level**		**Expert level**	
Main section indicator / metrics	**Solution / data source**	**Subsection indicator / metrics**	**Solution / data source**	**Indicator / metrics**	**Solution / data source**
RES Potential – Current production from RES					
Areas of energy sources / production	Survey on the current RES in the area.				
		Current production from RES			
		Total Electricity production (kWh/year)	Survey on the current RES in the area. Summary from the expert level.		
		Total Heat production (GJ/year)	Survey on the current RES in the area. Summary from the expert level.		
				Water energy	
				Areas, Electricity production (kWh/year), Heat production (GJ/year)	Identification of water bodies in the Area - map survey
				Geothermal energy	
				Same as for water energy	Individual survey

Basic level		Advanced level		Expert level	
Main section indicator / metrics	**Solution / data source**	**Subsection indicator / metrics**	**Solution / data source**	**Indicator / metrics**	**Solution / data source**
				Wind energy	
				Same as for water energy	Individual survey
				Bio energy	
				Same as for water energy	Individual survey
				Solar energy	
				Same as for water energy	"Individual search
RES Potential – New potential production from RES					
Areas for energy sources	Summary from the advanced level				
		Water energy			
		Areas for energy sources	Map survey on the rivers, creeks, reservoirs, mere/pond, weirs, water canals, irrigation canals.		
				Flow (volume, speed), average water level during the year, water gradient	Map of water flows Hydrological data
				Reservoir / pond outflow during the year	Map of water flows Hydrological data Individual survey (object manager)
		Wind energy			
		Areas for energy sources	Wind map Meteorological data		
				Wind flow rate in different heights	Wind map Meteorological data
				Suitable areas (without buildings, spacious, far from the residential buildings)	Map survey (based on suitable areas)
		Geothermal power			

Basic level		Advanced level		Expert level	
Main section indicator / metrics	**Solution / data source**	**Subsection indicator / metrics**	**Solution / data source**	**Indicator / metrics**	**Solution / data source**
		Areas for energy sources	Near surface geothermal energy survey (GIS)		
				Near-surface areas – free areas	Near surface geothermal energy survey (GIS)
				Underground	Geological surveys
		Bio power			
		Areas for energy sources	Map survey Individual search		
				Free areas for agriculture for biofuels	Map survey Individual search
				Current areas with biofuels farming + their use	Map survey Individual search
				Commercial forests + their use	Map survey Individual search
				Wood processing - sawmills	Individual search
		Solar power			
		Areas for energy sources	Map survey GIS		
		Overall solar irradiation	GIS		
				BUILDINGS (available roof area)	
				Roof area	Map survey, 3D model of city GIS Individual search
				Roof type	Map survey, 3D model of city GIS Individual search
				Slope and orientation	GIS, 3D model of city Coefficient
				Building type	GIS Individual search
				Building height	GIS, 3D model of city

Basic level		Advanced level		Expert level	
Main section indicator / metrics	Solution / data source	Subsection indicator / metrics	Solution / data source	Indicator / metrics	Solution / data source
					Individual estimation
				Restrictions - shading	GIS, 3D model of city Coefficient
				Restrictions - other	Individual search GIS
				BUILDINGS (available window and facade area)	
				Building type	GIS Individual search
				Orientation	Map survey, 3D model of city GIS Individual search
				Window area	Individual search
				Facade area	Map survey, 3D model of city GIS
				Restrictions - shading	GIS, 3D model of city Coefficient
				OTHER (available area)	
				Large water bodies (dams, reservoirs, mere, ponds)	Map survey GIS
				Free unused areas	Map survey GIS
				Parking (roofed and un-roofed)	Map survey
				Restrictions - shading	GIS, 3D model of city Coefficient
				Restrictions - other	Individual search GIS

Table 7 Level of data collecting for RES Potential

Basic level		Advanced level		Expert level	
Main section indicator / metrics	**Solution / data source**	**Subsection indicator / metrics**	**Solution / data source**	**Indicator / metrics**	**Solution / data source**
Utilization of energy recovery					
		Biological waste in the area or its surroundings			
		Total amount (tonnes)	City services statistics Estimation		
				Used amount (tonnes)	City services statistics
				Unused amount (tonnes)	City services /landfill statistics
		Production of other unused "combustible" waste in the area or its surroundings			
		Total amount (tonnes)	City services statistics Estimation		
				Used amount (tonnes)	City services statistics
				Unused amount (tonnes)	City services /landfill statistics
		Production of sorted waste			
		Total amount (tonnes)	City services statistics Estimation		
		Significant heat sources in the area			
		Areas	Individual survey		
		Types of heat sources	Individual survey		
				Amount of heat generated (GJ/year)	Individual survey Estimation / calculation
				Amount of unused heat generated (GJ/year)	Individual survey Estimation / calculation

Table 8 Level of data collecting for Greenery Potential

Basic level		Advanced level		Expert level	
Main section indicator / metrics	**Solution / data source**	**Subsection indicator / metrics**	**Solution / data source**	**Indicator / metrics**	**Solution / data source**
Greenery potential – current state					
Whole green areas	Map survey GIS Urban plans				
				Mature trees freestanding, forming an alley	
				Number of trees	Map survey Individual survey
				Type of trees	Map survey Individual survey
		Parks areas			
		Area	Map survey GIS Urban plans		
				Number of mature trees	Map survey Individual survey
				Type of trees	Map survey Individual survey
				Bush areas	Map survey Individual survey
				Grass areas	Map survey Individual survey
		Grass areas and self-setting greenery areas			
		Area	Map survey GIS Urban plans		
		Forests			
		Area of forests	Map survey GIS Urban plans		
Greenery potential – current state					
Whole green areas	Map survey GIS Urban plans				
		Unused or underused areas			

Basic level		Advanced level		Expert level	
Main section indicator / metrics	**Solution / data source**	**Subsection indicator / metrics**	**Solution / data source**	**Indicator / metrics**	**Solution / data source**
		Area	Map survey GIS Urban plans		
				Grass area with possible greenery extension	
				Area	Map survey GIS Urban plans
				Self-setting greenery areas	
				Area	Map survey GIS Urban plans
				Areas after demolition	
				Area	Map survey GIS Urban plans
				Other unused areas	
				Area	Map survey GIS Urban plans
				Flat roof areas	
				Area	Map survey GIS Urban plans
				Parking areas	
				Area	Map survey GIS Urban plans

Table 9 Level of data collecting for Restrictions

Basic level		Advanced level		Expert level	
Main section indicator / metrics	**Solution / data source**	**Subsection indicator / metrics**	**Solution / data source**	**Indicator / metrics**	**Solution / data source**
Restrictions					
Problematic areas	Cadastral register				

Basic level		Advanced level		Expert level	
Main section indicator / metrics	**Solution / data source**	**Subsection indicator / metrics**	**Solution / data source**	**Indicator / metrics**	**Solution / data source**
	GIS Urban plans				
		Heritage protection			
		Area	Cadastral register GIS Urban plans		
				Type/level of heritage protection	Cadastral register GIS Urban plans
		Urban development plan			
		Areas	GIS Urban plans		
		Other (easements, …)			
		Areas	GIS Urban plans		
				Type of easement	Cadastral register GIS Individual search
				Sustainability periods*	Individual search

* *Sustainability period is the time for which the beneficiary of the subsidy (e.g. for building renovation) must maintain the outputs of the project (usually no adjustments are allowed). The length of the project's sustainability period is set out in the Decision on the provision of the subsidy based on specifics of the subsidy scheme.*

5.3 Identifying options

Following the data collection at least at the basic and advanced level, technical and technological solutions for the implementation should be considered. A technical-technological analysis is therefore the first step, followed and accompanied by social, legal and political assessment. This chapter will provide a brief description of possible technical-technological solutions for further assessment.

5.3.1 Technical concepts

It is necessary to assess different solutions in terms of their benefits and requirements and with regard to their feasibility in the (preliminary) PED area, based on the data collection.

Within the PEDs, an effort is expected for maximum utilization of the area's potential to reduce the energy consumption, greenhouse gas emissions (GHG), and increase renewable energy production. Technical concepts are then used to develop models and scenarios for PED implementation.

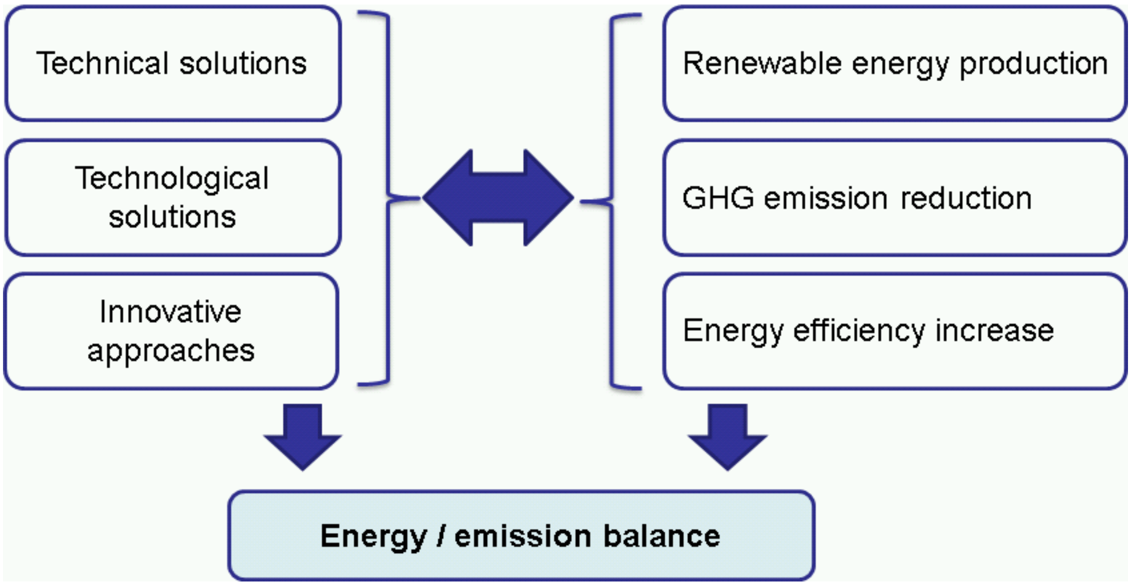


Figure 10 Technical concept of a PED

5.3.2 Aspects of individual solutions

- **Technical** (technological) – energy consumption reduction, renewable energy production, specific technical design / concept / solution
- **Environmental** – GHG reduction, improvement in the quality of the (local) environment (air, water, soil, …)
- **Economy**
  - Costs – investments, maintenance, operation
  - Revenues – energy sold within PED, sale of surplus energy outside PED, environmental taxes (entry of cars with combustion engines), energy savings
  - Non-energy benefits
    - economy and labour market (GDP increase, employment increase / unemployment decrease, increase in energy security)
    - health and well-being (morbidity, mortality & healthcare cost savings, increase in productivity, better quality living))
    - social impacts (energy poverty reduction)
    - public budgets (impact on public budget)
    - Industrial competitiveness (renovation and thermal insulation market grow, innovation market grow)
    - Value of buildings (increase in sale and rental values)

    Note: Non-energy benefits are difficult to quantify and their effect has a greater impact with a larger area addressed. It is assumed that non-energy benefits will not be addressed much within PEDs in terms of economic assessment (at least not all of them). Still, it is good to keep them in mind and present them as an accompanying effect of PED implementation.
- **Social** – social acceptability of the solution (e.g. visual identity, readjustment of lifestyle, adaptation to specific habits), participation and cooperation on the solution
- **Political/Legal** – the legality of the solution, political acceptance and support, usability of subsidies (given the funding conditions)

5.3.3 Energy demand and resources

The issue of energy consumption and its coverage is crucial in the case of PEDs. Positive energy districts are energy self-sufficient locations that **provide a secure supply of energy** while **responding flexibly to changing demand**, **balancing energy consumption peaks** and **optimizing energy supply**. Surplus production of renewable energy is integrated and supplied to the regional or national energy distribution network[17]. The goal of positive energy districts is to minimize energy consumption, use highly efficient systems and cover energy consumption with local renewables [18].

