Cities4PEDs

WORKPACKAGE 2

Definition of Positive Energy Districts

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Definition of Positive Energy Districts

Cities4PEDs WP2 Deliverable

What is a Positive Energy District?

> *If you can't explain it simply, you don't understand it well enough*
>
> - *Albert Einstein*

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How to use this document

This report is not a step-by-step guide on how to develop a PED. For the most part it is not aimed at stakeholders and developers of local districts, but instead addresses national, municipal and European policy makers and researchers: It discusses the different aspects and approaches of PED definition from a theoretical perspective and highlights the challenges and requirements for bridging the gap to a practical and operational definition.

The document is split into four parts, that contain

1) INITIAL OBSERVATIONS and results from the definition development process itself
2) the resulting CONSENSUS on PED definition within the project consortium, and
3) AN EXAMPLE of a possible national Definition Implementation and Operationalization and example Assessment of the C4P districts according to this definition.
4) FINAL OBSERVATIONS

	Chapter 1 APPROACHING a PED DEFINITION	Chapter 2 DEFINITION CONSENSUS	Chapter 3 EXAMPLE DEFINITION and ASSESSMENTS	Chapter 4 OBSERVATIONS
Inside	Observations on the way to a PED definition	Minimum consensus definition	Example assessments with quantitative definition of positive energy balance	Discussion of observations and outlook
	Challenges The definition from different perspectives Requirements of a definition	Common Ground of the three demo sites on PED definition	Primary Energy Balance to assess efficiency, local renewables and flexibility ambitious, yet achievable	

The following pages give you a more comprehensive look at what you will find in this deliverable.

1: Definition approach

This chapter recounts the approach to the definition development process taken in the Cities4PEDs Project WP 2. It gives an account of the steps taken as well as the reasons behind it and their main findings. This in itself constitute main results of WP2: Exchanging positions and approaches towards PEDs between different Countries, Cities and Projects and investigate the commonalities and differences, as well as determining the reasons for what works and what does not. It presents the heterogeneous practical requirements identified from the districts and compares them with a theoretical framework that should be able to give guidance on how to approach the definition PEDs. This first sections contents are structured as follows:

Sub-Chapter	What's inside?
Identify Goals and requirements of a PED definition	In this first step, ten goals were identified, that any possible PED definition should be entail to be deemed useful from the perspective of the three local PED sites.
Finding Common denominators between countries	Analysis of the differences and commonalities in terms of the dichotomies of "quantitative vs qualitative" and "Energy and Emissions vs Social Aspects"
Splitting the Definition into three regimes of Regionality: EU, National and Local	How to distribute the definition responsibilities between three appropriate levels of regionality to untangle the identified differences between districts while retaining the identified commonalities, in particular of common definition goals.
	This goes in-depth on the problems of definitions that remain to vague, as well why definitions must not be too specific without appropriate field testing
Communicating and using the PED definition on the ground	This chapter gives insights into the requirements and problems that the project stakeholders individually identify when dealing with the PED definition. This gives insights into the main pain points and threats to the implementation and adoption of PEDs as well as the perceived opportunities when using a PED concept on the ground

2: C4P PED Definition

The second part of this deliverable summarizes the formal PED definition as developed in the Cities4PEDs project:

Sub-Chapter	What's inside ?
Definition Goals and Requirements	1. The PED definition should support high quality implementations. 2. PED definition takes regional context and potentials into account. 3. The PED definition should cover all relevant phases but not set strict requirements for the process itself. 4. The PED definition should make PED projects comparable transnationally. 5. The PED definition focuses on the measurability of quantitative and qualitative targets. 6. The PED definition links district targets to regional/national targets. 7. PED definition enables the implementation in urban and rural areas. 8. The PED definition should allow some form of distinction between newly built and existing districts. 9. PED definition is neutral towards different technology and innovation levels. 10. PED definition takes regional context and potentials into account.
Common Definition Aspects	Positive Energy Balance System boundary includes: Operation and Plug loads of the Buildings, as well as mobility Weighting System: Nationally defined conversion factors (Energy End use, Primary Energy, Carbon) Balance Target includes context factors context factors climate, heritage, flexibility
Different and Open Definition Aspects	• Social and other qualitative Aspects (if and how to include them) • Weighting system: Which system should be used? • National definition of "onsite RES" • Quantification of Climate context factor • Quantification of Heritage context factor • Weighting Factors depicting grid-supportivness

3: Example Definition Operationalization and Assessment

The third section of this report is dedicated to showing how a theoretical framework can be used to draft a fully operational and assessable PED definition that achieves the previously identified practical goals and requirements. It is in the nature of this approach that this definition is targeting a single nation, in this example Austria. It also includes a comparative assessment of the three PED sites adhering to this definition.

This can be used as a blueprint to draft similar definitions with enough flexibility to account for national, regional and project specific contexts while still adhering to the same principles – an important feature, as will be discussed later.

4: Observations

Finally, main discussion points are summarized:

DISCUSSION	⌂ A common definition between projects satisfying all stakeholder needs is most likely not feasible ⌂ A common definition might only be necessary on a broad EU level without operationalization ⌂ Social and other qualitative aspects might be better defined and assessed by other means such as certifications, standards and city planning instruments

1 Definition Approach

The European Union wants to create 100 Positive Energy Districts (PEDs) by 2025 as part of its Strategic Energy Technology (SET) plan. The EU has set out a broad framework definition to describe what PEDs are:

"Positive Energy Districts are energy-efficient and energy-flexible urban areas 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 optimizing the livability of the urban environment in line with social, economic and environmental sustainability."

This gives a first idea of the objectives and the way in which such a PED can be realized. But in order to apply the definition, it is necessary to make the various aspects of it more concrete.

Cities4PEDs is one of the four research projects from the first JPI Urban Europe Pilot Call focusing on PEDs. The consortium consists of municipalities, experts, research institutions and civil society organizations from Brussels, Stockholm and Vienna. With this consortium we aim to contribute to a unified PED definition on a European level from the perspective of our own local contexts. As a consortium, we consider a PED as follows: it is the process of transformation or implementation of a district by means of instruments, tools, methods, collaborations, etc. towards ambitious objectives on the level of a positive energy balance, energy efficiency, energy flexibility, integration between systems and infrastructures, integration between users, livability, social sustainability, economic sustainability, environmental sustainability, etc. The definition is therefore twofold: it concerns both the process of transformation or implementation and the objectives themselves. In our research, we will examine both aspects. The methods, tools, instruments and collaborations needed to operationalize PEDs are investigated and structured in the PED Atlas, based on a series of cases. The objectives, criteria and targets are put central in this document.

The development of a common PED definition was undertaken in a collaborative process. Within work sessions with the whole consortium, an outline of the goals and relevant aspects were screened, discussed and sorted out. This was developed further by setting two different workgroups around two specific sides of the PED definition: the technical aspects and the process and social aspects. In this way it was possible to use everyone's expertise as efficiently as possible and have a more in-depth way of working on these specific aspects of the definition. In the technical deep dive sessions, it has been possible to start working on the nitty-gritty part of the definition, while other partners outlined how the definition could also include social dimensions and a step-by-step approach in becoming a PED enabling local processes of transformation. Newt to that, partners within our consortium joined the EU discussions and EU alignment task force on the PED definition. We harvested the resulting observations in this document.

1.1 Identify Goals and requirements of a PED definition

The PED idea can be interpreted and subsequently conceptualized in any number of ways. It then follows that the definition should cover all relevant aspects to that conceptualization.

With the definition development we started in the same way as in an actual district development: With the goals. The guiding question of the process was:

- What does the PED definition need to do?
- What do we want to achieve with it?
- What is it supposed to ensure, promote or prohibit?

Figure 1 Schematic approach of the development a PED definition in the Workshops (WP.2.2)

After clarifying that we can set out to develop a framework that delivers just that. As can be seen in chapter 2.1 however, the goals and requirements raised at the definition were quite extensive and heterogenous, to the point that it became infeasible and contradictory. For example, a definition required to include precise calculatory prescriptions can still be also designed in such a way that it is easy to communicate. But adding the requirements that the definition should also be attainable with similar effort in different climates and densities ban be unreconcilable. This can be illustrated with the following trilemma of common definition requirements: simplicity, determinism and achievability: Achieving 2 of 3 is straightforward, but all three simultaneously seems difficult.

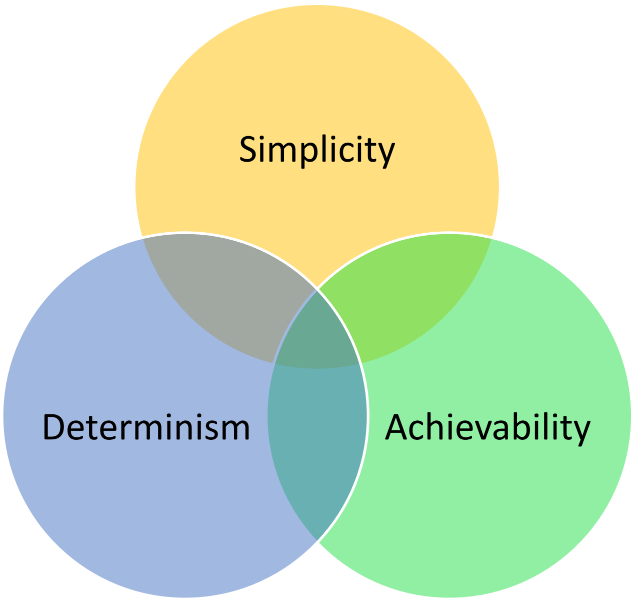


Figure 2 The PED Definition Trilemma: Simplicity, Determinism and Achievability

Table 1 Example PED definition framings for pairs of definition dimensions

Combination	Example Framing	Resulting Problem or Challenge
Simplicity + Determinism	"A PED has a Positive Energy Balance for its operation over a year"	Might not be achievable for dense urban districts compared to rural areas, very ambitious, but dense projects do not achieve this arbitrary balance
Simplicity + Achievability	Each district defines their own goals with their own process. "It's about the journey now, not the foggy destination"	No frame of reference for the existence and sufficiency of actual, quantifiable goals such as climate neutrality and necessary emission reductions lead to relative improvements while collectively failing
Achievability + Determinism	Rigorous technical definition of balance components with complex calculatory offsetting mechanisms (such as context factors) to quantify effort sharing on societal climate goals	Requires more models and assumptions that in turn need to be linked and calibrated. Not simple to communicate and requires more effort to operate

This constitutes a crucial problem of the PED definition: How to solve this Trilemma? Or, atleast, where do we position ourselves in this Venn diagram and why? What is possible? What is practicable?

1.2 Finding Common denominators between countries

In the development of WP2 Definition the consortium originally set out to find a common definition of what a PED actually is that the three demo cases in each city can adhere to. This process culminated in the observations and results on the ***purpose and goals of the definition***, which were also published as a distinct whitepaper.

However, it was gradually becoming clearer that a PED definition needed to accommodate the differences between the districts – both physical and temporal. To this end, a strictly common and unified definition was deemed either inadequate or outright impossible to devise without concrete examples of operationalization. Instead, it was accepted and anticipated that *PEDs would possibly need different definitions in different contexts.*

1.2.1 Commonalities

The first step, then, was to identify the commonalities between these contexts present in the C4P project:

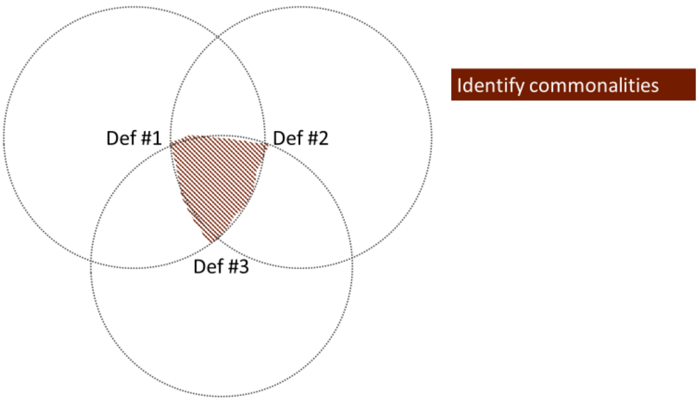


Figure 3 Different PED Definitions can have commonalities but also diverging aspects

These commonalities would form the core of the C4P Common Definition and included the determination of the following

- Key Performance Indicators
- Included Energy services

Also, among the consortium, several indicators on a technical level were brought forward as relevant, among which: (i) energy demand and consumption, (ii) renewable energy sources local production, and (iii) GHG emission reductions. During the discussions with the Brussels partners regarding the social and organizational indicators, the ones brought forward as most relevant are: (i) stakeholder engagement/co-ownership, (ii) funding instruments, (iii) financial impact on the inhabitants (which was not initially in the catalogue), (iv) improved quality of life (which was not initially in the catalogue).

1.2.2 Differences

At this stage it has become clear that there are sizeable national differences that would need to be addressed in the definition, but independently. The main areas of these differences include but are not limited to:

- Norms and Standards regarding Calculation of KPIs such as Energy End Use, Primary Energy Balance, GHG Emission Balance
- Energy and Emission Conversion Factors: Allocation and accounting schemes have a great impact on the resulting balance, but vary significantly as they reflect different political agendas and landscapes
- Impact of climate in the forms of heating demand, available solar radiation for renewable generation, etc.
- Types and quality of established instruments on
    - Spatial Energy Planning on a district scale
    - District development process criteria (e.g. through building code or certifications)
    - Qualitative criteria (e.g. through certifications, labels, municipal planning, etc)

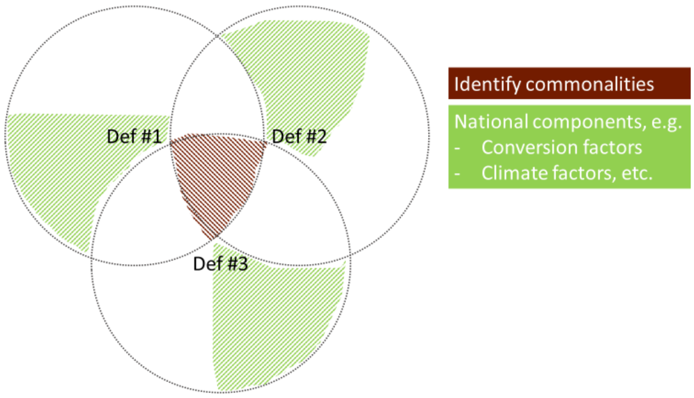


Figure 4 National definition differences are caused by national differences in operationalization and gaps in existing tools

On top of these national differences, there is a further layer that distinguishes regional and municipal differences that might require different definition considerations:

- Connection / compatibility with city instruments / processes and targets on emissions, participation, affordability, etc.

These can also result in individual aspects only relevant to a certain project.

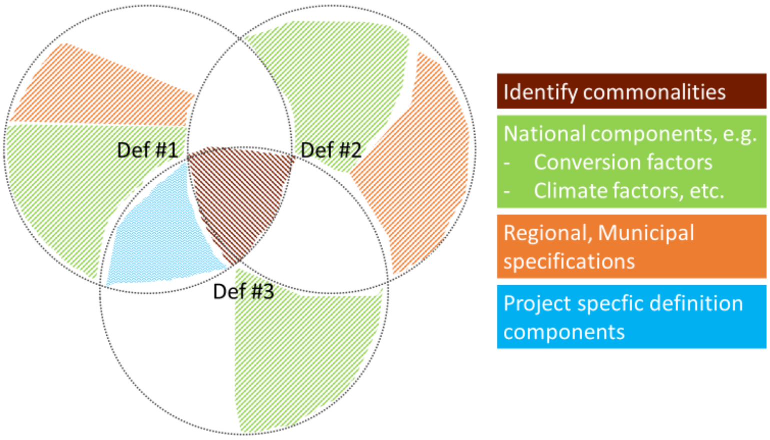


Figure 5 Definition aspects can include common (brown), national (green), municipal/regional (green) and project specific (blue) aspects

As the goals and motivations behind the usage of PEDs vary between stakeholders of different background, so does their requirements for the content and form of various definition aspects, again in terms of simplicity, determinism and achievability. This also means that when talking about the "PED definition" we are actually talking about definitions on at least four different levels: A definition that holds for all PEDs in Europe, one that defines all PEDs of a Member State, a region or municipality and finally a level of definition only applicable to a specific district.