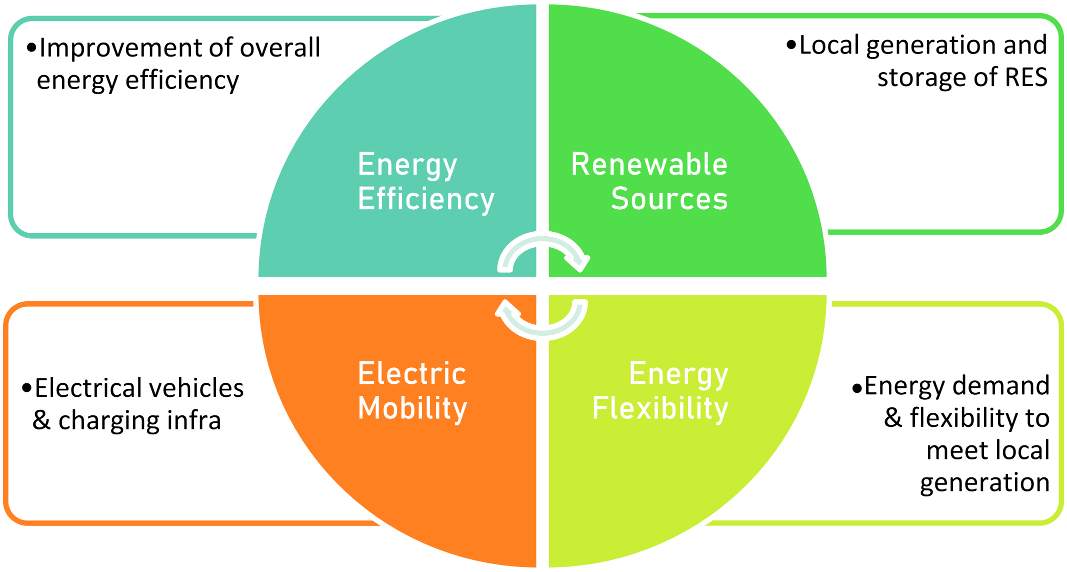


Figure 11 Four main subdivisions of a PED

A key element of energy positive districts is the **interconnectedness of buildings** that makes the site energy-plus, even if a certain number of buildings do not and cannot meet the plus-energy standard [4]. These include, for example, historic buildings that cannot undergo a deep renovation for historic preservation reasons. Another example are buildings with demanding operations that, due to capacity reasons, do not cover their own high demands on energy supply, such as freezers and cold stores, or buildings where a deep renovation is economically inefficient.

Each building will have to have its own energy performance target, having its own contribution / roadmap to meet the district target.

Positive energy districts work as small power plants, which produce energy with the help of plus-energy buildings, which have been built with an emphasis on high levels of energy efficiency, have smart grids and use local renewables. Plus-energy buildings can also be obtained by a deep and comprehensive renovation of the existing buildings of the site. In the case of the positive energy district, it is also important to set strict but realistic requirements for individual buildings so that the

[17] Urban Europe [online] JPI Urban Europe, 2020 [Accessed 17 April 2021] Available from: https://jpi-urbaneurope.eu/ped/
[18] Territoires à énergie positive [online] 100% RES COMMUNITIES, 2013 [Accessed 16 April 2021] Available from: http://www.territoires-energie-positive.fr/bul/presentation/qu-est-ce-qu-un-territoire-a-energie-positive

energy plus district is of investment interest to potential investors. In this regard, classical economic methods such as simple payback period, NPV or IRR are used.

However, positive energy districts should not be evaluated solely based on economic returns, i.e. only costs and revenues. **Positive energy districts bring a number of other benefits in a local and global context**, such as improved public health through cleaner air and more urban greenery, or the environmental impacts of using local resources and reducing transport emissions.

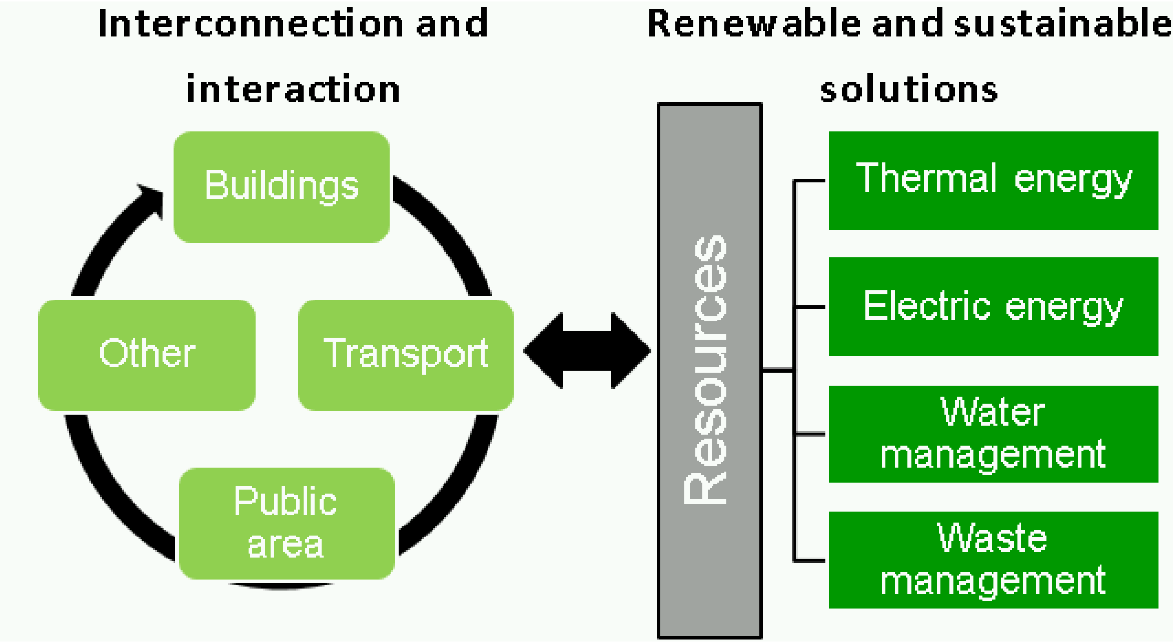


Figure 12 PED interconnection and interactions

The role of buildings and public area within PEDs

Positive energy districts include all types of buildings, from residential to public buildings to industrial buildings. Schools, town halls and shops are among the most common civic amenities in PEDs. The positive energy districts also include sports grounds and relaxation zones. Leisure zones include parks, urban forests, playgrounds and outdoor sports. PEDS are a modern, green districts, created for living, working but also for rest. At the same time, urban greenery serves as one of the elements ensuring a zero emission balance. Interconnection of individual buildings with the help of smart communication and information technologies (e.g. smart grids with self-healing element[19], smart metering[20]) is thus a key success factor.

All the buildings mentioned above use energy for their daily operation. **Each building in positive energy district has its specified energy target and the objective of increasing energy performance**, which is based on the consumption and the condition of the building. Based on the energy goals of individual buildings, the degree of necessary renovation of the entire district can be calculated. As part of the

[19] Kučerová, Makešová: Smart Grids in Czechia (1): Present and goals. In: Energie21. [online]. Profi Press s. r. o, 2013. [Accessed 10 February 2021]. Available from: https://www.energie21.cz/smart-grids-v-cesku-1-soucasnost-a-hlavni-cile/
[20] Enerfis: Smart metering – technical information. [online]. Enerfis, 2020. [Accessed 10 February 2021]. Available from: https://www.enerfis.cz/sluzby/smart-metering/smart-metering-technicke-informace

modelling and calculation of the positive energy district, a reference building is ideally determined (unless an individual assessment of buildings is allowed, e.g. in case of small PED area), on which the values and targets are defined and according to which the requirements for other buildings of the PED are subsequently determined[4]. This procedure is easier to apply to residential and civic buildings that are similar. Buildings require more difficult modelling and an individual approach with an atypical time course of energy use, such as hospitals, laboratories or storage halls serving as cold stores[21].

The role of transport within PEDs

Attention should also be paid to district mobility. Due to the definition of positive energy districts and the exclusive use of renewable energy sources, conventional petrol pumps are not considered as part of PEDs. Gas stations are replaced by charging stations and combustion engine vehicles are replaced by electric cars. Non-motorized mobility infrastructure of trails for cyclists, scooters, runners, and pedestrians is also considered.

An optimal mobility solution is the situation when all means of transport in the PED territory use renewable energy sources. This is easier to achieve with public transport, often sponsored by the city. With passenger cars, a more complex situation arises – electric cars are still a relatively new technology today, which is not yet fully financially affordable. The source of electricity charging the electric vehicles is also of concern. National networks are yet to be decarbonised, so charging from PED's own energy sources should be considered. Dynamic transition to renewables over the years would help.

The **promotion of non-motorized modes of transport** as well as **utilization of smart mobility solutions** and **vehicle sharing** is a matter of course, which can help reduce GHG emission as well as improve quality of life in the PED area.

Used energy and engineering networks

Users of positive energy districts use all available and known types of energy – electricity for lighting, appliances, charging communication technologies (mobile phones, computers, laptops, etc.), thermal energy for heating, hot water for showering and washing hands, cold water for drinking, food production, flushing and watering plants, cold air for air conditioning of buildings in the summer months, cold for cold stores and freezers, and the like. Positive energy districts address the issue of energy supply comprehensively and on a larger scale than energy-plus or zero-energy buildings. **The emphasis is placed on energy recovery and exploiting the maximum potential of resources including grey water use and black water management**, the issue of waste sorting and waste management.

The use of different types of energy creates new links, for example between individual owners of smart grids, owners of buildings and production facilities (photovoltaic panels, cogeneration units) and consumers/users. New links are emerging at the legislative, economic and social levels. It is necessary to capture the newly created links legislatively and economically, especially when one of the owners produces more energy than it consumes and starts supplying energy to the grid[4].

Table 10 Solutions and resources by macro-area

Sector of PEDs	Type of resources used in general	Area of application	Solutions within PEDs

[21] Válková, K. Structure of Positive Energy Disctricts. Czech Technical University in Prague, Prague, 2020.

Buildings	Thermal energy	Heating, hot water	Central heat supply from a local renewable source, *combined heat and power generation*, heat pumps (but require electric energy!), geothermal energy, solar heating, waste heat, energy storage
	Electric energy	Appliances, lighting, ventilation and cooling	Photovoltaics, combined heat and power generation, reversible heat pump, wind and water power plants, energy storage
	Water	Drinking and service water	Use of rainwater, domestic waste water treatment plants
	Waste	Waste from the operation of buildings	Use as biomass for energy production, *waste recycling*
Transport	Electric energy	Operation of vehicles	Electric energy from RES
	Fossil liquid fuels	Operation of vehicles	Replacement by full biofuels, bio gas or by electric energy from RES
Public area	Electric energy	Street lighting	RES
	Water	Street cleaning, care for urban greenery	Use of rainwater
	Waste	Public waste, green waste (from urban greenery)	Use as biomass for energy production, *waste recycling*
Other	Electric energy	Various uses	RES

Energy carriers

The definition of the positive energy districts excludes non-renewable energy sources and identifies renewable sources as the only acceptable energy carriers. However, a combination with non-renewable resources (e.g. natural gas) can be considered if a positive energy balance and at least a zero GHG emission balance are achieved in the PED, which can be quite challenging in this case. Moreover, this option must be also assessed with a view to future years in relation to the reduction of energy production from non-renewable energy sources and political goals (for example, EU policy on energy efficiency and climate protection).

Positive energy districts can use all available renewable energy sources and make room for new innovative ways of obtaining energy. The disadvantage of using renewable energy sources is their instability over time. Therefore, an **important part of PEDs is the way energy is stored** so that it can be used continuously and independently of the weather and time of day.

5.3.4 Selection of renewables

The principle of a positive energy districts is to always use only locally available energy resources. The availability of renewable energy resources varies according to the selected PED's locality, geographical location, and altitude.

It should be pointed out that current technologies and innovations offer numerous solutions for utilising renewable energy sources. It is no longer necessary to build large wind farms or expensive dams with hydroelectric power plants because there are plenty of **"micro" and "small smart" solutions.** And although they produce less energy, they can be used to a greater extent due to lower technical and spatial demands.

5.3.5 Possible technical solutions

This chapter presents examples of technical measures that can be used in PEDs. The commonly used technologies in such projects generally refer to the three energy pillars: **Generation, Efficiency and Flexibility**. Of course, due to the constantly emerging innovations, the list is not a complete summary of all possible solutions. However, it should serve as a basic overview, which will be further developed within the PED design. The categorisation of measures respects the division according to chapter 5.2.1.

When implementing any of the solutions below into PED design, it is of necessary to compare its requirements with the possibilities of the area (based on the data obtained within the data collection). The solutions can be combined in order to achieve the goals established for the project. This various combination possibilities will be the backbone of different use cases and scenarios that will be considered and simulated by the technical experts for the PED.

Table 11 Examples of possible technical solutions[22]

Buildings (Energy Efficiency)	
Improvement in thermal characteristics of the buildings: The objective is to provide thermal regulation and inertia to buildings. Improvement in thermal characteristics of the building should be made first before replacing the energy (heat) source, which is designed for specific performance (thermal insulation reduce heat energy need	**Thermal insulation of envelope:** ▪ External insulation – ETICS or ventilated façade – internal insulation with a vapour barrier, façade can be used for building-integrated photovoltaics (BIPV); thermal insulation of window linings ▪ Internal insulation – primary in history buildings, must be assessed on condensation, briefly reduces the interior space, does not impair the visual appearance of the building ▪ Green facades for thermal regulation in hot climates
	Thermal insulation of windows : ▪ Insulated windows and frames ▪ Sun reflector foils, special window films

[22] Based on: Lindholm O, Rehman Hu, Reda F. Positioning Positive Energy Districts in European Cities. *Buildings*. 2021; 11(1):19. https://doi.org/10.3390/buildings11010019

	▪ Combination with photovoltaic panels/foils (BIPV) ▪ Window shading – options include shades, blinds, draperies or curtains, some shutters, outdoor shading - awnings and sun blinds, exterior shutters, shades and solar Window Screens23 (operable/automatic window coverings should be connected to smart building systems)
	Thermal insulation of roofs: ▪ Internal insulation for slope roofs ▪ External insulation for flat roofs – replacement of old insulation or adding another insulation layer ▪ Bio-solar roofs – a combination of green roofs with photovoltaic mounted systems, primary on flat roofs ▪ Green slope roof
	Thermal insulation of floors and ceilings ▪ Ceiling insulation between heated and unheated space
Heat, cold and heated water: sources that are more energy-efficient for providing heat/cooling of rooms and heated water for users:	▪ Heat pumps and reversible heat pumps for room cooling/heating. ▪ Solar photothermic panels for the heated water. ▪ Geothermal energy for heated water and room heating. ▪ Combined heat and power generation (CHP). ▪ Central heat supply from a local renewable source (e.g. biomass) ▪ Heat and cold recuperation (from ventilation, from grey water) ▪ Cooling systems in combination with photovoltaics ▪ District heating (from non-fossil fuels sources)
Improvement of electricity consumption	**Smart systems & controls:** ▪ Building managements systems: sensors & data monitoring. ▪ Smart metering ▪ Control devices – shading, lighting, and appliances.
Other	▪ Insulation of water pipes & thermal recovery systems. ▪ Heating cables (e.g. HWAT system) on hot water pipes to reduce heat loss (applicable especially in buildings with a longer hot water circuit pipe or unbalanced hot water intake) ▪ Wastewater treatment plants ▪ Use of rainwater (rainwater tanks, green roofs and facades) ▪ Water saving spouts / aerators

[23] U.S. Department of Energy. Energy Efficient Window Attachment. Available from: https://www.energy.gov/energysaver/energy-efficient-window-attachments

	▪ Passive and bioclimatic designs: cross ventilation, façade orientation, passive techniques.
RES potential on-site (Energy Generation)	
Generation of local renewable energy: electricity	**Solar Photovoltaic:** ▪ BIPV ▪ Small plants ▪ Roof installation ▪ Shading installation: Bus stops, parking lots, sidewalks. **Wind energy:** ▪ Small vertical axes turbines – small scale ▪ Medium horizontal axes turbines – large scale **Hydro energy:** ▪ Small one – vortex turbine[24] ▪ Ultra-small / micro water power generator[25] **Combined heat & power (CHP):** ▪ Cogeneration based on biofuels/biomass **Wave power**
Generation of local renewable energy: heating	**Solar thermal collectors** **Geothermal** **Waste-to-energy** ▪ assuming that waste can be provided by the neighbourhood waste disposal **Boilers** ▪ Fuelled by RES sources **Heat-pumps** ▪ Fuelled by RES sources **Heat-waste recovery systems**
Generation of local renewable energy: cooling	**Reverse heat-pumps** ▪ Fuelled by RES sources
Energy Management (Energy Flexibility)	
Demand management	▪ Demand response system ▪ Peer to peer trading/ energy communities ▪ Energy flexibility principle
Storage systems	▪ Batteries ▪ Vehicle to Grid – Vehicle to Building ▪ Thermal storage units

[24] Turbulent Hydro: 15kW Vortex turbine with more technical details. Available at: https://www.youtube.com/watch?v=gY3p2e1-kN4 (Accessed 20 September 2021)
[25] Japan Video Topics – English: Ultra-Small Water Power Generator. Available at: https://www.youtube.com/watch?v=XjEgFlngZ04 (Accessed 20 September 2021)

	▪ Smart Charging – charging load is matched with grid capacity
Transport and mobility[26]	
Smart building logistics, sustainable delivery	▪ Optimization of logistic flows to construction sites ▪ Optimization of logistic/delivery parcels (e.g. neighbourhood parcel delivery rooms or micro-consolidation centres ▪ Distribution of freight using e-cargobikes in inner city or for last mile delivery
Alternative fuelled vehicles	▪ Charging stations for electrical vehicles ▪ Alternative fuel station infrastructure ▪ Promotion of alternative fuels in trucks/heavy duty vehicles and public transport ▪ V2X solutions (vehicle as a mobile energy storage for other applications, e.g. V2B: vehicle-to-building)
Smart traffic management	▪ Traffic management simulation tool for traffic optimization ▪ Travel Demand management applications for citizens ▪ Traffic signal priority (e.g. for heavy duty vehicles using alternative fuels or public transport) ▪ Traffic light-vehicle interactive communication (to reduce starts and stops on red lights)
Vehicle sharing including infrastructure	▪ Sharing e-vehicles including car-pooling applications (with priority for short distances) ▪ Sharing economy in freight transport ▪ Decarbonised modal sharing (e-scoters and bicycles)
Smart mobility solutions	▪ Public transport infrastructure coverage and availability ▪ Mobility stations (offering multiple travel alternatives) ▪ Smart taxi stand system (user sensors to improve queue systems at taxi stands and reduce search traffic) ▪ Eco-driving technologies and training programmes

5.4 Scenarios

This section presents the methods for assessing the different technical aspects inside a PED. In the first stage, boundaries, objectives, and scale should be defined based on the spatial analysis (section 5.2). **It is essential to have a clear description among all stakeholders of the PED boundaries, the energy and environmental requirements and the project's ultimate goal and objectives** – translated into indicators. Once these points are settled, the energy and project concept can be developed, including:

[26] Based on the GrowSmarter project. ACTION AREA 3: Sustainable Urban Mobility. Available from: https://grow-smarter.eu/solutions/sustainable-urban-mobility/

- → The standards and concepts for buildings renovation and or/construction according to the building topography, occupancy and final use.
- → The types of renewable energy sources and energy production estimation for different design scenarios.
- → The energy concept design and assessment: how much energy will be consumed? How much will be produced?
- → Energy flexibility: optimisation of energy needs according to on-site production
- → Mobility: what role does mobility play in the project? To which extend it will be included in the scenarios?