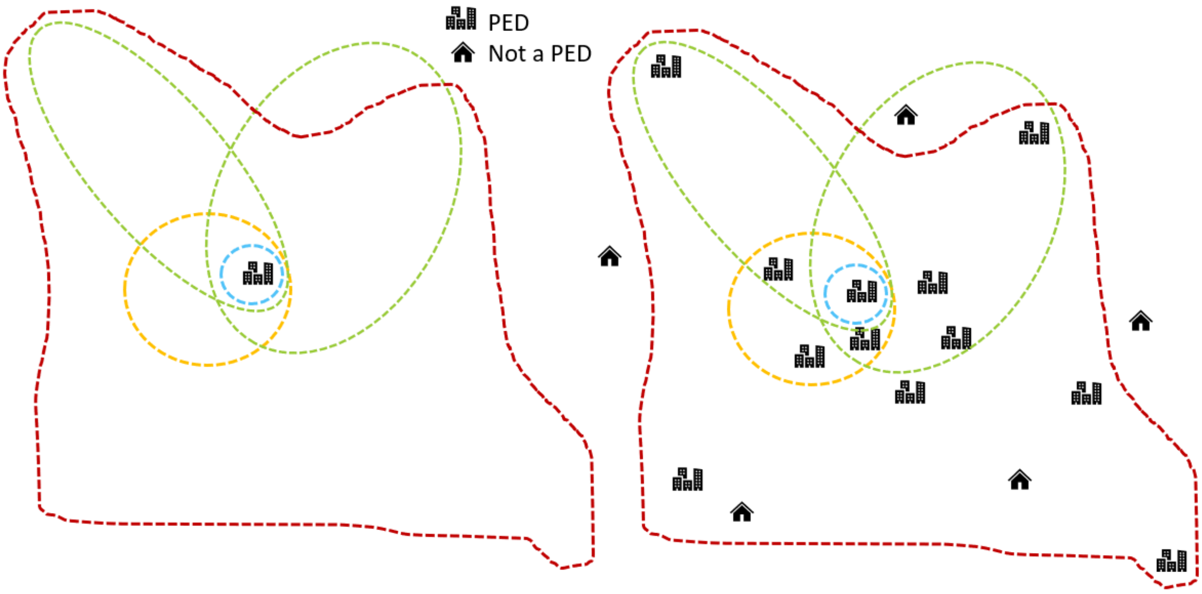


Figure 6 PEDs and other districts separated by various definitions (dashed lines)

The above figure shows dashed lines representing different possible definitions. The Icons represent districts that should or should not be considered PED. This further depends on who you ask. And explains why different definitions cover different districts as they are typically tailored to them: A single district can of course adhere to and fulfil different yet intersecting definitions. But as the number of districts that a definition should cover grows, so does the aforementioned trilemma of simplicity, achievability and determinism. The above schema illustrates this: The dashed lines represent possible definition designs. Their simplicity can be described as their "roundness", their achievability as their area (as it is more achievable to be inside a larger enclosed space) and their determinism by how many non-PEDs can be found within "by accident". With a single District it can be very straight forward to design a suitable definition. But as the number of districts that should fit within the definition grows, the trilemma becomes visible. But it also hints at a possible solution: Just use more than one definition to account for the different definition needs at an appropriate place.

Note how this is different from saying: "Every PED designs their own definition themselves". This *can* be a part of a definition, but it will not be the *only* one; there will also be other definitions on European and most importantly national and municipal level, that the PED needs to adhere to. This means splitting the definition into four different definitions of increasing determinism, complexity and regionality, that each district need to fulfil simultaneously: *European*, *National*, *Municipal/Regional* and *Project Specific*. This allows for a minimal common denominator between all European PEDs while still ensuring that more localized requirements can be detailed, assessed and enforced.

1.3 Splitting the Definition into three regimes of Regionality: EU, National and Local

It becomes apparent that the struggle towards a PED definition is rooted in the apparent divergence of two if its main goals: uniformity and locality which leads to problems when designing a common definition:

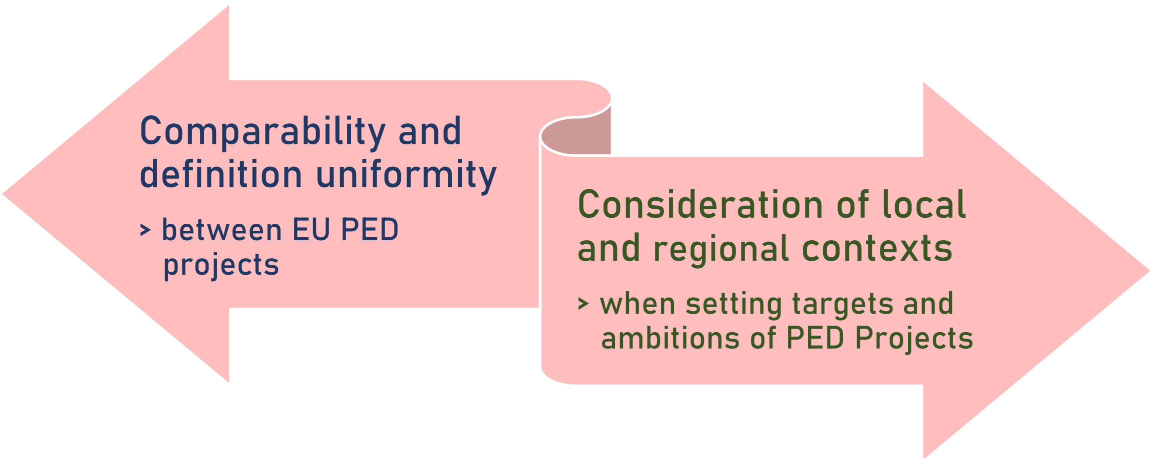


Figure 7 The divergence between two main goals: Uniformity and Locality

Analysis of the definition process within the project as well as in exchange with the other JPI UE projects furthermore showed that the results of the definition efforts are arbitrary to the extent as to which stakeholders and perspectives are most well represent. What a PED is, will always be a matter of interpretation, but it remains to be decided for *whose interpretation* that is.

In C4P we try to avert this "di/trilemma" by looking at all definition aspects that have been raised and try to compartmentalize them into different groups of regionality, that seem most suited to define this particular aspect with sufficient accuracy and detail. This means that we spread the definition aspects across multiple layers of different size from individual project level all the way to a pan-European level. The *definition items* and *aspects* can then be addressed to varying depth on different levels. This is an attempt at adding nuance to the current dichotomy between the definitions encompassing all EU PED projects[1] which must be very general in nature and project specific definitions that are partly operationalized in great detail, but can typically not be generalized beyond its specific project context. To

[1] Such as the attempt from JPI UE

put it more concretely: The proposed definition is divided into different *aspects* which in turn are defined to increasing degree of concreteness at every level from European to national to regional to municipal to project specific.

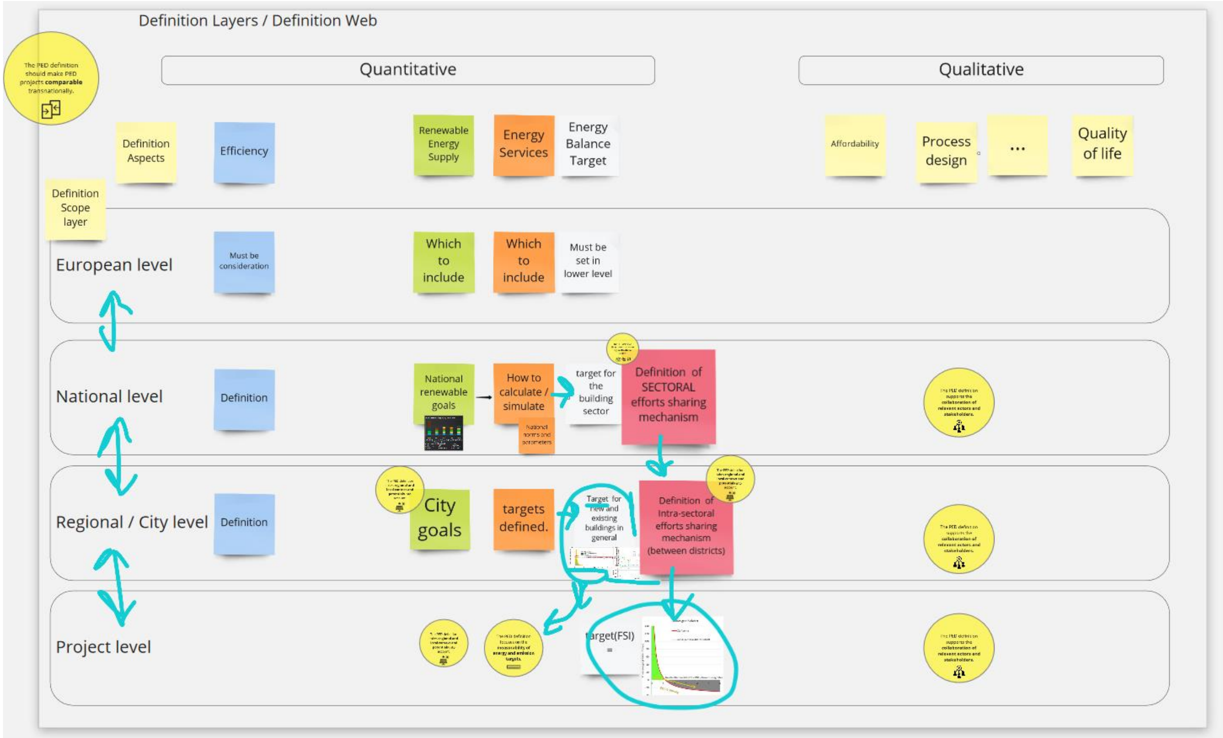


Figure 8 Schematic of definition aspects and "context factors" being defined at different levels

A consequence of this is that at each level the definition content and detail changes: From vague mission statement and intent at the European level to operationalized standardization scheme on a national level to a monitorable and communicable implementation plan on project level.

The advantage of this approach that it allows *for as much cohesion as possible* by pulling every aspect that turns out as common between projects as high up as the European level as necessary. And at the same time allows for *as much context flexibility as necessary* as projects seem fit to implement their local PEDs.

It also is clear that the mediation of national stakeholders such as funding agencies and standardization bodies is required to separate the PED definition aspects into nationally common and project individual aspects. It is ultimately up to them to decide how open or narrow the definition should be developed in the respective country.

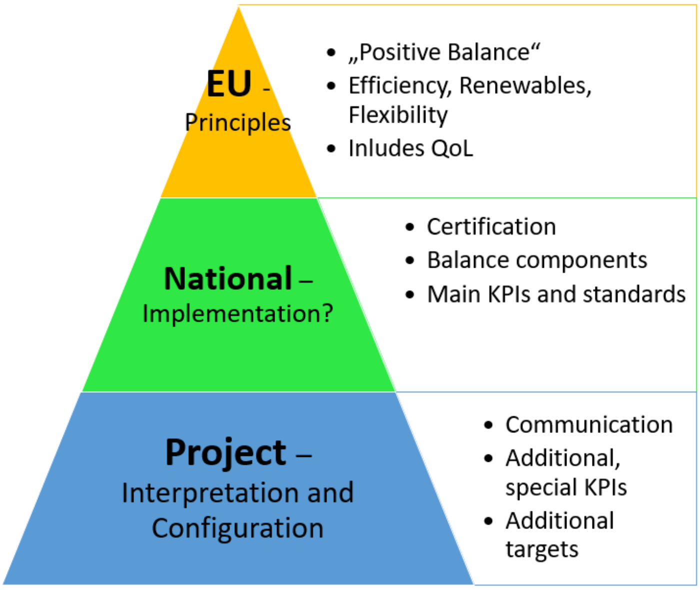


Figure 9 Definition aspects split into three layers of regionality

This becomes necessary due to different adjustment requirements of PEDs in different countries, cities and districts to ensure feasibility in different *densities, heritages and climates.* It is however important to decide which level is responsible for which context factors.

Example: A urban density context factor should be defined at national or regional level, but not uniformly at EU level to allow for country building density differences (e.g. Sweden vs Belgium), and also not on district level to avoid "cherry picking". If e.g. Urban Density context factor definition is indeed decided to be national responsibility, every country could employ their own suitable method of calculation their factor, including *not* using it at all. However, Regions / Cities and Districts would not be allowed to define their own context factors anymore.

1.4 Communicating and using the PED definition on the ground

There is a divide between the concerted efforts for definition development that adheres to as many goals and requirements on the one hand, and on the other hand being manageable and communicable, or just plain useful, for the actors involved at the ground, actually implementing said PEDs. Their requirements to the definition are much more focused on practicability, assessability and communicability. The following table gives a broad cluster of needs and their most likely associated stakeholders:

Table 2 Main definition requirements

Definition Requirement	Important for Stakeholder
Scientific rigidity	Scientific community, Practitioners
Certifiability	Project Developers, Administrations
Achievability	Project Developers, Governmental Bodies, Practitioners
Comparability	Transnational and national stakeholders: JPI UE, European Union, Researchers
Comprehensibility	Governing bodies, project developers, users

Since a PED definition needs to satisfy all requirements, it is paramount to fully understand them: where they originate, what their purpose is and if and how they can be compartmentalized into different regimes of responsibility. The following results therefore show the consortium's own perception on key questions regarding the usefulness of the PED concept and the PED definition at the last half year of the project.