Models and assessments are critical instruments for a pre-design feasibility study. The site's limitations and the potential need to be carefully examined, unveiling the project's possibilities based on the site existing conditions, building codes, regulations, and other legal restrictions[27].

For the different sectors of a PED, the four areas (see 5.3.5.) must be cessed and integrated when possible. That means when the **buildings** and construction sites are being planned, there should be considerations made towards the **mobility** (location and integration of EV charges, pathways…), the **RES generation** (especially shading over PV sites, incorporation of roof and façade panels...) and **flexibility**.

5.4.1 Model buildings scenarios

To determine the energy demand of sites, the delimitation and definition must first be considered (see 5.1.2). Once it is clear which energy uses are to be taken into account, a method must be defined for determining them in an early planning phase.

Generally, two methods can be assumed in this phase:

- Benchmark characteristics (Top Down)
- Simplified calculations (Bottom Up)

Benchmark parameters are the results of calculations, measurements and analyses of different types and uses of buildings and the derivation of appropriate parameters for energy use. These characteristic values can be designed with different levels of detail: Characteristic values for the entire building according to the use or also more detailed in different types of use of rooms in the building. Regardless of the level of detail of these characteristic values, values should be taken for PED that meet very high energy efficiency requirements. These requirements are then to be included in the planning of the building.

Simplified calculations are based on very simplified building models. These building models must comply with essential parameters in order to derive reasonable results: Compactness of the building, the ratio between window and wall, plausible assumptions for the efficiency of the building services. For existing buildings, a building model can be dispensed with and the real geometry of the building can be used. With these key data, the energy demand for different types of buildings and uses can be

[27] Samadzadegan, Bahador, Soroush Samareh Abolhassani, Sanam Dabirian, Saeed Ranjbar, Hadise Rasoulian, Azin Sanei, and Ursula Eicker. 'Novel Energy System Design Workflow for Zero-Carbon Energy District Development'. Frontiers in Sustainable Cities 3 (29 April 2021): 662822. https://doi.org/10.3389/frsc.2021.662822.

determined. **High demands are placed on the building envelope** and building services in order to be suitable for a PED.

In addition to the energy parameters for the buildings, **parameters for mobility** must also be taken into account. This energy consumption can be based on a survey of mobility behaviour in the vicinity of the area. At the same time, assumptions must be made for future mobility behaviour (extent, type, energy source).

Furthermore, the **grey energy of the buildings must also be taken into account**. This energy usually accounts for the smallest share of energy use and can only be included in a later phase. The early phase aims to provide orientation as to whether grey energy is taken into account and what priority it is given in the further planning process.

Based on the methods and available data, **different scenarios for the energy demand of PED** could be calculated. This should show additional efforts in reducing the energy demand of all energy uses in the PED. These **scenarios could be combined with renewable energy scenarios to find a good solution** for the PED.

5.4.2 Renewable energy generation scenarios

The goal is to **align the on-site renewable energy production with the PED boundary's energy needs** and **ideally generate a surplus** that could be injected into the grid. There are many forms and standards for calculating and assessing this matchmaking between energy generation and consumption, which are highly dependable on the energy requirements defined for the project, the selected solutions of energy generation and the building and infrastructure scenarios under evaluation. A list of the possible RES solutions and their energy outputs is presented in section 5.3.5.

After selecting which solutions to consider, the energy system design and model can be structured detailing the schematics, energy flow and the types of energy sources that will be used for the PED supply. Depending on the local conditions, seasonal variations and regimes, various solutions may be adopted in combination, thus generation several energy flows. The objective is to **classify which energy used inside the PED boundary will be supplied by RES and optimise it to attend the consumption** as much as possible.

The methodology used for the scenario modelling should be aligned with local regulations and standards, when available, or international ones, such as the EN 15316 series about the Energy performance of buildings and efficiency methods. But ultimately, the **RES generation has to be integrated from the beginning in the planning process** so that conflicting objectives can be analysed and solutions prioritised – e.g. PV generation vs Green façades or terraces.

It is essential to **consider and model different scenarios for the energy generation in the PED** since each solution combination has its advantages and disadvantages from the financial, technical and efficiency perspectives. Therefore it is essential to quantify these aspects and compare them to find the best suitable option according to the project goals. The table below exemplifies this comparison:

Table 12 Comparing aspects from each scenario analysed

USEFUL RES ENERGY (OUTPUT)

		PV	BIPV	Wind	Geothermal	Bionergy	Waste heat	[...]	Total energy from RES
CASE 1	Electricity								
	Thermal								
CASE 2	Electricity								
	Thermal								
CASE N	[...]								

The concept of Load match factors expresses the degree of direct use of on-site RES energy generation over a period of time – e.g. day, month, and year. The assessment should be done on an hourly basis to correctly model the energy delivered and consumed inside the PED boundary.[28]

5.4.3 Energy balance estimation

Energy balance concludes previous analyses and shows a PED's energy flows in a condensed format. Apart from Greenfield PEDs, it is important to describe the **current energy balance** at the moment **and** the other in the **final state with the energy efficiency measures implemented**. Figure 13 presents a flowchart detailing the different steps and analysis involved in the energy balance of a PED.

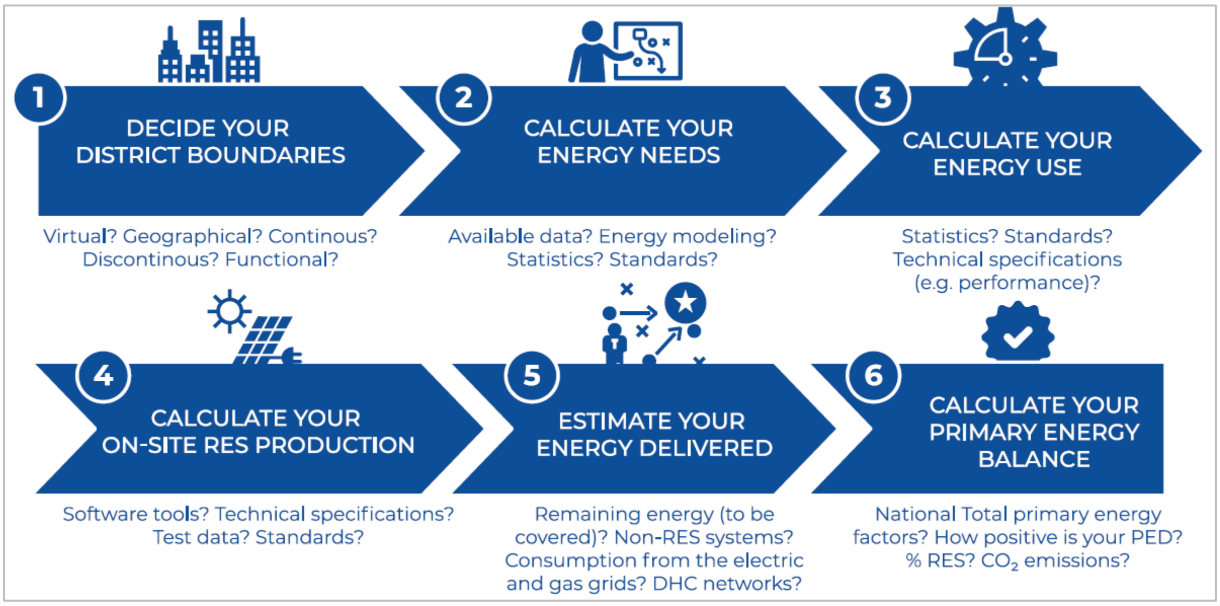


Figure 13 Flow chart summarising energy balance steps[2]

Data categories

[28] Salom, J & Tamm, M.: Methodology Framework for Plus Energy Buildings and Neighbourhoods. syn.ikia project; 30 September 2020 https://www.synikia.eu/library/

Energy balance includes complete energy consumption and production within the whole area. It should use all the available data and monitoring to be as precise as possible. Following data categories should be covered:

→ **Basic information**

This category covers basic metadata about all the buildings in a PED. The exact location of the building as well as operation regimes, such as operating schedule or capacity, should be obtained. Basic information is usually provided by the building owner and/or management. However, it is practical to verify the information on the ground and ask a building caretaker who has hands-on experience with the actual operation of the building.

→ **Construction**

Construction features of the building are derived from documentation and inspection in place. Up to date construction documentation is a must for proper energy analysis. When current documentation is not available, which is often the case with older buildings, it is necessary to inspect the building. Construction documentation is used to determine heat loss and general energy performance of a building. It can however provide much more information and energy efficiency measures can be designed based on it.

→ **Energy needs**

Energy consumption is obtained from energy bills and readings in buildings. An invoice that includes price and physical amount of energy consumed along with the efficiency of given source or appliance are the single most important data in energy balance. Building managers usually archive the invoices so they are the source of the first choice with the energy providers being the second. Any calculations should be verified in the building in question.

It happens, however, often that energy bills and readings are not available in early-stage of PED project. Then, consumption has to be estimated based on available benchmarks and other calculations.

→ **Energy sources**

Finally, energy sources are described. When the sources are located within the building, an auditor can accurately determine the renewable energy share. For imported sources located outside of the area, the share must be estimated. This is the case of electricity from the grid as well as heat from district heating.

Outlook of indicators

The Indicator for energy could be final energy or primary energy or GHG emissions. The conversion factors of primary energy and GHG emissions for electricity and district heating are constantly changing. Targeting a completely renewable energy supply in upcoming decades, we see a major change of conversion factors. When using primary energy or GHG emissions, we should also include a perspective for the forthcoming years and the change of conversion factors based on additional renewable energy use.

Table 13 Possible inputs to be considered in the energy balance

Buildings	Basic info	Purpose, usage, operation, occupation, floors
	Envelope	Materials, insulation, windows, structure
	Energy demand	Heating, cooling, ventilation, boilers, heat pumps, lighting, appliances
	Resources	Water, waste
Mobility	EV private transport	Electric vehicles
	Fossil private transport	Fossil vehicles
	EV public transport	Electric buses, trams
	Fossil public transport	Fossil buses
Other	Conversion	Transformers
	Storage units	Batteries, thermal storage

An energy balance is in fact a comprehensive input/output model that can be conveniently depicted by Sankey diagrams or other specialized calculation tools (e.g., City Energy Analyst or District Energy Concept Adviser…). Detailed energy flows may be aggregated to show individual buildings within a PED or different energy uses within buildings or the whole PED The following figures show such sample balances.