Table 3 Reflection Questions on the PED Concept and the PED Definition from the Perspective of the C4P stakeholders

Area	Question	Purpose
PED Concept	**How or why is it useful to you?**	This shows, what the goals and possibilities of the PED concept are, maybe already partly realised. It also aims to identify the perceived *requirements* for its usefulness
	Threats to usefulness	The last two questions can be seen as somewhat complementary. The difference in threat perception and usefulness requirements can be seen in the relative risk of it failing. Greater focus is therefore warranted for the threats instead of the more easily attainable requirements
	Biggest Pains in use	The last two questions can be seen as somewhat complementary. The difference in threat perception and usefulness requirements can be seen in the relative risk of it failing. Greater focus is therefore warranted for the threats instead of the more easily attainable requirements
PED Definition	Requirements and reasons behind them	Get a better understanding of the importance and purposes behind the definition requirements

The questions were posed in an mutual interview setting with 24 responses from the expert fields of the C4P consortium. The following word cloud gives a qualitative impression of the present occupations and roles:

Figure 10 Background and Role of the C4P stakeholder participants in the reflective interview [2]

The following sections summarize the answers and insights into the posed questions:

[2] larger words have been named more often

1.4.1 Usefulness of the PED concept

The first question was split into two possible answers, that indicate the usefulness ("because…") and requirements ("if…"). As can be seen in the following graph, the usefulness of the PED is perceived to lie in two distinct fields: The communication of various PED aspects and the promotion of certain key activities and goals:

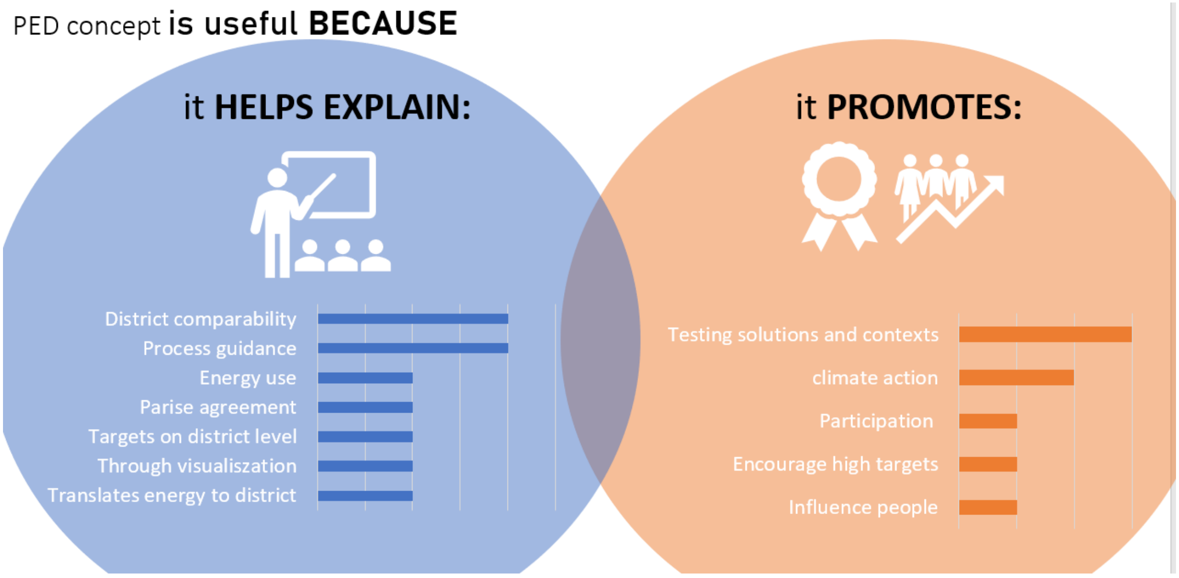


Figure 11 The two main uses of the PED concept in the eyes of the C4P consortium

1.4.2 Requirements to the usefulness of PED concepts

A reflection on the requirements for the PED concept itself – independently of the question of a PED definition – yields interesting results. As the figure below illustraties, the answers can be clustered in 4 general areas of requirements to the PED concept:

1. First are **specific goals**
2. Requirements to the **PED targets** themselves
3. **Standardization** and (inter)national recognition
4. **Communicability** to important facilitating stakeholders

Figure 12 Requirements for the PED concept in the eyes of the C4P consortium

Interestingly, there is a strong sense that the PED concept itself is not useful without simple, concrete and concise, yet attainable targets.

1.4.3 Usefulness of the PED definition

Usefulness of the PED definition can be divided into two main categories: The description of what a definition *is* and what the definition *has* to be useful, which can be roughly seen as definition *attributes* and definition *requirements* respectively:

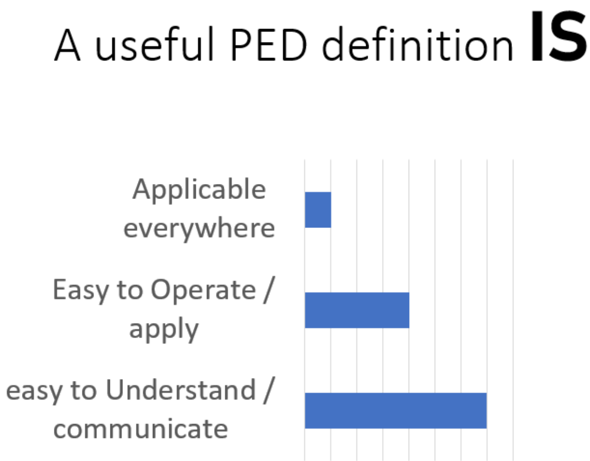


Figure 13 Main Attributes of a useful PED Definition n the eyes of the C4P consortium

Here it can be seen that the main focus of the involved practitioners is a*pplicability* and *communicability*. This shows a rather cohesive outlook on the definition. When it comes to the requirements and attributes a definition should *have*, there is more diversity but nonetheless a clear picture.

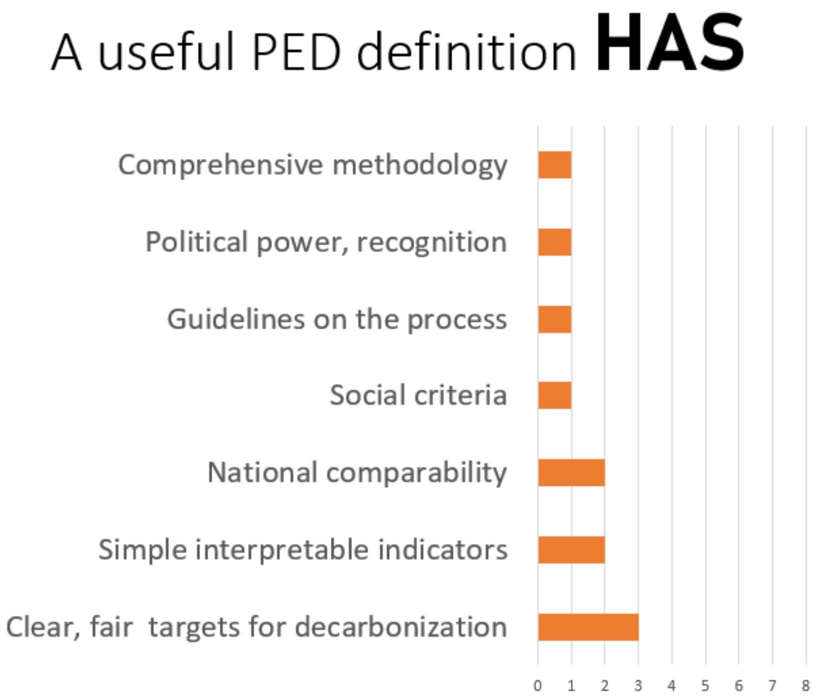


Figure 14 Main Requirements of a useful PED Definition n the eyes of the C4P consortium

What is interesting here is in particular what does not show up: Note that from the practitioners view, the definition does not necessarily has transnationally common features. It does not have unified specifications on system boundaries, energy balancing systems or the like. Although this is not particularly surprising, it is important to keep in mind that local stakeholders have very different requirements and from transnationally and nationally operating actors. The PED definition needs to be able to reflect and address these different needs.

1.4.4 Threats to the PED Concepts

The last two questions of the interview can be seen as inverts of the questions before. It is intended to identify the biggest threats and most pressing concerns, that should be addressed moving forward:

Figure 15 Main Threats to the PED concept in the eyes of the C4P consortium

The risks to loosing support for the PED concept are seen in several different areas, such as *lacking ambition*, but at the same time lacking *general achievability*. These can potentially be diverging, if not opposing threats, similar to the *lacking speed of the definition process* and the *lacking clarity, precision*. Ultimately, this snapshot is reflective of the diverse group of stakeholders and their diverging interests with the PED concept in the C4P consortium.

When it comes to the greatest perceived pains with PEDs currently, the majority of stakeholders identify two main aches:

1. The Vagueness of the PED concept and the amount of undefined parts and
2. That they don't understand what a PED exactly is themselves.

Some of the other mentioned pains can also be seen as more concrete or symptomatic pains rooted in one of the above causes:

Figure 16 Main Pain points of working with the PED concept in the eyes of the C4P consortium

Despite their statistical insignificance, these results nonetheless give insight of how key people involved with PEDs feel about the most pressing issues: It is probably safe to subsume that this research design setting bringing together experts and stakeholders from all areas of PED research, implementation and support is not equipped to adequately address the definition question by themselves.

As pointed out before, it becomes transparent how different stakeholders value different properties of PEDs for a variety of reasons. This carries over to their perceived PED definition requirements – which diversify quite extensively as a consequence. This is a rather remarkable observation, given that it could be argued that many concept benefits could be obtained without having to explicitly define them. Many of the perceived benefits of the PED concept of communicating and mobilizing ambitious projects for example would arguably be still valid, if the definition was not easy to operate or communicate, but the concept still was, as they are two different domains with different stakeholders involved. Instead, the fact that the PED concept and the PED definition are seen in this close interlink could possibly have more to do with the questionnaire setting putting them in proximity in the first place. That, and the fact that everybody in the project team was questioned on the topic of the PED definition, regardless of whether their role would actually put them in contact with it or not. This further highlights two important unanswered questions:

Which stakeholders are exposed to which part of a PED definition?

> Who is responsible for designing the interfaces between different parts of a PED definition?

This could be connected to another perceived missing key: This are stakeholders that have a mandate to define the legal frameworks such as municipal and national building codes. Such an authority was felt missing in addressing all PED definition requirements in their entirety.

2 Commonalities in PED Definition of the C4P Partners

The following chapter describes the commonalities and consensus on common goals and aspects of a PED definition. A common operationalization is not part of this picture, but an example operationalization that adheres to these principles can be found in the later chapter 3. The extent – or rather the lack thereof – of concrete definition aspects and how they are to be operationalized in three different countries and cities is a testament first and foremost to the differences of the district themselves and the purpose the PED concept is envisaged to play in their development. It is perhaps one of the most important insights of this project, that they cannot yield unified and operationalizable definitions across a wide range of district applications. Even though the need for such a definition from the practitioner's side – as shown in chapter 1.3. is undeniable, the focus of the C4P research project was in exchange rather than unification. This is also indicative of the call structure with a limited number of demo cases comparing and exchanging results and methods.

As such, the obtained definition is lacking and too vague for some and too tight and irrelevant for others. Nevertheless, it underpins the common ground of understanding and ambition, and hints at possible implementation solutions down the line, that – nevertheless – have to be developed in a more thorough - and most likely nationally individual – process.

Table 4 Overview of common definition Aspects and design decision

Definition aspects	Design decision	Unit
Spatial balance boundary	Geographical district boundary	
Temporal balance boundary	Annual balance	
Functional System boundary	See below	
Indicators	**Total primary energy balance**	[kWh/m²a]
	Green house gas emissions	[kg/m²a]
	Life cycle differential costs	[€/m²30a]
Energy Balance Target (over spatial and temporal system boundary)	**Positive**	
Context factors to be included in the Energy Balance	No common design decision, to be decided individually per PED Site / Country	

2.1 Definition Goals

The question we start with is: why do we need a more concrete definition? In the end, every contribution made to the energy transition is a step in the right direction, and it is up to each country or city to draw the lines for such a policy. Then, why is it necessary to set criteria that are the same for the whole of Europe? From the perspective of city administrations and politics, the need for such a unified definition is underlined. In fact, it will be a tool that allows and pushes for high-quality implementations at the district level and serves as a lever for capacity building by including indications on the development process and a defined step-by step approach.

At the same time, and because it is a Europewide definition, it should make PED projects comparable transnationally. It therefore allows for the measurability of the set targets, and further for the connection of district targets to the supra-local (regional and rational) targets. Coming from different geographical backgrounds, and not wanting to exclude PEDs based on their location, the definition should be applicable in different types of areas, such as urban and rural areas, and existing as well as newly built areas. In order to achieve this, it is important that the definition enables the collaboration of relevant actors and stakeholders to have a broadly supported PED with more chances of success, and covers all relevant phases of a PED development, from setting up the process until after realization.

2.1.1 Common Criteria

The following illustration shows the ten main goals or criteria identified for the C4P common definition. They illustrate core concerns of the consortium and were later refined into a whitepaper on common goals of a definition, which is available as a separate deliverable.

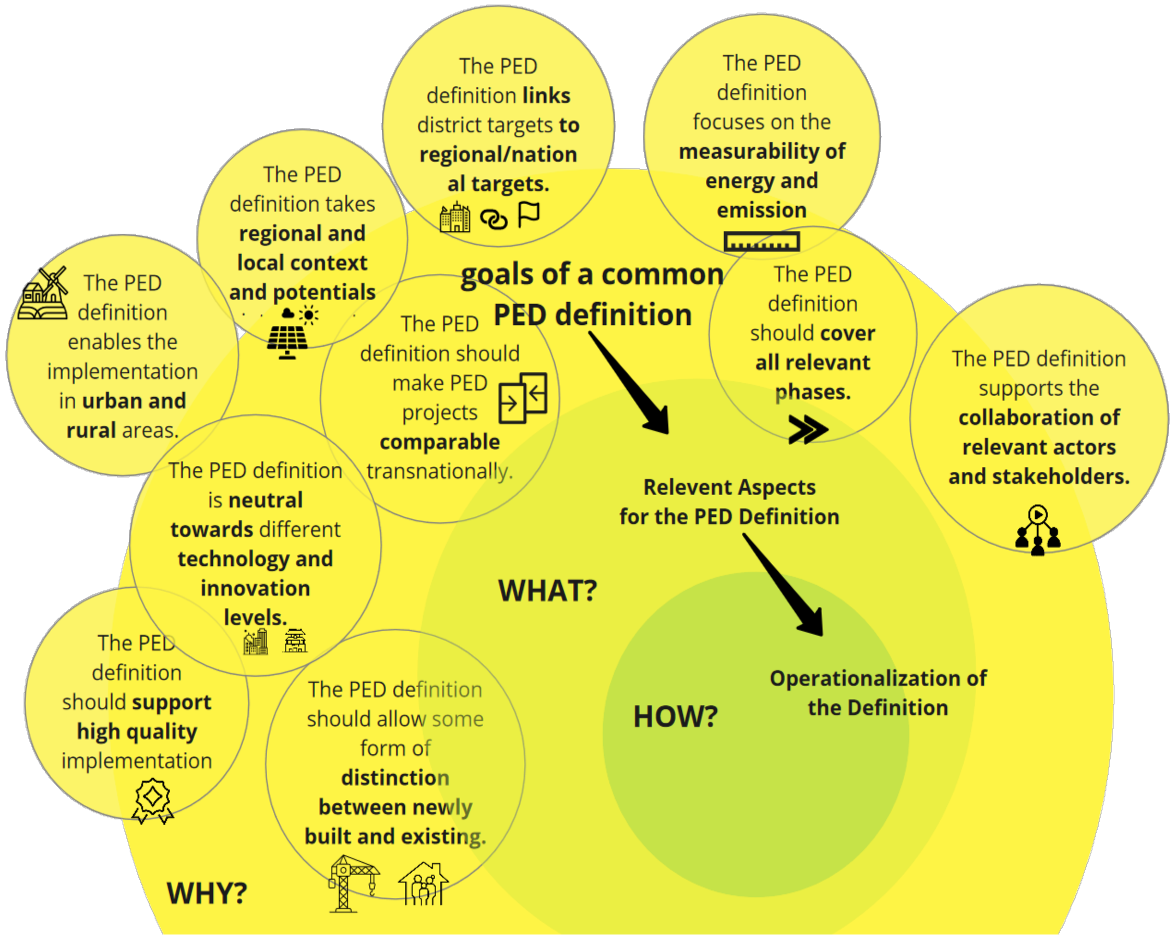


Figure 17 Main Goals and Criteria for the PED definition from the perspective of the C4P consortium

Based on this preliminary identification of PED definition goals, the following five goals were agreed to be most important to the Cities4PEDs consortium at large:

The PED definition should allow and push for high quality implementations.

The more sharply defined criteria for a PED should allow districts to push for high quality transformations and developments. In order to achieve the ambitious targets by 2025, 2030 and 2050, our districts will have to meet far-reaching requirements. The PED criteria provide a framework for cities and their partners to make this quality measurable. On this basis, cities and others can award a PED label and encourage PEDs financially, legally, etc.