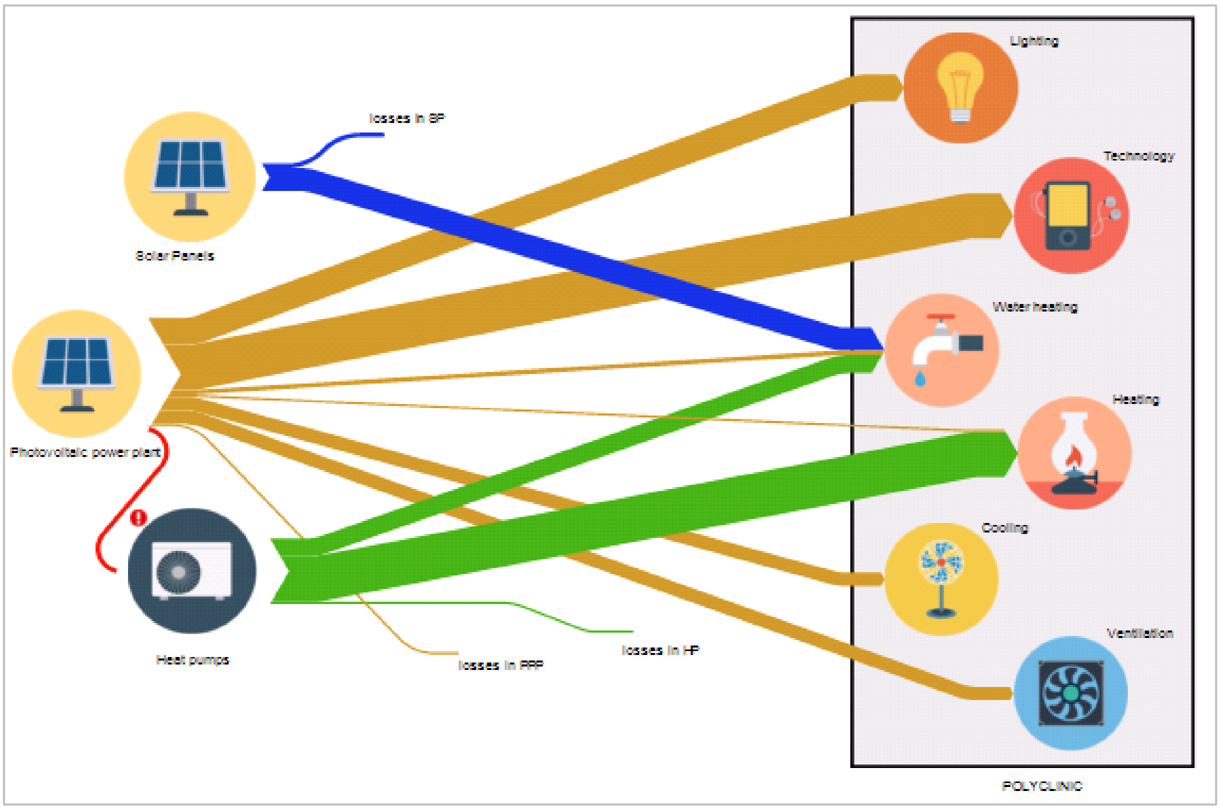


Figure 14 Sample energy balance of a building in PED

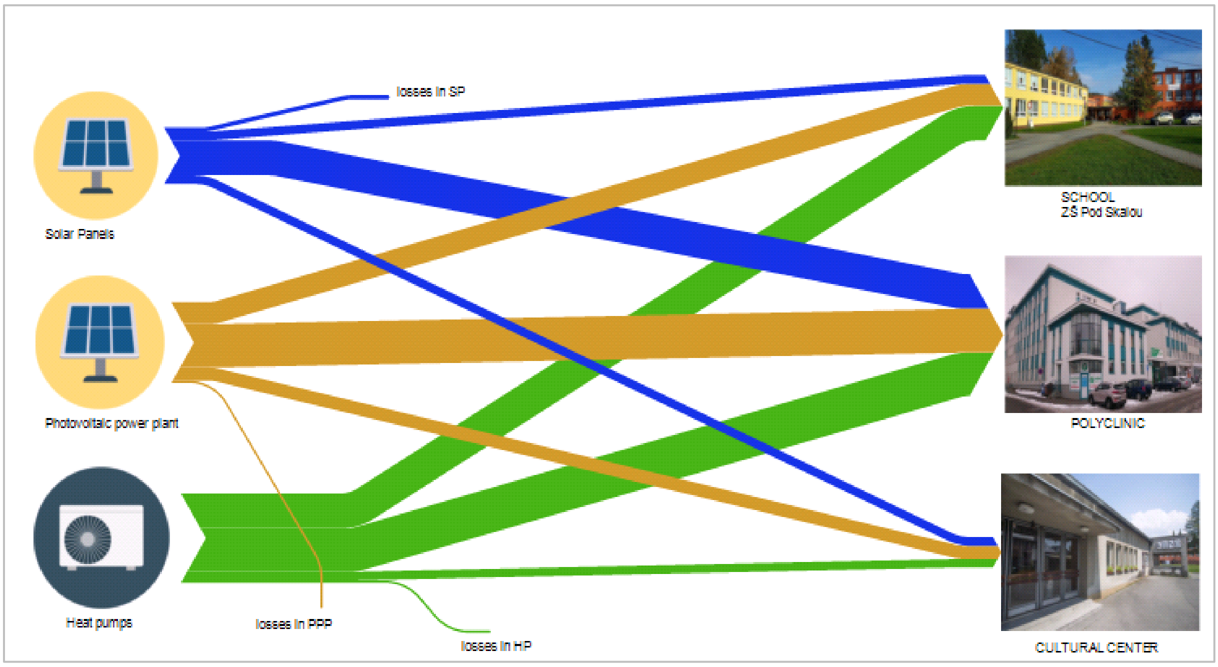


Figure 15 Sample energy balance of a PED

Final state energy balance

After describing the current state of the proposed PED, an **energy balance of proposed measures can be compiled**. On a community level, the options for energy efficiency and renewable energy transitions increase as the portfolio increases. As some buildings in the portfolio will not be able to be very efficient (cost-effectively), whereas others will be positive energy-producing buildings, thus an energy balance will allow each to compensate for the other.

In order for this to work, a community grid is needed to allow for bigger variations. A transactional / internal trading system between buildings allows for some renovations to be less deep whereas some buildings and RE systems give back to the grid. Ultimately, a baseline would be set at the district level – minimum energy performance – and all the buildings would add up to positive or zero energy.

Energy flexibility

With the increase of renewable energy sources, such as wind power and PV, **it is necessary to consider the energy flexibility of districts in the assessment**. A standard method for estimating the energy flexibility potential of PEDs is still under development. Yet, to match the energy demand with the RES production inside the PED boundaries is necessary to conduct a **dynamic building simulation of energy flows** with a temporal resolution of an hour or even shorter time steps.

The Austrian Zukunftsquartier[29] guidelines, the districts are encouraged to purchase RES energy surpluses directly from energy providers that would otherwise have to be shut off. For example, this energy from wind power and PV peaks is considered neutral in terms of primary energy balance. The prerequisite for this is exclusively energy from volatile generation peaks that would otherwise not

---

[29] Schöfmann, P, T Zelger, N Bartlmä, S Schneider, J Leibold, and D Bell. 'Zukunftsquartier - Weg zum Plus-Energie-Quartier in Wien', n.d., 203. Available from: https://nachhaltigwirtschaften.at/de/sdz/projekte/zukunftsquartier.php

enter the grid. This measure stimulates demand-side management programs and better use of the RES available.

5.4.4 Economic analysis

For a correct assessment of the project from an economic point of view, it is necessary to perform its evaluation. An important basis for deciding on the project's feasibility is the evaluation of the **project's economic impact.**

The **efficiency of the project in terms of economics is measurable primarily by money**. The economic evaluation does not take into account other aspects of the project, such as ecological evaluation, the contribution of society or the benefits for the environment.

It is appropriate to **use multi-criteria evaluation** to evaluate energy projects (such as the construction of new renewable energy sources or the implementation of energy-saving measures). It is appropriate to use multi-criteria evaluation. The economic part will also be a part of this evaluation.

Each economic evaluation of the project compares, in particular, the achieved economic returns, which are the reduction of energy or operating costs, with the costs, which are most often in the form of the necessary investment in the installation of new equipment or the construction of cost-saving measures. **The life cycle assessment method should be used** as it can assess all costs over the life cycle. However, it needs to be adapted for the whole PED, which can be quite difficult. Also, the preliminary funding options based on stakeholder consultations should be resolved during this phase.

The economic efficiency of the project depends mainly on the following factors:

- Necessary investment costs for the implementation of the project;
- Operating costs for project maintenance;
- Project lifetime;
- Achieved energy savings and achieved financial savings;
- Other benefits and costs of the project can be expressed financially.

Basically, the economy is considered in direct relation to investments, energy consumption and production but **for larger PEDs it is appropriate to include also various non-energy benefits**.

Calculation of economic evaluation of the project

One of the important aspects of selecting and designing appropriate measures is their economic return. The period for which the investment returns is calculated. This is the period when the invested funds will be compensated by the savings achieved in the form of reducing the operating costs of the building and technology.

Determining the cash flow of a project

For each project, it is necessary to determine the method of its financing. Cash flows (expenses and revenues) are determined for the entire life of the project.

$$CF_y = (R_{ES} - OE_y) - IN_y + (C_y - CC_y)$$

CF_y .... *project cash flow for project year y;*

R_{ES} .... *project revenues (financially valued energy savings, energy sales) in year y;*

OE_y .... *operating expenses of the project in year y;*

IN_y .... *investment expenditure in year y;*

C_y .... *income provided to the loan in year y;*

CC_y .... *expenses for amortization of the loan (including tax) in the year y.*

After determining the amount of energy savings by calculating the annual energy balance of the current state and the state with the proposed austerity measures, it is possible to determine the return on the proposal.

Payback Period (PP)

Payback period is for the simplest and fastest estimate of the economic viability of a project of austerity measures or projects to produce energy from renewable energy sources. The simple payback period indicates the number of years needed to offset the project investment by reduced operating and maintenance costs.

$$PP = IN/CF$$

IN .... *investment costs for the establishment of the project;*

CF.................. *annual cost savings compared to the original state, Cash-Flow project, equal to the product of energy savings and energy prices.*

Simple payback period is the simplest indicator, so it is used primarily as a supplementary indicator.