The PED definition should translate national or regional goals to a district level

The framework of PEDs will allow the translation of European, national and regional targets into measurable objectives at the district level, which will then lead to a feasible project scale. In this way, the often vague, large-scale objectives are broken down into achievable projects. The criteria should therefore take into account the specific national or regional objectives.

The PED definition should make PED projects comparable transnationally.

One of the main reasons for a shared definition on an EU scale is that local, context-specific aspects of districts can be compared. We can measure whether districts perform high in comparison to each other, but also this can allow to build a basis for exchange at the European levels on learning and success factors around the PEDs implantation, initiating process of acceleration. To do so in a meaningful way, we need to go beyond a "one-size-fits-all" approach.

The PED definition should make PED projects in different contexts comparable

It is very difficult to compare the development of districts in different contexts. In rural areas, for instance, much more open space is available for energy production via wind, whereas in inner-city districts, more energy is needed and far fewer options exist. The shared criteria for a PED definition would allow the deployment of these different contexts to be compared in a meaningful way

The PED definition should enable cities and stakeholders to initiate and engage in the cooperation towards PEDs

A shared PED definition can also be very mobilizing towards a broad group of stakeholders. A European definition provides a framework for a process of cooperation and stimulates local commitment. It is a recognition that can attract different actors to participate and it gives the process a degree of credibility.

Definition Non-Goals

Non-goals were not identified and collected in a structured way, but a number of concerns and non-goals popped up from various stakeholders such as:

- Unified Definition – is it necessary or desired? And if so which parts are unified?
- Economic considerations

2.2 Common Definition Aspects

Based on the above-mentioned definition goals, the consensus was to define a PED through the achievement of a positive energy balance. The following common determinations regarding system boundaries and considered energy services have been made:

2.2.1 Considered Energy services

The energy demand for room conditioning (heating and cooling), domestic hot water, lighting and building services as well as the energy demand for living, working and services (e.g. appliances, computers) are taken into account in the PED definition.

Table 5 Considered energy services in different boundary definition with related assessment. The energy balance calculations is carried out in hourly steps.

	Energy services		Possible assessment method
Building Operation	Heating	✓	Dynamic building simulation methods, stationary monthly methods, or forecasting methods
	Cooling	✓	
	De-/humidification	✓	
	Ventilation	✓	
	Auxiliary power for heating system	✓	
	General electricity & elevators	✓	
	Lighting	✓	
Industrial Operation	Process heating	×	Not included, as energy is used to serve a wider range than the district itself and should therefore also share the burden of energy supply
	Process cooling	×	
	Electricity demand for production	×	
	Electricity demand for general building use and services	✓	Hourly load profiles are needed

2.2.2 System Boundary

Within Cities4PEDs the *functional system boundary* was decided on district Operation and user electricity aka plug loads. There was agreement to *not* include the embodied energy and emissions in the functional system boundary for two main reasons:

- Required effort for LCA assessments
- The notion, that balance could not be positive when including embodied energy. (This could be addressed with appropriate context factors, as exemplified in (Schneider et al., 2023)[3])

[3] S. Schneider, T. Zelger, D. Sengl, und J. Baptista, „A Quantitative Positive Energy District Definition with Contextual Targets", *Buildings*, Bd. 13, Nr. 5, Art. Nr. 5, Mai 2023, 10.3390/buildings13051210.

For the *spatial boundary* we propose geographical boundary of the district up to building height and down to 300 m below the ground. This is a rather arbitrary distinction and should not make or break the system. In fact, it is of lesser concern than defining the functional system boundary, and can therefore be left for individual project definition.

One important rule however should be that drawing the *geographical system boundaries* must not make it harder for other districts to later also become a PED ("Gerrymandering")

2.3 Existing Definitions: Are they suitable?

In an effort to find suitable definition approaches for the identified definition design goals, a broad literature review was conducted. The focus was to cluster and compare different PED definition approaches along the following characteristics:

Table 6 Description of analyzed characteristics of PED definitions found in literature

Characteristic	Description
Definition Designation	Name of the definition / concept
Focus and Approach	Interpretation of the main focus compared to the other identified methods
Target/Indicators	Which and how many KPIs are used?
Target Values Characteristics	Are there sufficiency requirements or targets defined for the KPIs in use and if so for which KPIs and which targets?
Ambition Control	How does the definition deal with differently challenging situations, how can a district modulate or even choose its ambition level?
Energy Services in Balance	Which energy services such as building operation, user plug loads, mobility and even embodied energy for construction and maitenance are included in the assessment of the energy balance
System boundary used / defined	How is the system boundary for the energy flows defined? (Physical functional or vitual, or other
Target calculation methods	Is there a calculation methodology for energy balance targets defined?
Temporal resolution	Is there a specific temporal resolution or aggregation period defined, such as hourly, monthly or annualy for modelling accuracy and resolution of flexibility and other timedependent grid interactions
Analysis period	Which period is used for balancing

The results are shown in Figure 18. In a second step, the identified PED definitions were compared with the previously identified PED definition design goals and requirements of the Cities4PEDs consortium. This analysis is presented in Figure 19. It shows that some definition goals can readily be met with most definitions, but there are a number of goals that can hardly be satisfied by any existing definition. The most challenging goals are:

- "The PED definition should make PED projects comparable transnationally": Most definitions do not consider context specifics such as climate or density when setting the target of a positive energy balance. As a consequence, districts of different location and density can achieve a positive balance with very different ambition levels, this making the projects incomparable transnationally from an action and ambition perspective (rather than that of a nominally positive balance).
- "The PED definition links district targets to regional/national targets": This definition requirement is not readily satisfied in any definition except the one specifically designed for it (Schneider et al., 2023)

Figure 18 Characterization of PED definitions found in literature

Figure 19 Compatibility of PED definitions found in literature with the identified PED definition goals and requirements in Cities4PEDs

Table 7 Investigated PED Definitions

	Definition	References
0	JPI Urban Europe Framework Definition	(JPI Urban Europe, 2019)
1	Syn.IKIA	(Salom and Tamm, 2020)
2	Making Cities	(Gabaldón Moreno et al., 2021)
3	ZEN Norway	(Fufa et al., 2016; Wiik et al., 2019, 2018)
4	IEA EBC Energy Positive Neighbourhoods	(Hedman et al., 2021)
5	PED Switzerland	(U. Nyffenegger, 2018)
6	Zukunftsquartier Austria	(Schneider et al., 2023, 2019a; Schöfmann et al., 2020)
8	EU JRC PED	(European Commission. Joint Research Centre., 2020)
9	CityXChange	(Dahlen et al., 2020)

2.4 Differing and Open definition aspects

The following aspects were also identified as relevant criteria to be dealt with in the definition in one way or another. For these, however, there was consensus found on how it should be included in a uniform definition, with a certain level of ambiguity or incoherence remaining. Nevertheless, these aspects can be addressed and operationalized, as exemplified in the last chapter, but it might not be purposeful to try and solve this uniformly across Europe.

The PED definition should cover all relevant phases but not set strict requirements for the process itself.

It remained unclear how this could be satisfied, since "relevant phases" varies between green- and brownfield development, and even between green field developments in different settings such as urban or rural developments. It was also not clear who would be responsible in enforcing or monitoring the adherence to a PED definition in different phases of district development and if district developers or their could or should be held accountable for violations.

This possibly hints at a mix-up between requirements of the PED definition and the PED implementation itself. It might be easier to have the PED definition include that their IMPLEMENTATION CONCEPT should cover all relevant phases without the definition explicitly prescribing the process itself.

The PED definition focuses on the measurability of quantitative and qualitative targets.

This was not uniformly shared. As laid out in the previous chapter, focusing on getting the quantitative targets a specific meaning in a municipal, regional and national context can be seen as one of the great opportunities of the PED concept. In practice this is not necessarily the core concern of many involved stakeholders and as such this aspect also receives little support by some.

PED definition enables the implementation in urban and rural areas.

As the stakeholders in the C4P project all come from cities, the feasibility in rural areas did not receive great consideration and did not have any particular advocates.

The PED definition should allow some form of distinction between newly built and existing districts.

This was widely accepted as requirement, but unclear as to how this could be solved in a unified way across the participating countries and cities. Again, a way forward would be to uphold the requirement, but reduce its uniformity to a national level, e.g. by different MS adopting different context factors for vintage or heritage, that reflect the composition of their building sector and the relative targets of the groups within it.

PED definition is neutral towards different technology and innovation levels.

Again, this aspect was agreed upon but not operationalized due to the differences in the participating cities. To satisfy this requirement however, a PED definition must simply not make specifications technologies or innovations required or prohibited.

3 Example PED Definition and assessments

This chapter has two parts: The first is addressing the principles of using a positive energy balance as a sole definition criterion for PEDs and introducing its conception primarily as a design question. It theoretically introduces "context factors" as a way of allocating an external, possibly national effort-sharing scheme into the energy balance requirements of a PED to ensure feasibility in the desired urban contexts.

Second, this quantitative definition approach is exemplified by exercising it on the three districts of the Cities4PEDs project: The Stockholm Royal Seaport, the Brussels North district and the Vienna Seestadt Aspern.

3.1 How to Use a Positive Energy balance to assess the main PED goals of energy efficiency, flexibility and local renewable production

Even though many different definition and assessment frameworks have been put out over the last few years ((Ala-Juusela et al., 2016; Alpagut et al., 2019; Civiero et al., 2021; Gabaldón Moreno et al., 2021; JPI Urban Europe, 2019; Koutra et al., 2018; Marszal et al., 2011; Salom and Tamm, 2020; Schneider et al., 2019b; Wiik et al., 2018), it is widely accepted that at the core of a PED is the sufficiency criterium of a positive energy balance. This is widely regarded as the common ground and smallest denominator of the PED idea. Subsequently though, expectations and approaches quickly diverge amongst participants:

The positivity condition is simple to state, yet hard to specify.

A basic principle in science is that a measurement consists of two parts: One, a precise definition of the quantity being measured and second, the measurement result itself. Obviously, measurement results are only useful if the quantity being measured is controllably invariant and different measurements can be taken on the same quantity, making it comparable and possible to check the validity of the measuring process. Once this process is established, then and only then can there also be meaning to a *threshold* of the measurement.

A zero positive energy balance is such a threshold: namely on the measurement of the energy balance of a district. Contrary to other well-defined metrics such as heating demand or energy end use however, this is not clearly defined: It is like saying, something on a scale should weigh no more than zero kilograms without specifying which items the weighing needs to include, and the balloons and items representing the onsite renewable energy supply and the accountable energy demands and services in the district respectively).

It is therefore insufficient to assess that PEDs "achieve a positive energy balance". What that really means is that one of many different possibilities to draw the system boundaries has a positive energy balance. This is important, because it means that it is in principle arbitrarily achievable to reach a positive energy balance by using appropriate system boundaries, inclusions and exclusions from the balance. In practice this enables projects to "achieve a positive energy balance", but only covering heating and cooling energy demands while other include mobility demands except flights or including purchasable offsite renewable generation credits, etc. The ambition of these projects and whether are in line with their embedding climate goals cannot be derived in general terms but for each project specifically at most.

This does not mean that these project approaches are not valid, not ambitious or flawed in any way: They simply reflect local conditions in the aspiration to adhere to the PED principles of having a "positive effect" on the surrounding energy system. They can in fact be very ambitious, but these achievements can hardly be put in perspective due to the lack of comparability and assessment standardization.

There is no one to blame for this either: In the absence of a recognized standard definition, projects currently do not have a choice but to creatively draw their own system boundaries to fulfil an arbitrary condition of "something must be > 0" so as to adhere to the overarching PED concept.

On the other hand, definitions with rigorous assessment standards and detailed operationalizations - as required by practitioners - that could in theory provide comparability suffer from a trade-off of different nature: Either they are tailored to a specific situation that is only applicable to a small subset of possible districts of a certain characteristic and fail to request achievable results in other cases. Or if they aim to include a broad variety of districts, the methodology needs to ensure their achievability over a wide range of configurations, which means that the calculations need to depict that with various edge cases and generally become more convoluted. With this in mind, the question of PED definition transforms into a whole other question:

- Which districts should be able to achieve adherence to a PED definition?
- Is it just very ambitious individual lighthouse projects or
- should the definition be a framework that most of the building sector can aspire to?

The argument can be made either way, but the main feature will arguably feasibility: A definition framework can adopt multiple layers of goalposts, targets, or levels of achievement for different groups of districts.

3.1.1 Possible Approaches

Approaches to defining Positive Energy Districts can be distinguished based on two key characteristics:

- Whether quantitative target values are used for definition or not and
- how the derivation of these target values is carried out methodically (bottom-up project-specific or top-down across projects).

As (Shnapp et al., 2020) elaborates, there are the following methodological options to determine target values for a district:

- Derivation from monitoring and measurement data relative to a baseline
- Derivation from target values of reference buildings.
- Determination by means of modelling and simulation of corresponding district energy systems
    - Either with static energy balance targets greater zero or
    - Dynamic targets based on additional typological parameters

But independent of the methodological approach of determining and arriving at a target for the PED energy balance, there is an arguably more fundamental distinction between different sets of PED targets or criteria. PED definitions often employ both simultaneously.

Table 8 Types of PED assessment targets / criteria

Criterion	Interpretation	Example in the context of the definition of Positive Energy Districts
Sufficiency	➔ A concrete goal **must** be achieved. Positive energy balance	⌂ Positive energy balance ⌂ Positive emission balance
Maximization	➔ Shall be achieved as far as possible ➔ Shall be maximized	⌂ As much local renewable generation as possible ⌂ As much energy efficiency as possible ⌂ As much energy flexibility as possible ⌂ As low cost of living as possible ⌂ As high quality of life as possible

The key difference between these two types of criteria is mainly that only the first, i.e. sufficiency criteria, can distinguish different groups, such as the group of "plus-energy districts" and that of non-plus-energy districts through verifiable quantification.

Is that even the goal? Many approaches take a different path and interpret the quantification criteria of a PED according to what is technically and economically feasible and goes beyond the existing state of the art. These approaches can be characterized by focusing on the development process of the PED and individually suitable criteria themselves. This is certainly more accessible to a wide range of districts and particularly helpful for districts where there is a lack of focus and instruments to address the development and planning process of a district itself.

However, it can be argued that the greatest opportunity of the Positive Energy District concept is precisely that the definition already implies a quantifiable balance target and since targets may be aimed towards a goal, PED targets could be interpreted to *quantify the contribution to climate neutrality*. This important point is often not considered in the development and discussion of possible draft definitions, so it should be explicitly pointed out again here. The opportunity lies not only in a uniform framework for certifying greater quality of buildings and renovations in the European Union, but also in the quantification of the sufficiency of climate neutrality of districts. The claim should be to define as generally valid as possible, and as concretely as necessary.

Regardless, to form any definition framework the following questions must be answered:

- Which criteria are considered?
- Are they "sufficiency criteria" or "maximization criteria" or neither?
- How is the evaluation method of the criteria determined in order to assess the fulfilment of sufficiency or the quantification of maximization?
- And for sufficiency criteria: How is the target value at which "sufficiency" is achieved determined?

In principle, a definition can include any number of these criteria and can also include a combination of sufficiency and maximization criteria. The original "PED Framework Definition" by (JPI Urban Europe, 2019) can be understood as one such definition:

> *„A positive Energy District has an annual positive energy balance by maximizing local renewables, energy efficiency and energy flexibility* "

This constitutes one sufficiency criterion and three maximization criteria:

- Sufficiency
  - Energy Balance greater zero
- Maximization
  - Local renewable energy generation
  - Energy Efficiency
  - Energy Flexibility

The lack of concrete statements on how these imperatives are to be evaluated has resulted in a whole range of different interpretations being developed, each of which has been suitable for the associated district(s). However, the above questions must be answered unambiguously for each dimension of the assessment at the latest when specific projects are evaluated. In practice, concrete answers and operationalization interpretations to some of the above questions are typically only made based on individual research or development projects that can inherently only include a handful of districts at most. This, again, means that PEDs run the risk of being largely incomparable in terms of their goal achievement and ambition. As stated before, this need not automatically be a problem, if for example the use of PEDs is primarily in their exploration of conceptual and technological frameworks from which lighthouse projects are to emerge. However, if general quantifiability towards climate neutrality and comparison of districts is of concern, then clear and uniform regulatory and quantitative specifications must be made on a higher than individual project level. At this point, the following important fact should also be pointed out:

> *To clearly distinguish between two groups, such as PEDs and non-PEDs at least one clearly operationalized sufficiency criterion is required as part of a definition*

In this context, the sufficiency criteria, i.e. the target values, can also be defined individually for each project, as suggested in a number of approaches. However, this generally precludes comparability between districts.

Note that most approaches to defining PEDs today are quantitative in nature, which seems to be rooted in the fact that the name "Positive Energy District" alone implies a sufficiency criterion that must by definition be quantifiable. Nevertheless, there are also a number of approaches that call for qualitative criteria, usually in addition. In doing so, the human being, the inhabitant, the user, the worker, etc. moves into the center and qualitative criteria of the district evaluation almost inevitably result, such as

- Affordability
- Safety and security
- Social and physical inclusion
- Social mix
- Sufficient green and open space
- Space for positive social gathering and expression
- Holistic and environmental sustainability
- Reduction of urban heat islands
- Et cetera

Here, it is generally more difficult to formulate cross-project target values and to make statements about their fulfilment or non-fulfilment.

There is no shortage of categorizations of these evaluation dimensions in literature. The fact that these criteria are repeatedly and increasingly becoming the focus of attention is good and important. Not least because they are seen by many stakeholders and experts as essential for implementing a PED: The categories governance, incentives, process, market, technology, social and context are attested by more than 50% of the experts to be important to very important for the implementation of a PED (Steemers et al., 2022).

The question is however how these qualitative criteria should be included in a PED definition and to what extent. This depends on who you ask, and it could also not be answered by the C4P team with certainty. However, as the positive energy balance as a quantifiable sufficiency criterion is such a prime feature and opportunity of the PED concept, one should be careful not to "overburden" it with considerations and quality insurance that might be better addressed elsewhere. At the end of the day, nothing prevents PEDs from also adhering and aspiring to other standards and goals apart from a climate neutral, positive energy balance.

3.1.2 Anatomy of a quantitative definition using a positive energy balance

The definition of the energy balance can be broken down into three major parts, of which only the first two typically receive plenty of attention: (1, left) the system boundaries and subsequent energy sources and demands considered within it, (2, middle) the weighting /assessment scheme for different energy flows in and out of the system boundary and their cumulative balance and finally (3, right) the target of that balance in possible adherence to an allocation or offsetting mechanism to take the district's context into account without generalizing this context.

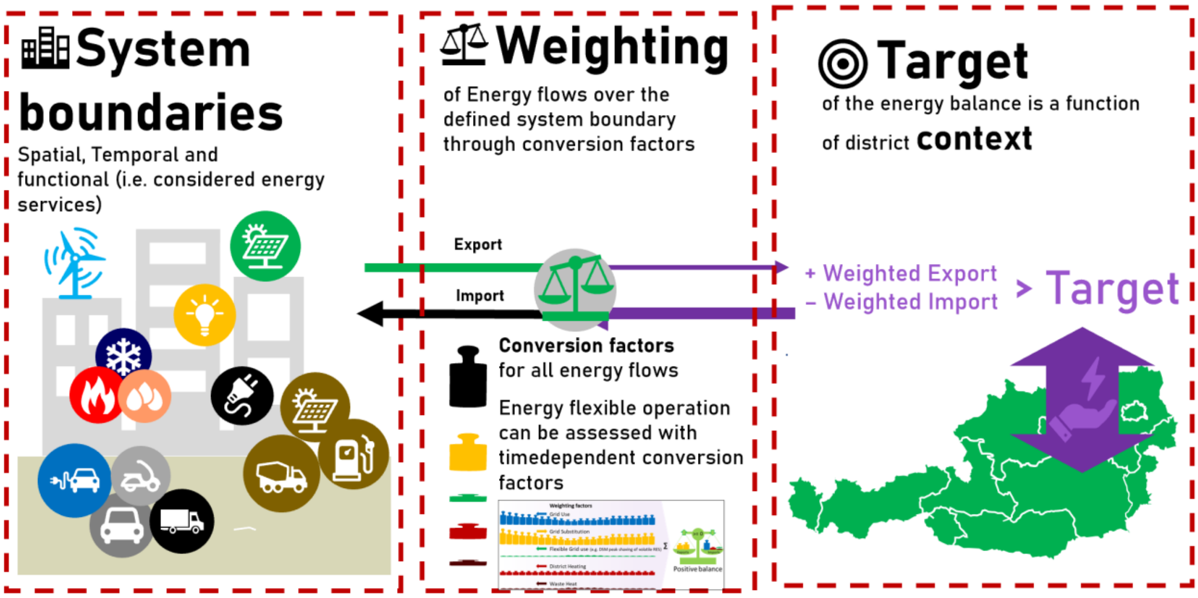


Figure 20The three main design elements of a positive energy balance assessment (Schneider et al., 2023)

These three areas of district system boundary, system balance weighting and balance targets correspond to the three questions a quantitative PED definition via the energy balance needs to address in unison distinct design problem. The balance target is not necessarily positive or zero, but can in principle be a function of any set of parameters deemed relevant. Thus, the definition through an energy balance target can include both project-intrinsic and project-extrinsic factors. On the one hand, this is an additional challenge, but at the same time it is the great opportunity: With this, dynamic external requirements can be related to project-specific proposed solutions.

But to achieve this, a definition must be able to answer the following three questions:

1. Where is the functional system boundary of the balancing drawn?

- Which energy services have to be covered? Is this selection district-specific or more generally defined?
- Which renewable energy sources are considered "local", i.e. within the system boundary?

2. Weighting
   - How are the energy flows over this system boundary weighted in the balance?
   - Are all flows treated equally as physical quantities?
3. Allocation of external resources expressed as a target function
   - What energy or GHG budgets are available to the project from external sources?
   - Which local and external contexts need to be considered?

The following pictures is an adaptation of (Sartori et al., 2012) and summarizes these questions:

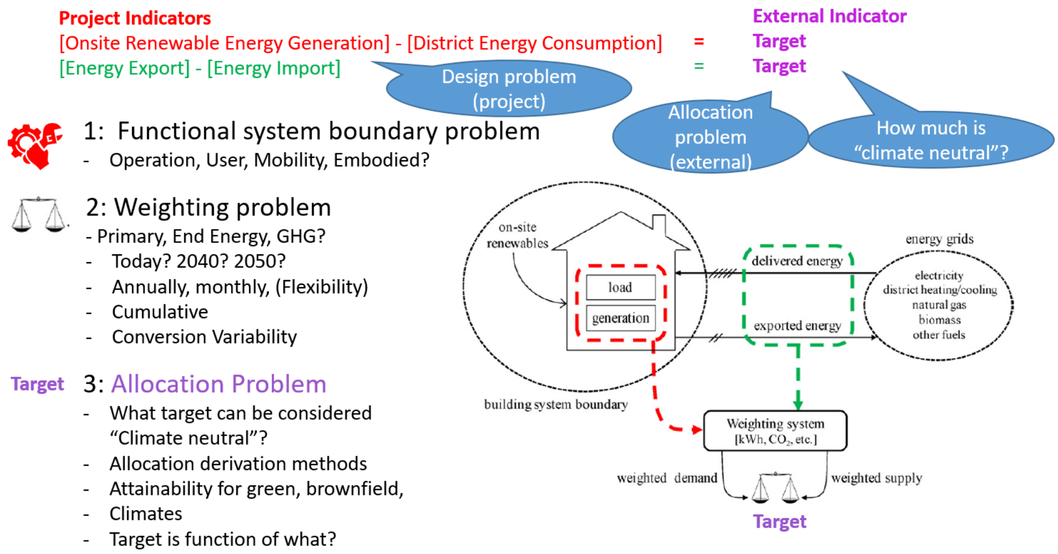


Figure 21 The three problems of defining a positive energy balance, based on (Sartori et al., 2012)

The advantage of this lies in the possibility to separate *project-specific* planning topics on the one hand and *project-independent* target values not only as conceptual topics but also in the practical derivation and operationalization. This would also be true when the PED target value is set to a fixed zero. However then, only implicitly and without further coordination between the targets and the surrounding energy system. Note that the definition of an externally derived balance target value is equivalent to the definition of an external renewable energy budget that can be used in the district and added to within a "virtual system boundary". This can also be seen the previous illustrations.

Determining the externalities of a district – via an allocation budget or the equivalent target value – is necessarily part of a balance-based PED definition.

This analogy is explained in detail in the section on the balancing targets. From this perspective, almost all quantitative definition approaches today use some form of mechanism to adjust the ambitions, i.e. the relationship between the energy services considered, their weighting and their balance target value to the respective project circumstances. They mostly do this only implicitly by setting certain system boundaries or weighting systems without much consideration whether this approach is also feasible for different districts with different contexts. The typical alternatives to the above allocation approach of external budgets and thus definition of a target value is summarized in the following table, alongside typical possibly problematic consequences:

Table 9 Alternatives to context-specific RES allocation

Alternative to context specific RES allocation, i.e. balance targets	Possibly problematic consequences
No allocation of external resources	Achievability is more difficult Positive energy balance is often only achievable by not considering many energy services (such as plug loads, mobility, and embodied energy), Non-consideration in turn diminishes statement on climate neutrality achievement
The usability of external renewable energies is proven individually by projects: For example, through certificates, purchase contracts, or similar.	Does the project then overuse external resources? Will there be enough external energy left over for the rest? Does the RE balance add up on a municipal or national level if every district adopts this approach? These questions usually cannot be answered beyond doubt or cannot be answered in the same way for a large number of districts
Flexible or individual definition of system boundaries and considered energy services	The term "Positive Energy District" then loses the quantitative dimension of comparability: One "PED" may consider only heating and cooling, but another also operating energy, mobility and embodied energy, a third excludes energy-intensive uses of the industrial plant from the consideration, a fourth extends the system boundary to remote wind power plants.

The following image illustrates the differences between a project-specific bottom-up approach to defining system boundaries, balancing, and goal setting on the left with the top-down method presented here through the uniform allocation of credits, shown here as "context factors" on the right. By individually defining system boundaries, energy services considered, and "local" renewables (left), the definition must be made anew for each district. On the other hand, locally different districts can meet the same quantitative definition if it includes an allocation approach that assigns external budgets according to district context (so-called "*context factors*") This quantitative allocation approach is necessarily project-independent (right).

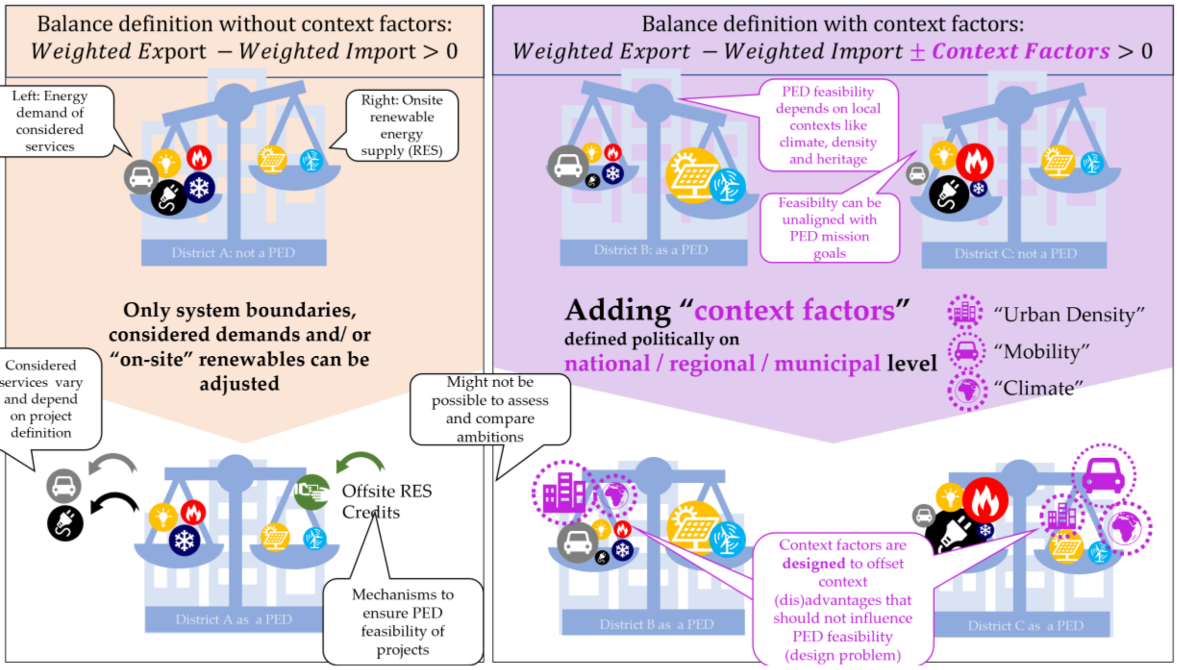


Figure 22 How can different districts in different local contexts meet a quantitative PEQ definition? (Schneider et al., 2023)

In the section 3.1.5 the allocation problem and how to derive possible context-sensitive external budgets are described in more detail, in particular:

1. A "Density factor": An allocation based on the building density of the district to compensate for practical differences in the generation potential of local renewable energy relative to the energy intensity of the land use. Density is one of the main governing factors for reaching any energy balance target
2. A "Sectoral credit of the national renewable energy system": Nationally available RES for the building sector allocated to the district according to its share of usable space created of the national building stock. This also covers and compensates for the mobility needs arising from the use of the district.

3.1.3 System Boundaries

The definition of system boundaries is required to enable balancing of flows *over* these defined boundaries. Typically, and as used here, this refers to boundaries of the ENERGY SYSTEM and the associated energy flows. Nevertheless, when defining the system boundaries, it is important to distinguish between different types: *spatial*, *functional*, *and temporal:*

Spatial means that there is an actual physical boundary that can be defined and in theory, all energy flows over this boundary can be measured. In practice, this approach quickly becomes cumbersome or unspecific when faced with the need for a more nuanced distinction between different energy services.

Functional system boundaries are more flexible, as they identify specific energy functions, uses or demands to be included or excluded according to function, rather than spatial proximity. Functional system boundaries can be further differentiated in renewable energy supply within the system boundary, often referred to as on-site, and energy services to be accounted for in the balance. Note that "on-site" here does not necessarily mean spatially on-site but rather "within the system boundary", counting positively towards the energy balance.