Discounted payback period (DPP)

In contrast to the simple payback period, the real payback period considers the effect of time on the investment project. The calculation is extended by the effect of the discount rate. This indicator more accurately shows the return on longer-term projects, where the effect of reducing the value of money cannot be neglected.

$$\left[\sum_{t=1}^{T_R} CF_t(1+r)^{-t}\right] - IN = 0$$

CF_t .... *annual cost savings compared to the original state, Cash-Flow project in year t;*

r..................... *discount rate;*

IN .... *investment costs for the establishment of the project.*

Discounted payback period considering energy price development

For projects that deal with energy savings or the construction of new energy sources, it is appropriate to consider the effect of rising energy prices in the calculation. The development of the energy price can have a high impact on the return on the project.

$$\left[\sum_{t=1}^{T_R} (ES \cdot EP_t)(1+r)^{-t}\right] - IN = 0$$

ES .... *annual energy savings after the implementation of energy saving measures;*

EP_t .... *energy price in year t;*

r..................... *discount rate;*

IN .... *investment costs for the establishment of the project.*

Net present value (NPV)

Another indicator of investment evaluation is the net present value of the project. This is one of the most appropriate and used financial indicators. This indicator indicates how much money the investment will bring. It is a more complex indicator, which also includes the effect of the value of finances over time.

The net present value is based on the principle of calculating the funds that the investment (project) will bring in the selected lifetime. The calculation result is the absolute value of the project benefit in current prices. If the NPV is positive, the project is admissible, on the contrary, any negative NPV value means that the intended project is loss-making.

$$NPV = \left[\sum_{t=1}^{T_L} CF_t (1+r)^{-t} \right] - IN$$

CF_t .... *annual cost savings compared to the original state, Cash-Flow project;*

T_L................... *project lifetime;*

r..................... *discount rate;*

IN .... *investment costs for the establishment of the project.*

The net present value can be used to compare multiple projects. For projects, their different investment benefits are compared. Projects with a higher NPV value are preferred. It is appropriate to supplement the comparison of projects with other indicators.

Net present value considering the development of the energy price

As well as the calculation of the payback period, it is appropriate to supplement the calculation of the NPV with the effect of the development of the energy price. Especially for longer-term projects, it is necessary to include the impact.

$$NPV = \left[\sum_{t=1}^{T_L} (ES \cdot EP_t)(1+r)^{-t} \right] - IN$$

ES .... *annual energy savings after the implementation of energy saving measures;*

EP_t .... *energy price in year t;*

T_L................... *project lifetime;*

r..................... *discount rate;*

IN .... *investment costs for the establishment of the project.*

One of the additional parameters that is sought is the internal rate of return of the project. This factor is mainly used to compare several austerity measures with each other, when evaluating variants from each other from an economic point of view.

Internal rate of return (IRR)

Another indicator of the economic evaluation of the project is the IRR. This indicator evaluates the return on investment. The indicator provides information on the yield, which can be compared with the reference interest rate or the yield of another project. When comparing more projects, a project with a higher profitability value is better.

$$\left[\sum_{t=1}^{T_L} CF_t(1+IRR)^{-t}\right] - IN = 0$$

CF_t .... *annual cost savings compared to the original state, Cash-Flow project;*

T_L.................. *project lifetime;*

r..................... *discount rate;*

IN .... *investment costs for the establishment of the project.*

The IRR is primarily an evaluation mechanism for comparing two investment options. Suppose we know the return on another investment or interest rates. In that case, it is possible to use IRR to find out whether it is more advantageous to carry out a project or invest money in another project.

Evaluation using IRR is only from an economic point of view, if there is a requirement to evaluate the project from other points of view, such as environmental, it is necessary to use multi-criteria evaluation.

5.4.5 Emission analysis

The different objectives and targets of a PED shall culminate in an urban district that generates more renewable energy than consumes and has a **climate-neutral impact, net-zero greenhouse gas emissions**. There are still discussions on a common methodology for calculating the GHG emissions for PEDs, thus the specific procedures and assumptions.

From the energy generation perspective, an accurate estimation of CO_2 emissions is a complex subject due to the many interdependencies of local and European energy markets. The characteristics of fluctuating renewable energy production and exchange between market actors make it harder to assess the origins of the energy entering the boundaries. Consequently, the direct use of the conversion factor for emission estimation becomes difficult and inconvenient

Another general recommendation is **embedded energy emissions** and how PEDs should incorporate them into the emission balance. The consideration of the embedded energy (e.g. energy used in manufacturing, transportation, maintenance, disposal and so on) in GHG emission calculations is fundamental to assess impacts of different case scenarios and understand the whole life cycle emission process. For this assessment, methodologies such as **Life-Cycle Assessment (LCA)** can be used to analyse the environmental impacts of goods, services, materials, and account of embedded energy sources. The standards **ISO 14044** series details the methodology to be followed.

As it happens for the energy balance, the emission balance comprehends a great variety of sources that should be appropriately identified and analysed:

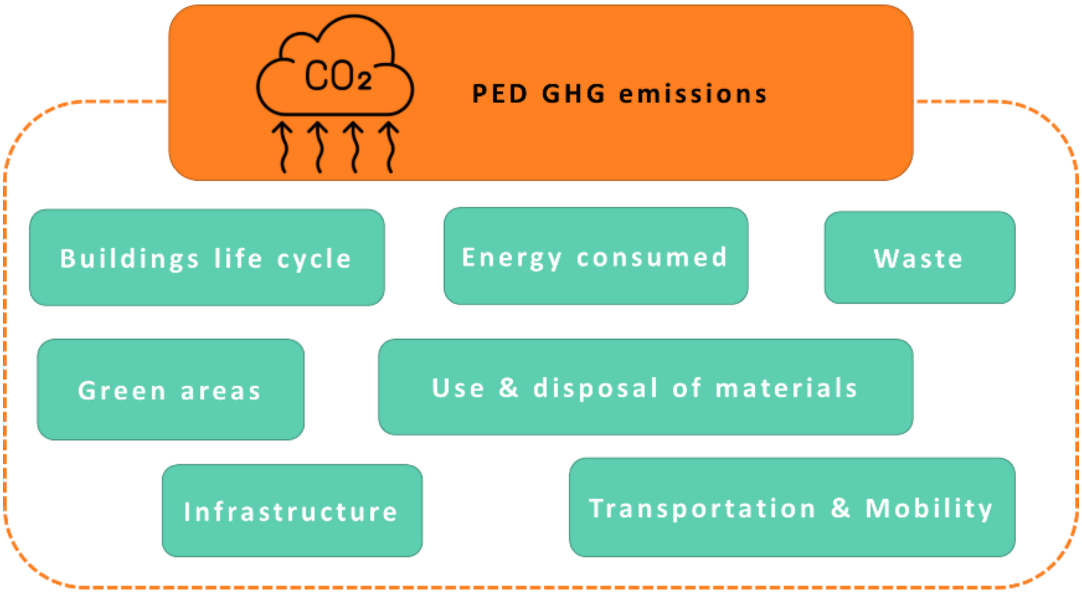


Figure 16 Aspects of a PED project that influence the estimation of the GHG emissions

Once again, the delimitation of the system boundaries has a considerable impact on the emission assessment. By boundaries, we mean the definitions of what aspects and physical elements in the district will be accounted for. Still, the most comprehensive analysis includes buildings, transport, and other elements listed in Figure 16. In such studies, it is shown that **buildings (including embedded account for up to 52% of the total GHG emissions** of a PED, followed by **transportation with 40%[30].** Therefore, mobility and transportation systems are major sources of GHG emissions in PEDs, and should be considered in the assessment.

The urban green spaces and vegetation are capable of absorbing carbon dioxide, thus contributing to the net-zero balance. The presence of green areas can also be accounted as a positive factor in the emission balance. Different methods and conversion factors can be used to assess the amount of carbon sequestration per area of vegetation. Depending on the density of the size and location, one method will be more appropriate.

A general procedure for assessing GHG emissions for PEDs at an early stage planning using LCA is proposed by Lassoulet et al.[30] It consists of a two-dimension LCA scope to cover both the physical elements (buildings, mobility, open spaces and so on) and the life cycle stages (production, use, disposal…) as shown in Table 14. Essentially, for each category analysed, there should be a distinction of the life stage that will be considered inside the PED boundary. The elements and stages in the LCA can be adjusted according to project specifications and targets.

[30] Lausselet, Carine, Vilde Borgnes, and Helge Brattebø. 'LCA Modelling for Zero Emission Neighbourhoods in Early Stage Planning'. Building and Environment 149 (February 2019): 379–89. https://doi.org/10.1016/j.buildenv.2018.12.034.

Table 14 Assessing GHG emissions for PEDs

Included elements	Emissions considered															
	Product			Construction		Use							End-life			
	Material	Transport	Manufacturing	Transport to PED	Installation	Use	Maintenance	Repair - renovations	Replacement	Energy for operating	Water consumed	Transportation	Demolition	Transportation	Waste processing	Disposal
Buildings	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Mobility						X	X	X	X	X	X	X	X	X	X	X
Open spaces																
Networks						x	x	x	x	x	x					
On-site energy																
[....]																

Many options and scenarios are under consideration at the early stages of PED planning, which means the different arrangements of buildings and energy systems are analysed simultaneously. The emission analysis and **LCA tools can be allies in assessing the case scenarios for various building and energy configurations and be used as a predominant factor in making decisions** between one set of solutions and others. In summary, the main aspects to be carefully analysed and defined in the emissions balance of a PED are:

- **Define GHG emissions work scope and boundaries**: What elements will be included? What stages of their life cycles? To what extend?
- **Lifetime**: What is the horizon of the assessment? The period of the life cycle?
- **Green potential**: What tools and methods for accessing carbon sequestration will be used? What are the scenarios for green spaces (green roofs vs PV panels ...)?
- **Assessment of the carbon emission from different case scenarios for buildings and energy solutions**: Which solutions present the best GHG emissions and surplus RES productions ratio?
- **Conversion factors of energy imported by the PED**: Correctly account for carbon emissions from these energy sources.

5.5 Selecting the solutions

Determining the final extent of PEDs depends on the indicators and information inputs considered and how we evaluate them. **Technical and economic constraints as well as preferences of a wide range of stakeholders must be taken into account**. Therefore, the decision on the solutions and strategies to be implemented in a PED needs to follow an evaluation of multiple criteria, both quantitative and qualitative (e.g., ensuring the quality of the indoor environment). It is not easy to combine the various scenarios and criteria for energy, finance, emissions, and stakeholders preferences, and imply in an iterative process until the final concept is achieved. It lays on quantitative methods, with stakeholder input proves to be challenging and to calls for a holistic approach to support decision making.