The functional system boundaries and the included energy services can be roughly grouped into three regimes of increased responsibility:

- Operational energy and user electricity
- Energy demand for everyday mobility
- Embodied energy

The following figure illustrates three different functional system boundaries with their included energy services and RES potentials respectively. They also include rough indications of the spatial system boundaries

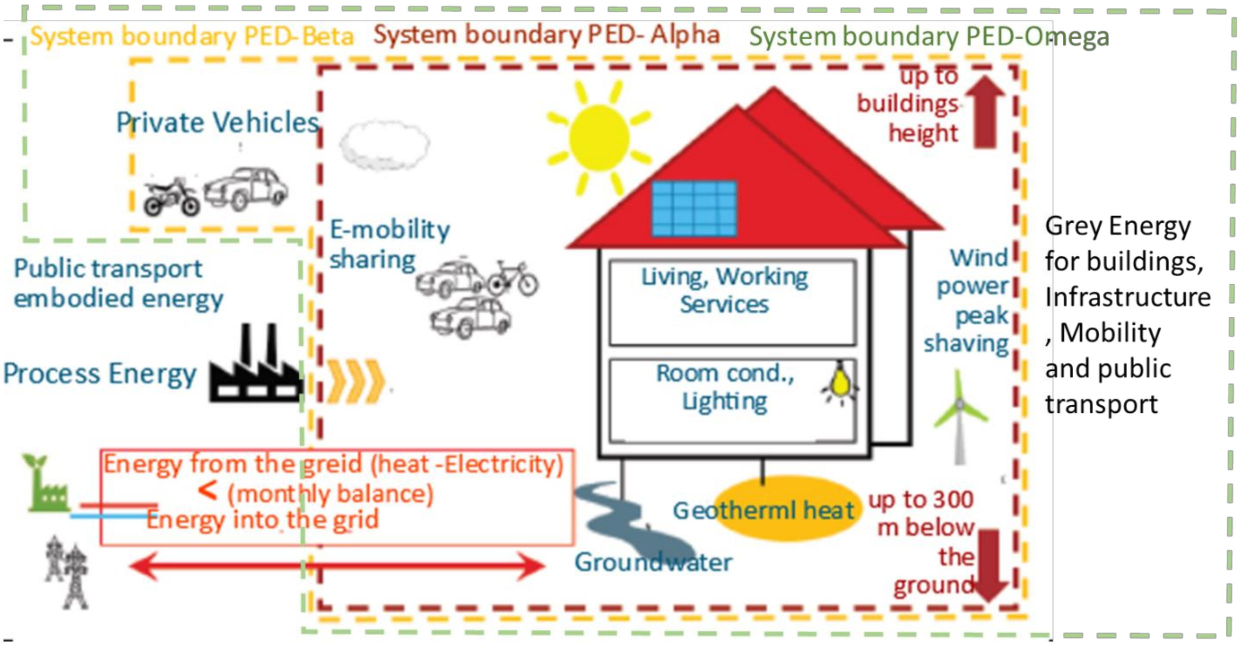


Figure 23: Three EXAMPLE system boundaries of a PED energy system

Finally, *temporal* system boundaries are often not specifically addressed but instead implicitly assumed to be one operational year without further distinction for degradation, maintenance et cetera. This typically only becomes relevant once trying to include embodied energy and emissions in the balance, at which point typically a number of years, or life span, is defined as a temporal system boundary.

3.1.4 Weighting System

One of the fundamental questions in the PED definition is the weighting of the different energy flows in a PED energy balances. This is sometimes framed as deciding between different predefined energy measures such as final energy or renewable, non-renewable or total primary energy, or greenhouse gas emissions in terms of CO2 equivalents. But this extends to the more general question of which physical energy flow is assigned which weight in the balance, and perhaps more importantly, why. As illustrated in the figure, every weighting system entails inherent consequences on the achievement of the resulting PED balance, independent of the actual energy flows and services considered. Or put differently: Each district can find a weighting system under which the energy balance is positive. It is therefore important to not just *choose* a weighting system when defining the energy balance of a PED, but also lay out the reasoning behind it and assess the feasibility of different districts.

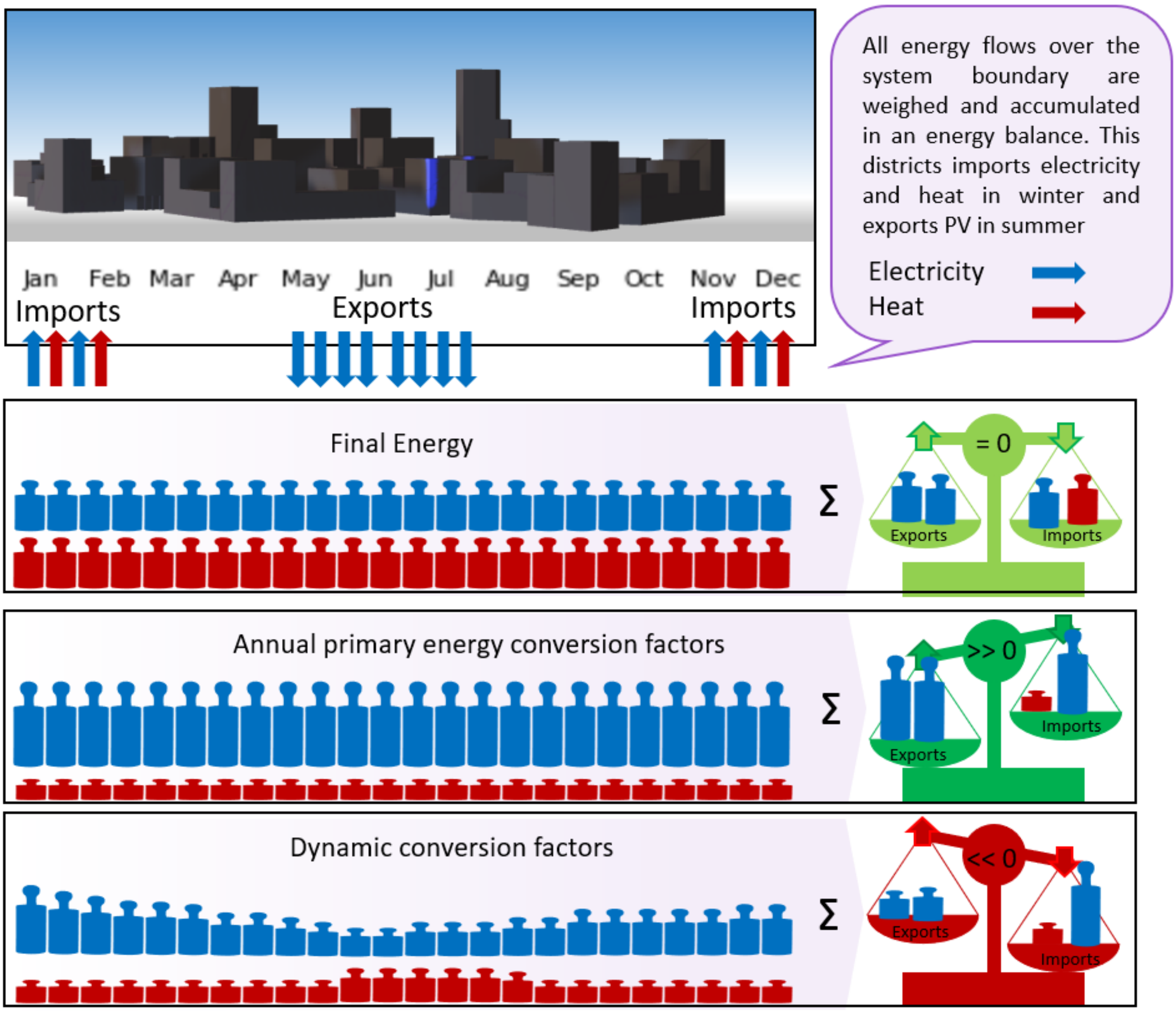


Figure 24 Weighting systems assign each energy flow of a district a weight by multiplying with a weighting factor. The resulting weighted energy flows are aggregated in the energy balance (right). For the same district, different weighting systems (three boxes on bottom) lead to different balances and with it different assessments.

Final energy or primary energy?

If equal weights of 1 are adopted across the board, they correspond to balancing the final energy flows over the system boundary. However then, the amount of energy generated and consumed must be equal. This prohibits a qualitative comparison of different energy carriers, particularly electrical and thermal energy. For example, a district could import 10 MWh of grid electricity and feed in 11 MWh of thermal energy to the surrounding to achieve a positive final energy balance. Whether this thermal energy is actually useful, in particular AS useful as the electricity imported from the grid, is highly situational and therefore not suited for general use.

Using a primary energy weighting instead allows the consideration of waste energy through the whole process chain, as well as overall energy efficiency, and actual energy impact of the district depending on the energy sources. Consequently, countries that generate significant energy more from renewable sources profit from this energy balance calculation. This also allows the comparison and balancing of embodied energy, operational energy, thermal, and electrical energy by converting all types of energy to primary energy.

Internationally, a number of different methodologies with their own strengths and weaknesses are used, particularly for factors related to the conversion of final energy to primary energy and greenhouse gas emission equivalents[4]. A public, unified dataset does not exist; instead, there are a number of national and international[5] methodologies and datasets, some of which are outdated or not publicly available, or only represent specific energy conversions, often only for specific regions.

Assessing Energy Flexibility through balance weighting factors

The main concern with temporal resolution of the energy balance is with enabling the quantification of energy flexibility provided by the PED. The key to achieving economic, environmental, and social objectives of PED is designing a flexible and sustainable energy system in the district. The main part of flexible energy system is the smart grid, that decides best time to store, use and extract energy. Smart grid provides the possibility to use the storage capacities of the system as much as possible and adapt the energy demand without a negative impact on user comfort.

There are a number of ways to quantify the energy flexibility of an energy system, which all come with different requirements and limitations, such as simulation of different baseline and flexibly controlled systems under various grid scenarios. Apart from notable exceptions[6], these approaches require higher temporal resolution of the energy flows, which in turn necessitates dynamic building simulation and/or monitoring data.

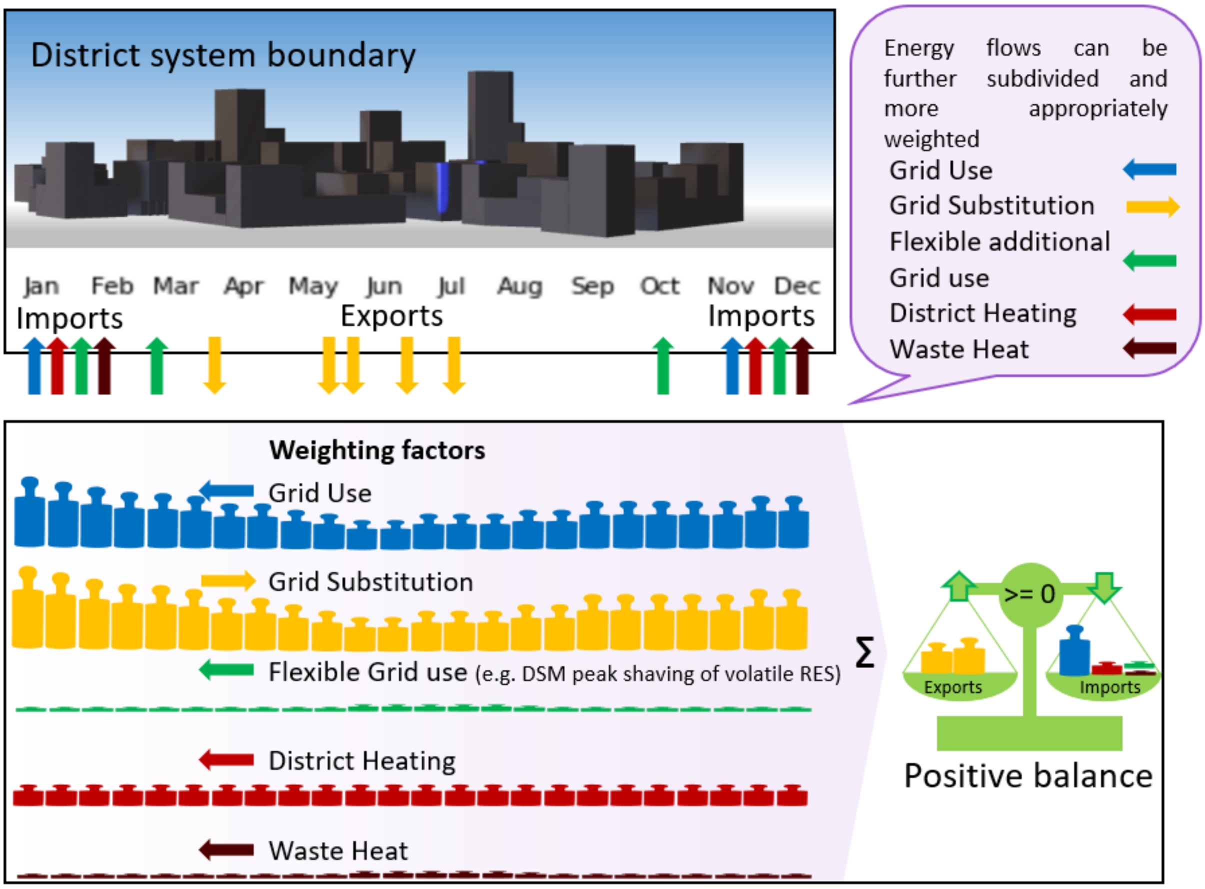


Figure 25 Example of time-dependent weighting factors of energy flows

[4] See (Hamels et al., 2021)
[5] For example, the CEN (prEN17423) and ISO (52000) standards differ substantially from one another
[6] See e.g. (Märzinger and Österreicher, 2019)

The above figure illustrates how time-dependent weights can be used to assess energy flexibility in the energy balance: The Energy balance is calculated by cumulating all incoming and outgoing energy flows of the district with the specific weight assigned to that energy flow at that time. These weights depending on time and type of energy reflect their relative importance and availability (or scarcity) in the surrounding energy system in a way appropriate to it (e.g. economic, ecologic, exergy content or else).

District Energy flexibility can be divided into two categories corresponding with the associated district internal and external effects: The first and immediate effects for a district through flexibility are mainly derived from synergy concurrency and efficiency effects, namely the reduction of peak power demands and increased load balancing, which in turn translate to economic benefits

The second and more intermediate effect of flexible district operation can lead to benefits for the surrounding energy system, such as providing buffer storages and load shifting potential, in turn leading to lower system costs, but also possibly the inclusion of a higher share of volatile renewables in the grid.

The external requirements of energy flexibility need to be communicated to the district energy system though. Although in principal any kind of signal would be possible, the most predominant in research and practice was the use of price signals. Their main advantage is typically that they are readily available, easy to use and communicate. The downside however is that prices reflect only the flexibility demand and not the flexibility supply potential of the district itself. This means that without additional care of interpreting the price signals and modulating such that it considers the district energy system and its limitations, it can lead to unintentional behavior and suboptimal performance from the perspective of the PED conceptual ideas.

Within the PED concept and it's idea of a positive energy balance, there is the opportunity to also include an assessment of the energy flexibility in it: The idea of assessing energy flexibility in the energy balance is simple: Through appropriately designed weighting factors the energy imports and exports of the districts are weighted with a set of temporally highly resolved weighting factors, typically hourly, that reflect the usefulness of the energy import / export at that given time for the external grid.

In this context, energy flexibility is a service of the district to its surrounding to incorporate more renewables into the overall energy system. As such, it is important that the assessment weighting scheme is therefore also a determination of the surrounding energy system and not a design choice of the district. Instead, it should communicate flexibility demand and supply between district and the "hinterland". This can have a number of implications in terms of *operationalization*, which will be exemplified in detail in chapter 3, particularly section 3.2:

- *Transient Simulation* of energy flows including e-mobility (at least hourly)
- *Hourly load balancing* with appropriate weighting factors
- Inclusion of *energy flexible control schemes and DSM* to increase utilization of volatile RES and increase PED target score
- Inclusion of *building thermal storage potential* to increase utilization of volatile RES and increase PED target score

3.1.5 Balance Targets (context factors)

As shown before, most definitions use some form of virtual offsetting and crediting system that change the requirements of the energy balance in one way or another. The European alignment task force call these mechanisms "context factors". They can be defined on a project level, but should really be taken care of on at least municipal, regional or even better yet national level.

With the introduction of context factors, considering more energy services such as mobility and embodied emissions does not necessarily increase the difficulty to achieve a positive balance, but rather have increasing scope and increasing number of "context factors" attached. With that, though, comes increasing modelling and calculation effort. There are two immediate parts to a district's energy balance and its feasibility to reach a numerical net zero or positivity target, as illustrated in the following Figure:

- The choice of accountable Energy services and onsite RES to be included within the balance and
- The weights or "conversion factors" given to the resulting energy flows over the system boundary

The colored cogs show three prime examples of adjusting a PED balance. Selective design of any of these parts can have a great impact on the resulting energy balance. Due to the lack of a uniform definition of system boundaries, which energy services to consider and how to convert to the weighting balance, every PED project is required to do this –implicitly or explicitly – to show a positive energy balance. It is not surprising that a given district can show a net zero or positive energy balance for a given definition and a negative balance for a different configuration.

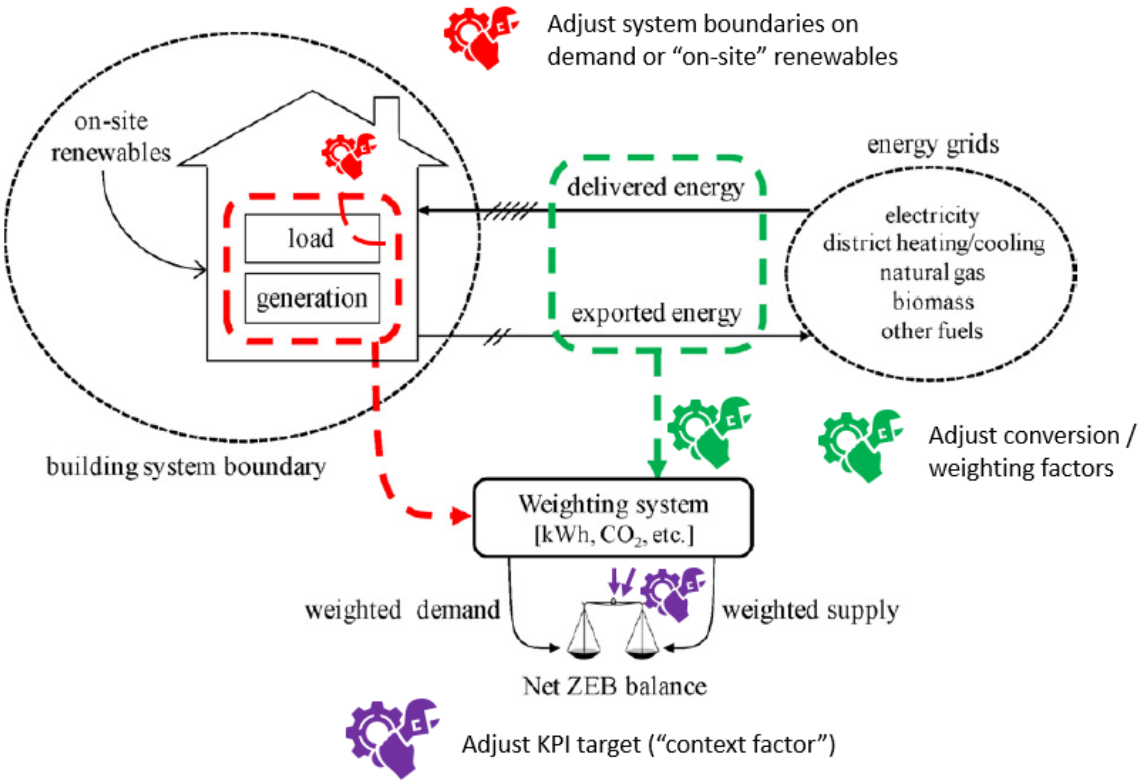


Figure 26 Positive Energy District Assessment framework adapted from (Sartori et al., 2012)

It is important to point out that the different definitions factor in different contexts implicitly by designing their system boundaries and considered energy services and onsite renewables according to considerations appropriate to their districts. Therefore, definitions *implicitly* include "*context factors*".

What are they? In the following, "*context factors*" are introduced as virtual factors included in the energy balance to deliberately offset certain effects of local contexts on the energy balance. This means that instead of changing the system boundary or the considered energy services or onsite renewables, a context factor is changed and included in a otherwise unchanged balance instead. This allows to replace context specific definitions of an energy balance, where the considered supply and demand are variable and incomparable like

$$Positive\ Balance = Supply\ (variable\ definition) - Demand(variable\ definition) > 0$$

to a more general and uniform definition of an energy balance with fixed system boundaries and considered energy services, where only the context factors vary:

$$PE\ Balance = Supply(fixed)\ - Demand(fixed) + Context\ Factors(variable) > 0$$

Note that in the second definition, what is fixed is the kind of energy services and supplies considered in the balance, not the actual flows themselves. The consideration of the local and regional context is explicitly moved away into its own term of the context factor, to separate concerns: The ones that the district can actively shape and the ones that it has no control over but are important to inform the district's goals in its respective surrounding.

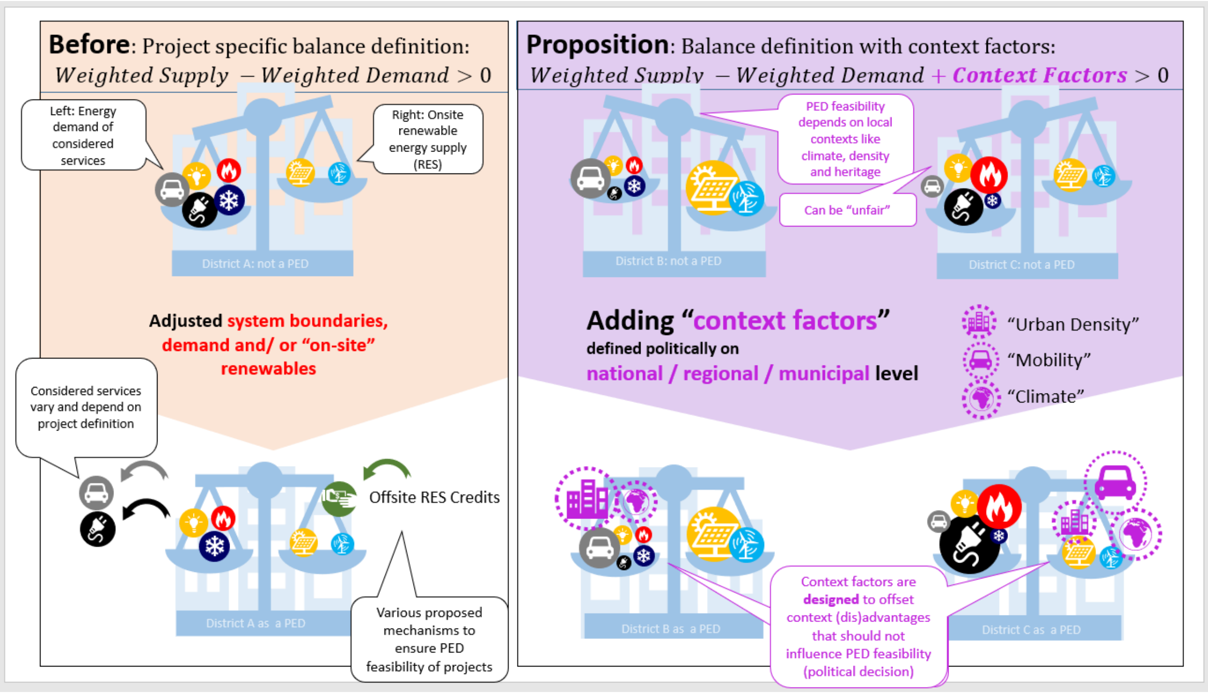


Figure 27 Comparison of offsetting strategies for achieving a positive energy balance

Although both lead to quantitatively positive energy balance for some districts, achieving this by the means of context factors offers the following advantages:

- Districts can still adhere to and achieve the same definition
- Differences are explicit (in form of the context factor) rather than implicit (in the form of different definitions)
- Comparability within a given context

The downside is that we need increasingly complex context factors if we want to increase the dimensions over which projects should be comparable but are actually not (density, climate, vintage, etc.). The principle idea of the context factor is to determine the *inverse* of the context effect and apply that to the assessment as a correction factor.

There are a number of possible contexts put out there. The following figure illustrates them and also hints at the difference between countries when dealing with them. Some, such as density might be more important to countries and cities with large spreads in district and city densities, whereas the factor might not be as important for countries and communities with fairly homogeneous densities. Likewise, climates are more different between countries and within them, making this context more important for transnational comparability, but still relevant for tweaking the overall level of energy balance performance required within a country given a certain climate.

Another important aspect is that of heritage and the context of renovation. Generally, if renovations of buildings can achieve the same energetic performance as that of green field developments, it is only with additional effort and resources. Except for special edge cases, refurbishing the existing building stock to achieve a positive energy balance is virtually impossible for all but the most limited system boundaries. At the same time for the achievement of the Paris goals it is critical to conduct swift and broad renovations to a sufficiently high energy performance standard. The height of this energy performance standard in turn depends on the national energy systems at large and their envisioned demand and supply structure compatible with Paris 2015. This can give an indication on how to derive an energy balance target for existing districts that is connected to the rest of the building sector and the future energy system and considers context specific renovation potential. This could further be detailed by considering the vintage and construction materials of the district.

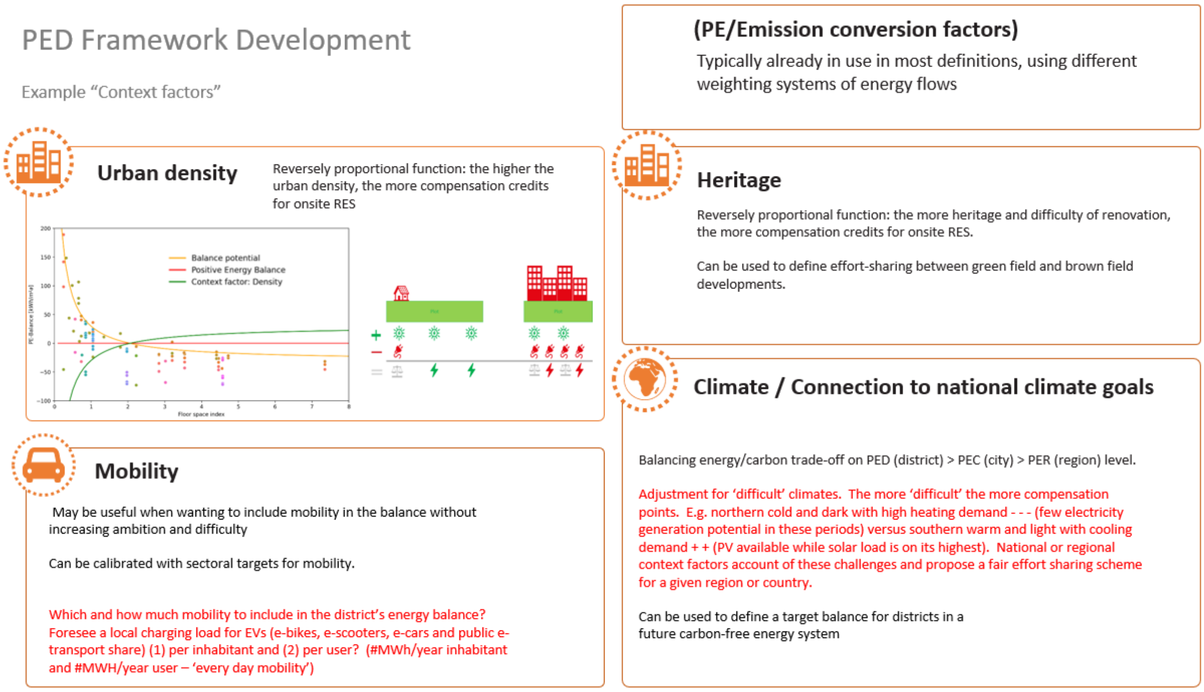
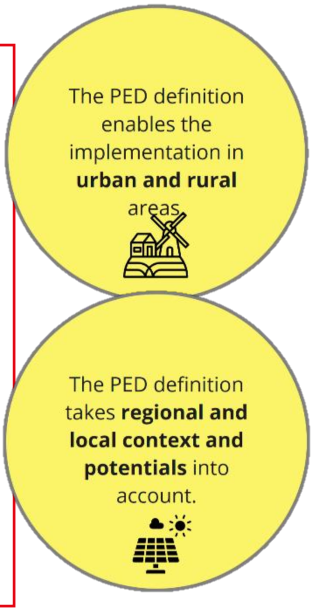


Figure 28 Examples of possible contexts that influence the energy balance and could be accounted for by designated factors

3.1.6 Context factor 1: District density and urban feasibility

The following is an example for how local potentials – in this case district density – can be accounted for in a definition fit for a wide range of uses. Please also note that the parametrization of the PE-balance target function was done for Austria, but could also be adapted for other EU member state.

- **Every PED definition inadvertently also defines a position on Effort Sharing** by defining relative achievability: This needs to be done **explicitly** rather than implicitly:
- *Local renewable energy potential (RES)* is determined by available land and plot size, *energy demand* on the other hand by useable floor area: A classic static positive target independent of density leads to **disproportionate effort sharing** between sparse and dense districts.
- Available land is a scarce resource, its use must be fair and efficient: Inefficient use of available land (e.g. SF detached housing) must not be incentivised by requiring less RES per land used to achieve PEDs.
- Intensity of local renewables should balance out with intensity of useable floor area per land use.



Ceteris paribus, districts with a low building density have an inherent advantage as they have relatively large space per person available for cost effective on-site supply of renewable energy. In contrast, dense districts struggle to meet their own energy demand on-site. This is simply due to the difference in available renewable energy versus accountable energy demands as illustrated in the following figure. A possible indicator for this is the *floor area ratio* (FAR = gross floor area per plot area): The share of renewable energy production of low FAR districts can be more than the share of renewable energy production of high FAR buildings as they have less place to produce renewable energy (thermal and PV) on site.