Such an approach has been explored in a study[31] which encouraged stakeholders to scrutinize the quantitative modelling results in a structured manner through a **Multi-Criteria Decision Analysis (MCDA)**. In the initial phase of PED planning, city stakeholders and other facilitating actors, such as consultants, investors, developers, researchers etc., should be brought together in a co-development process for enhancing sustainable urban planning through an integrative and multidisciplinary planning process. The approach addresses the issue of integration between the cities administration staff, as well as between the decision-makers and the different relevant departments in municipalities.

MCDA follows technical analysis presented in previous sections (5.1 to 5.4) and introduces additional criteria – economic, social, regarding urban planning etc. The aim is to benchmark technical scenarios vis-à-vis more subjective criteria beyond simply achieving PED energy balance or not. Evaluation can also be used to compare different PEDs.

Table 15 Quantitative criteria

PED level

• Total investment cost (CAPEX)
• Investment efficiency (specific cost of saved energy and CO_2)
• Operational costs (OPEX)
• Degree of energy self-sufficiency
  ○ Export
  ○ Import
• Total energy consumption decrease
• Total GHG emissions decrease
• Total RES energy production

Individual measure level
• Total investment cost (CAPEX) • Investment efficiency (specific cost of saved energy and CO_2) • Operational costs (OPEX) • Energy savings (%) • Energy savings (TJ) • Total GHG emissions decrease

Table 16 Other criteria

Qualitative criteria
• Urban development • Improving life quality • Overall feasibility and demands of PED implementation

[31] S.G. Simoes, L. Dias, J.P. Gouveia, J. Seixas, R. De Miglio, A. Chiodi, M. Gargiulo, G. Long, G. Giannakidis: InSmart e A methodology for combining modelling with stakeholder input towards EU cities decarbonisation. Journal of Cleaner Production 231 (2019) 428-445.

• Social acceptance • Aesthetics, appearance, inclusion in the area • Legal barriers
Economic assessment
• Payback period • Available subsidies
Non-energy benefits
• Technical – condition of the buildings, quality, life cycle, energy security, energy independence • Social – public health, content, contentment, labour productivity, life standard • Environmental – local and global climate impact • Other – urban development, public acceptance, appearance…

The application of multi-criteria decision making in PED development should follow a few basic steps that can be extended when needed. Importantly, the assessment of qualitative criteria is linked with stakeholder engagement. Therefore, an outcome will differ from case to case and the process of decision making is highly dependent on actual participating stakeholders.

(1) **Defining criteria** together with stakeholders and allocating weights to the different criteria with stakeholders. Participating stakeholders discuss and allocate weights to each criterion in a two-step process. Firstly, they should agree on a common basis of understanding the meaning of criteria and then allocate the weights individually. After the ranking is made, the weights may be reviewed and adjusted in additional discussions if deemed necessary.

(2) Definition of the **decision-making scheme**, regarding the objective function and preference function. A Deliberative Multi Criteria Evaluation (DMCE) approach was used and Hinkle's resistance to change method (Hinkle, 1965) was applied towards the conclusion of representative preferences that were used as weights in the decision-making scheme afterwards.

(3) **Deciding** according to defined criteria by characterizing the results of each tested scenario in the energy analysis. Some of the model results provided direct inputs in the MCDA (i.e. investment costs), whereas some criteria required qualitative assessment by all stakeholders.

The quantitative criteria were calculated using the results of the city-ESM, while the qualitative criteria were assessed based on the input from the stakeholders. In this way, stakeholders participated in the definition of the scenarios which were modelled, but also on the ranking of the scenarios

As a result, a ranking of alternative scenarios, based on the quantitative outputs and on their perception of the qualitative characteristics, is produced, prioritizing the actions from the one with the best to the one with the worst compromise among the evaluation criteria. Again, this ranking can be discussed with the stakeholders, looking for the necessity of changing the criteria's weights.

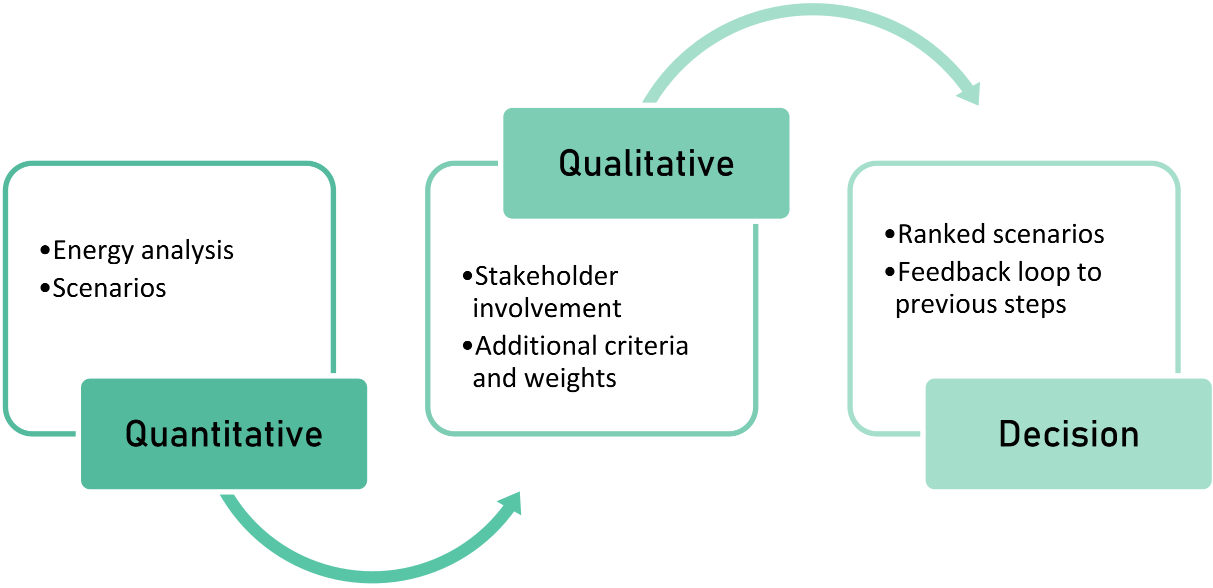


Figure 17 Multi-criteria decision-making scheme

6 Tools and methodology

Assessment of PED area in early development phase requires a lot of data from various application areas to be analysed and calculated. There is often a situation where the necessary data is not available or is incomplete. Then it is necessary to make estimates or only rough calculations (e.g. based on the indicative, standard or benchmark values).

Various tools or already developed methods can be used to simplify the whole process. This chapter present some of them. However, this is not an exhaustive list and many more tools can be found depending on the target requirements of the analysis or calculation.

6.1 Tools and methods for energy / need

- **City Energy Analyst** (www.cityenergyanalyst.com): City Energy Analyst (CEA) is open-source software for analysing energy systems in cities. CEA helps you analyse the effects of building retrofits, land-use planning, district heating and cooling and renewable energy on the future costs, emissions and energy consumption of neighbourhoods and districts. In addition, CEA helps you find the optimal location, size and operation of energy generation and distribution technologies for a neighbourhood or a district of your choice. Currently, CEA supports analysis in Temperate (e.g., Switzerland) and Tropical climates (e.g., Singapore).

  It has the potential to be used in the PED concept, reduced model approach. Input may be limited to Geographic information and a low level of detail building models. Buildings and occupants are characterized by archetypes and a basic description of the energy system and building envelope. Outputs include large-scale district heating and cooling demands, electric grid demands, and general evaluations concerning different scenarios, benchmarking, cost analysis, transport/mobility and life-cycle analysis. Time resolution is between hours and years. Spatial resolution is between a single buildings, to a group of buildings.

- **TEASER** (Teaser (rwth-aachen.de)): Is an open-source tool based on Python for modelling large numbers of buildings, using reduced order models. It can be run on a personal computer as most of the tools. As input, CityGML and Modelica (see below) datasets, as well as Python code might be used.

- **Energy Plus** (https://energyplus.net/): It is a building energy simulation program that models both energy consumption—for heating, cooling, ventilation, lighting - and water use in buildings. It is used in several other urban building energy modelling tools as a heat-balanced physics simulation engine for example in CityBES.

- **CityBES** is another powerful simulator comparable to CEA. It is a Web-based service uses similar input data and delivers output in a high time resolution.

- **TRNSYS** (http://www.trnsys.com/): It is designed to simulate the transient performance of thermal energy systems while building input data is entered. It can be used for to include the effects of urban microclimate in building stock simulations. It is a frequently used tool for modelling the energy system part of larger projects. For large scale modelling, other languages require less development time and yield higher quality results as TRNSYS.

- **Modelica** (https://modelica.org/): This language that offers an extensive set of libraries for control, thermal, electrical and mechanical systems. Several multi-domain modelling and simulation solutions existing in USEM (Urban-Scale Energy Modelling) are based on Modelica. Especially the simulation environment Dymola is very useful for simulating reduced model approaches, with comparatively low computational requirements and sufficient accuracy.
- **District Energy Concept Adviser** (https://www.district-eca.com): The Fraunhofer Institute for Building Physics IBP developed this tool to support actors in the field of urban planning during the first stages. The goal is to assist the planning of energy-efficient district concepts. The very heart of the software is a tool for the energy assessment of districts, which uses archetypes and other pre-set configurations to allow for a simple and quick data input mapping all the buildings in the district. It makes easier the identification of energy saving potential in the areas of building construction, technical building systems, and centralized supply systems.

6.2 Tools and methods for renewable energy

Depending on the technologies and resources that will be used for generating local renewable energy, different methods and tools should be used.

- **PVGIS** (https://ec.europa.eu/jrc/en/pvgis): This online GIS tool provides free and open access to PV potential for different technologies and configurations of grid-connected and stand-alone systems. It displays data about the solar radiation and temperature (monthly averages or daily profiles), full-time series of hourly values of both solar radiation, Typical Meteorological Year data for nine climatic variables, Maps, of solar resource and PV potential. It is great tool to access PV potential for e certain area and estimate hours of production.
- **PVSites** (https://www.pvsites.eu/): This software is result of an EU funded project that aimed to create a tool for the joint simulation of BIPV products and building energy performance, supporting the integration of BIPV into the design, construction and management of buildings. PVSITES software suite is based on the BIMsolar platform developed by CADCAMation and allows users to easily model and evaluate BIPV projects in terms of architectural design, energy production estimation, thermal impact and light transmission.
- **PolySun** (https://www.velasolaris.com/): Is a private software that allows users to simulate solar-thermal, PV and geothermal systems. The software simulation provides additionally reliable functionality, energy efficiency, and profitability results – from single-family homes to districts. It allows the combination of different technologies, such as solar thermal, PVT, photovoltaics, heat pumps, ground-source loops, cogeneration units and others).
- **Windnavigator** from UL®: This online GIS tool offers 200-meter resolution mesoscale mapping system for quick and easy way to assess and prospect areas for wind energy production. The information available are the long term year-average wind speed (at hub heights up to 140 m), air density, mean power density, Weibull parameters, Uncertainty of modelling, Wind rose and Monthly distribution. It's an open access tool that allows designers to prospect and analyse the wind energy potential for a certain area in a preliminary stage.

7 Conclusion and recommendation

This handbook shows that Positive Energy Districts can be spatially feasible and economically superior over regular consumption-only urban area that is connected to electricity grid and covers all its energy needs by imports. That is, PED is possible in climatically favourable conditions.

Variations of PED definition according to source are presented, but it is a common understanding that **PED is an (urban) area, which generates more energy than it consumes and integrates RES sources and sophisticated ICT-aided management features**.

However, **careful analysis is needed** to delineate and design a PED and calculate its many dimensions. Due to the specific conditions across the municipalities and different areas, there are barriers to overcome. One of them is to **clearly define the PED boundaries** and the degree of solution complexity, which is crucial within the solution assessment. **The interconnectedness of different sectors** can be challenging for proper evaluation or application of the life cycle assessment method. To reach a **balance of energy sources and energy need**, a significant amount of **data input needs to be gathered**. This is not always practical as there is often not much data available in the initial phase of project planning. Thus, a planner should always be prepared to compromise (e.g. aggregation or estimation of data) in order to reach feasible outcomes and balance the insatiable need for data with the ability of his/her counterparts to deliver the data.

The **technical assessment must be considered comprehensively** as it consists of 8 basic categories, which should be covered and for which it is necessary to find the optimal solution for PED:

- buildings;
- infrastructure;
- transport and mobility;
- other municipality objects;
- RES potential;
- utilization of energy recovery;
- greenery potential;
- restrictions.

The **available solutions cover a wide range of options**, from common and proven practices to innovative solutions and new modern technologies as well as changes in user behaviour towards the principles of sustainability and in accordance with PED management (e.g. with regard to energy flexibility). This guidebook focuses in particular on basic list of technical solutions and their technical-economical-environmental assessment with respect to Positive energy district concept.

Nevertheless, the technical assessment does not exist in a vacuum. Due to the PED implementation represents a significant transformation in the social, economic and environmental areas, hand in hand with technical assessment of a PED, **a thorough stakeholder engagement process has to occur**. Interactions with stakeholders are dealt with in other deliverable of this project. A guide on how to communicate this handbook to a general audience follows as a deliverable D3.2.

8 References

Alpagut, Beril, Akyürek, Ömer, Miguel Mitre, Emilio: Positive Energy Districts Methodology and Its Replication Potential. Researchgate [online]. 2019. https://doi.org/10.3390/proceedings2019020008

Byrne, J.,Taminiau J., Kurdgelashvili L. and Kim N. K. A review of the solar city concept and methods to assess rooftop solar electric potential, with an illustrative application to the city of Seoul. Renewable and Sustainable Energy Reviews, 2015. https://doi.org/10.1016/j.rser.2014.08.023

Cartuyvels, P. et Bartholmes, J. Positive Energy Blocks. Smart Cities Marketplace, 2016. Available from https://smart-cities-marketplace.ec.europa.eu/action-clusters-and-initiatives/action-clusters/sustainable-built-environment/positive-energy#management

Enerfis: Smart metering – technical information. [online]. Enerfis, 2020. [Accessed 10 February2021]. Available from: https://www.enerfis.cz/sluzby/smart-metering/smart-metering-technicke-informace

European Commission. The Strategic Energy Technology Plan – at the heart of energy research and innovation in Europe. 2018. Available from: https://op.europa.eu/en/publication-detail/-/publication/064a025d-0703-11e8-b8f5-01aa75ed71a1

González, Ainhoa; Donnelly, Alison; Jones, Mike; Chrysoulakis, Nektarios; Lopes, Myriam (2012). "A decision-support system for sustainable urban metabolism in Europe". Environmental Impact Assessment Review. 38: 109–119. https://doi:10.1016/j.eiar.2012.06.007

Gouveia, P. J et al. Positive Energy District: A Model for Historic Districts to Address Energy Poverty. Frontiers in Sustainable Cities, 2021. https://doi.org/10.3389/frsc.2021.648473

GrowSmarter project. ACTION AREA 3: Sustainable Urban Mobility. Available from: https://grow-smarter.eu/solutions/sustainable-urban-mobility/

Hernandez, P. et Kenny, P. From net energy to zero energy buildings: Defining life cycle zero energy buildings (LC-ZEB). Energy Build, 2010. https://doi.org/10.1016/j.enbuild.2009.12.001

IEA EBC. Annex 83 - Positive Energy Districts. Available from https://annex83.iea-ebc.org/

Japan Video Topics – English: Ultra-Small Water Power Generator. Available at: https://www.youtube.com/watch?v=XjEgFlngZ04 *(Accessed 20 September 2021)*

JPI Urban Europe: EUROPE TOWARDS POSITIVE ENERGY DISTRICTS: A compilation of projects towards sustainable urbanization and the energy transition. Available at: https://jpi-urbaneurope.eu/wp-content/uploads/2020/06/PED-Booklet-Update-Feb-2020_2.pdf

JPI Urban Europe. Towards 100 Positive Energy Districts and Neighbourhoods (Leaflet). 2019. Available from: https://jpi-urbaneurope.eu/wp-content/uploads/2019/09/PEN-Leaflet-190924.pdf

JPI Urban Europe / SET Plan Action 3.2 (2020). White Paper on PED Reference Framework for Positive Energy Districts and Neighbourhoods. https://jpi-urbaneurope.eu/ped/

Kučerová, Makešová: Smart Grids in Czechia (1): Present and goals. In: Energie21. [online]. Profi Press s. r. o, 2013. [Accessed 10 February 2021]. Available from: https://www.energie21.cz/smart-grids-v-cesku-1-soucasnost-a-hlavni-cile /

Lausselet, Carine, Vilde Borgnes, and Helge Brattebø. 'LCA Modelling for Zero Emission Neighbourhoods in Early Stage Planning'. Building and Environment 149 (February 2019): 379–89. https://doi.org/10.1016/j.buildenv.2018.12.034

Lindholm O, Rehman Hu, Reda F. Positioning Positive Energy Districts in European Cities. Buildings. 2021; 11(1):19. https://doi.org/10.3390/buildings11010019

Salom, J & Tamm, M.: Methodology Framework for Plus Energy Buildings and Neighbourhoods. syn.ikia project; 30 September 2020 https://www.synikia.eu/library/

Samadzadegan, Bahador, Soroush Samareh Abolhassani, Sanam Dabirian, Saeed Ranjbar, Hadise Rasoulian, Azin Sanei, and Ursula Eicker. 'Novel Energy System Design Workflow for Zero-Carbon Energy District Development'. Frontiers in Sustainable Cities 3 (29 April 2021): 662822. https://doi.org/10.3389/frsc.2021.662822

Schöfmann, P, T Zelger, N Bartlmä, S Schneider, J Leibold, and D Bell. 'Zukunftsquartier – Weg zum Plus-Energie-Quartier in Wien', n.d., 203. Available from: https://nachhaltigwirtschaften.at/de/sdz/projekte/zukunftsquartier.php

Schöfmann, Petra, Thomas Zelger, Nadja Bartlmä, Simon Schneider, Daniel Bell, und Jens Leibold. 2019. „Zukunftsquartier, Weg zum Plus-Energie-Quartier in Wien". Berichte aus der Energie- und Umweltforschung 11/2020. Stadt der Zukunft. Wien: Bundesministerium für Klimaschutz, Umweld, Energie, Mobilität, Innovation und Technologie (BMK).

Shnapp, S., Paci, D. and Bertoldi, P., Enabling Positive Energy Districts across Europe: energy efficiency couples renewable energy, EUR 30280 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-21043-6, doi:10.2760/452028, JRC121405.

Simoes, S.G., L. Dias, J.P. Gouveia, J. Seixas, R. De Miglio, A. Chiodi, M. Gargiulo, G. Long, G. Giannakidis: InSmart e A methodology for combining modelling with stakeholder input towards EU cities decarbonisation. Journal of Cleaner Production 231 (2019) 428-445.

Positive Energy Districts Solution Booklet. EU Smart Cities Information System, 2020. Available from: https://smart-cities-marketplace.ec.europa.eu/insights/solutions/solution-booklet-positive-energy-districts

Territoires à énergie positive [online] 100% RES COMMUNITIES, 2013 [Accessed 16 April 2021] Available from: http://www.territoires-energie-positive.fr/bul/presentation/qu-est-ce-qu-un-territoire-a-energie-positive

Tulane Universities Libraries. Spatial Analysis. Last modified July 26, 2021 Available from: https://libguides.tulane.edu/geographicinformationsystems/spatialanalysis *[Accessed 23 August 2021]*

Turbulent Hydro: 15kW Vortex turbine with more technical details. Available at: https://www.youtube.com/watch?v=gY3p2e1-kN4 *(Accessed 20 September 2021)*

U.S. Department of Energy. Energy Efficient Window Attachment. Available from: https://www.energy.gov/energysaver/energy-efficient-window-attachments

Urban Europe [online] JPI Urban Europe, 2020 [Accessed 17 April 2021] Available from: https://jpi-urbaneurope.eu/ped/

Urban Europe: EUROPE TOWARDS POSITIVE ENERGY DISTRICTS. In: Urban Europe. [online]. JPI, Urban Europe. Únor, 2020. [Accessed 11. January 2021] Available from: https://jpi-urbaneurope.eu/wp-content/uploads/2020/06/PED-Booklet-Update-Feb-2020_2.pdf

Válková, K. Structure of Positive Energy Disctricts. Czech Technical University in Prague, Prague, 2020.

Wikipedia. 2021. Spatial analysis. Wikipedia [online]. Last modified August 17, 2021. Available from: https://en.wikipedia.org/wiki/Spatial_analysis#Spatial_data_analysis *[Accessed 23 August 2021].*

PED-ID TEAM

Coordinator:

	e7 Energy Markt Analyse GmbH (e7)

Partners:

	Czech Technical University in Prague, Faculty of Civil Engineering (CVUT)
	SEVEn, Energy Efficiency Center, z.ú. (SEVEn)
	Sustainable Innovation AB (SUST)
	White Arkitekter AB (WHITE)

CONTACT

Project Coordinator:

e7 Energy Markt Analyse GmbH

Camilla Borges Rampinelli | camilla.rampinelli@e-sieben.at

This project has received funding from the European Union's Joint Programme Initiative Urban Europe programme.