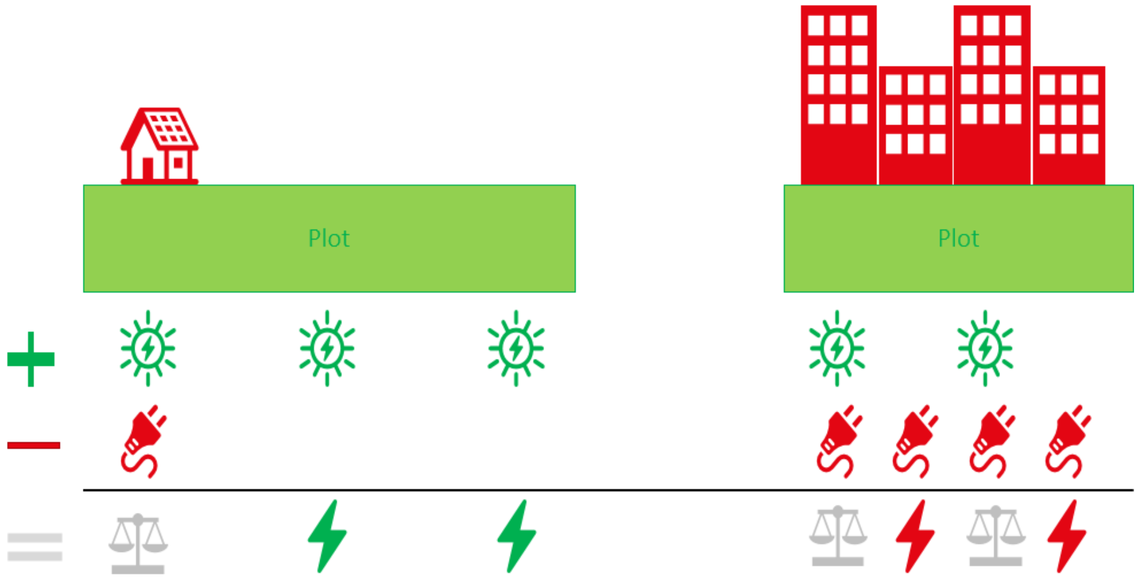


Figure 29 Schematic comparison of energy supply and demand of low- and high-density district typologies

As illustrated here, ceteris paribus, district density can be the defining element for the feasibility of a positive energy balance. To take these unequal conditions into account in structured and transparent way, *a function of density is introduced for the energy target of the district*. This can be done by analyzing the primary energy balance of a district, which in its simplest form can be characterized like this:

$$PEB = RES - OE, \qquad with\ RES\ \dots Renewable\ energy\ supply\ within\ the\ System\ boundary,$$
$$OE \dots Operational\ energy\ of\ the\ district$$

The physical RES potential is depending on the available plot area, as it determines the amount of available irradiation and environmental heat. Operational energy on the other hand is proportional to the energy reference floor area. Substituting for their area specific energy intensities, the above formula expands to:

$$PEB = f^*_{RES} A_{plot} - f^*_{OE} A_{floor}$$

$$PEB \ldots Primary\ Energy\ balance\ \left[\frac{kWh}{a}\right]$$

$$f^*_{RES} \ldots Primary\ Energy\ potential\ of\ renewables\ onsite\ per\ buildable\ plot\ \left[\frac{kWh}{m^2_{plot} a}\right]$$

$$f^*_{OE} \ldots Primary\ energy\ demand\ for\ district\ operation\ per\ floor\ area\ \left[\frac{kWh}{m^2_{floor} a}\right]$$

$$A_{plot} \ldots Available\ plot\ area\ [m^2_{plot}]$$

$$A_{floor} \ldots Reference\ floor\ area\ of\ the\ building\ [m^2_{floor}]$$

$$FAR \ldots floor\ area\ ratio, = \frac{A_{floor}}{A_{plot}}$$

Dividing the above formula by A_{floor} and expressing the result in terms of the floor area ratio gives the specific primary energy balance on the left side as inversely proportional to the floor area ratio:

$$PEB(FSI) = f^*_{RES} \frac{1}{FAR} - f^*_{OE} \quad \left[\frac{kWh}{m^2_{floor} a}\right]$$

This can now be used as a context factor for the primary energy balance:

$$Context\ Factor: CF_{density} = f^*_{RES} \frac{1}{FAR} - f^*_{OE}$$

$$PEB_{in\ context} = \mathrm{PEB_{classic}} - \mathrm{CF_{density}} > 0 \quad \left[\frac{kWh}{m^2_{floor} a}\right]$$

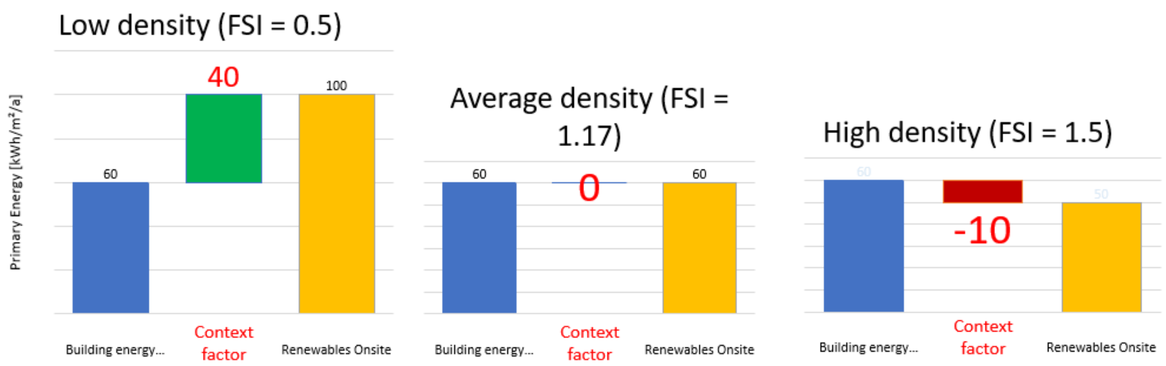


Figure 30 Example of district density context factor offsetting the balance gaps between supply and demand due to density

The context factor communicates a general sense of achievability *within a certain climatic and technological frame of reference and must be specified on a national or municipal level*. In this regard, they are similar to legal heating demand requirements as a function of compactness[7]. This also represents a physical

[7] In Austria, the maximum allowed heating demand is a function of the characteristic length of buildings, with less compact buildings having higher thresholds.

dependency being linked with technically feasible target values within a certain climatic and technological frame.

The below function shows the context factor depending on district density, which is equal to the primary energy balance target BEFORE applying the factor. Below a FAR of nearly 1.2, the energy balance must be above zero (green), while at higher FSIs it may be below (grey). Applying this definition, a positive balance can be achieved across a much wider range of districts and districts of different densities.

3.1.7 Context factor 2: Inclusion of mobility

In much the same way, the above approach can be carried out, with the inclusion of a portion of the mobility into the accountable energy services of a district and thus within the district system boundary. The context factor can be calculated by determining the required energy demand and deciding to what extent the district has to cover it by itself: This can range from "Not at all" to "100%" and anything in between. "Not at all" corresponds to a context factor equal to the required energy demand, making it a zero sum position. "100%" corresponds to a context factor of Zero. In between could be a context factor as shown in the figure below: A "mobility energy budget per capita" derived from sectoral effort sharing in a Paris 2015 compatible future scenario.

However, the context factor does not necessarily be derived from complex system analysis: A municipality could simply *define* a "mobility budget per capita" that reflects their desired typical modal split. Districts that can show that they will not induce more than this traffic have a zero-sum game: The context factor exactly offset the energy demand for the mobility. Districts with higher than municipal desired mobility energy demand need to either implement additional mobility options or other measures such as increased efficiency or RES to offset the deficit.

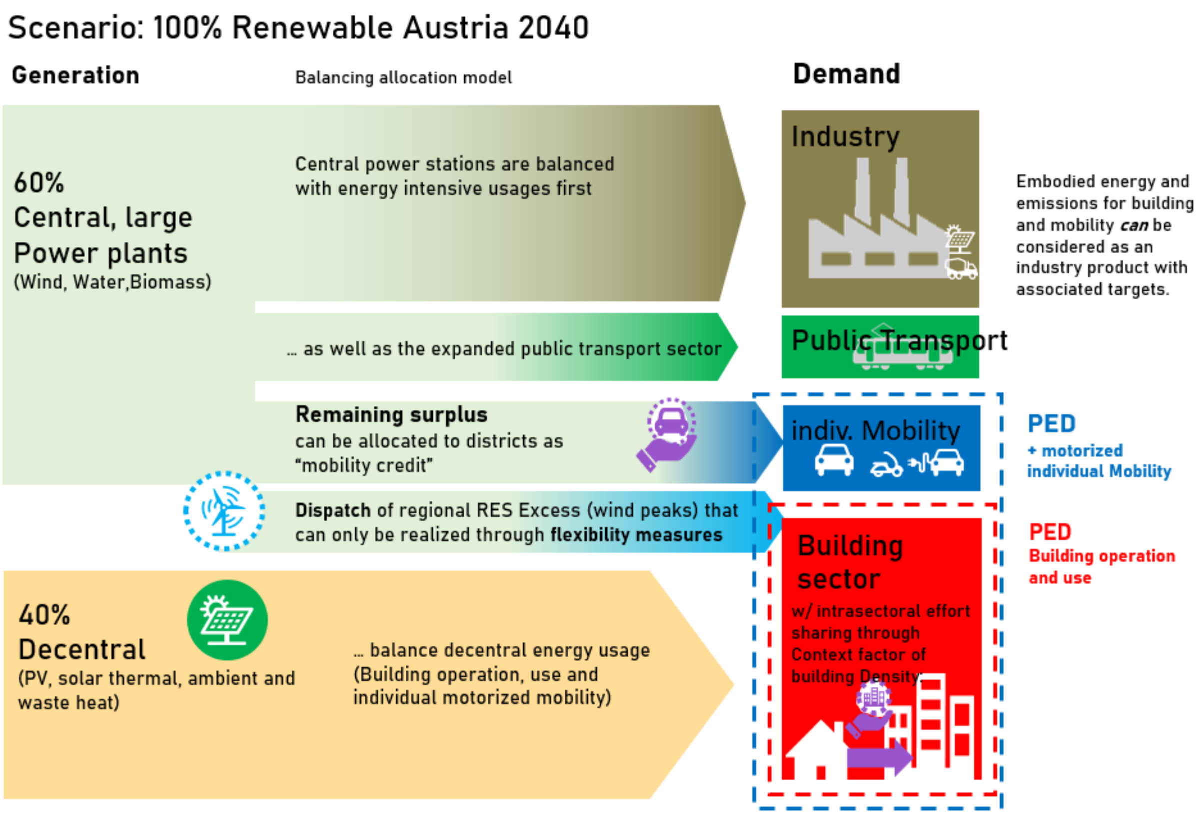


Figure 31 Example allocation of national energy supply and demand scenarios to the building and mobility sector informing district energy performance targets

Motorized individual mobility (MIM) can and should be included in the PED energy balance, if there is an allocation mechanism as depicted here in the center of a national supply and demand matching: It requires both supply and demand targets for each sector that are in line with a sustainable energy system. A concrete operationalization is published in (Schneider et al., 2023) and exemplified for the Cities4PEDs demo sites in section 3.2 of this report.

3.1.8 Difference between green and brown field development as a context factor

Although the topic has been increasingly researched in recent years, one key trend emerges across most approaches: The definitions do not make a quantitative connection between national climate goals and their analogous district target values to a renewable energy balance and GHG balance reduction.

Most approaches do not include a statement about the allocation of the overarching GHG and energy budgets that climate change scenarios and plans indicate are available to achieve the ambitious climate goals. In the authors' view, however, this is one of the most pressing problems. Without a quantitative model for effort sharing, positive energy districts are an arbitrary communicative concept. The approach presented here therefore focuses less on "What is possible?" and more on "What is needed?"

This question can only be answered by considering the scenario of a future climate-neutral overall energy system. The central question is how the effort sharing required for this can be divided up and mapped within the PED definition. From the authors' point of view, such approaches, which determine project-specific potentials and target values, are only useful if they also allow a statement about the effort sharing.

For a country, region or municipality it can be useful to define a desired energy balance of their entire building sector and many state corresponding targets in their climate strategies. This allows for further quantification of the effort sharing within that building sector: The higher energy balance of the green field developments, the lower the renovation targets can be and vice versa. This is a specific case of the general approach outlined in the section above.

3.2 Example PED definition through Energy balance assessment

The following section gives an overview of the assessment results of the three Cities4PEDs districts when using a quantitative PED definition with a primary energy balance with context factors for density and mobility.

3.2.1 Stockholm Royal Seaport

The Stockholm Royal Seaport Loudden district model is illustrated in the following site plan with residential usage (white), educational usage (rose), office and commercial usage (blue) and retail usage (yellow) indicated:

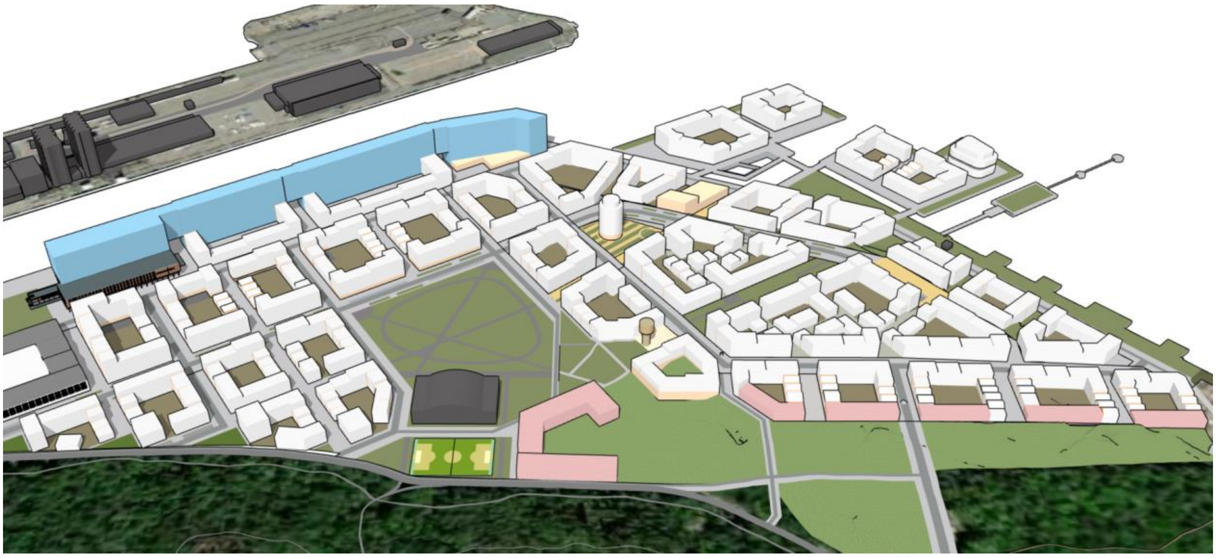


Figure 32 Stockholm Royal Seaport Loudden site plan

The model yields the following reference areas and usage distributions:

Table 10 District characteristics

Reference Areas		
District Area	55.56	ha
Gross Floor Area	647 331	m²
District Plot Area	236 471	m²
Building Storeys (avg)	5.2	
Floor Area Ratio [FAR]	2.74	FAR
Net to Gross Floor Ratio	85%	

Table 11 District Usages

Space Use			
Residential	80%	516 717	m² GFA
Commercial	14%	92 043	m² GFA
Highschool	2%	14 524	m² GFA
KIGA & Primary School	1%	4 785	m² GFA
Retail	3%	19 262	m² GFA

The following site plan shows the net construction areas of each plot that is used to determine the floor area ratio by dividing the gross floor area by it. It is important to distinguish this area from the total district area, that also includes spaces for traffic and green and blue infrastructure, which is typically not available for renewable solar energy generation.

Figure 33 Net construction areas (crimson) of the district is the reference area for density calculations

The following table shows the density context factor of the district. According to the example definition operationalization, this factor needs to be included in the primary energy balance of the district to assess whether it achieves a PED positive energy balance. Another way to think about this is that due to its density, the district needs to only achieve a primary energy balance of negative -27.5 kWh PE per square meter gross floor area. Note that this is only the case for dense urban districts. For neighborhoods with low density (with FAR < 1) the density context factor is negative, meaning their energy balance must be that much more positive.

Table 12 Density context factor Stockholm Royal Seaport

PED Alpha	
Context Factor due to Density	
27.5	kWh/m²GFAa
32.3	kWh/m²NFAa

As introduced in Section 3.1 in principle and 3.1.6 in particular, this context factor represents an effort-sharing allocation from low-density districts to high-density districts, reducing the energy balance target of the latter by the given amount of primary energy.

PV Model

The PV Modelling was carried out in 2 steps: First, a theoretical PV system application with a maximum (100%) utilization of the available roof areas was modelled as can be seen in the figure below. Second, the resulting yields were incorporated in the district energy simulation in 3 variations, each scaling the yield of the 100% example roof to the total district roof area with a given utilization rate: The analyzed variations were:

- 25% of district roof areas utilized by PV Systems
- 70% of district roofs areas

- 90% of district roofs areas

PV System parameters can be found in the Appendix. PED Assessment Results

Results were obtained investigating 3 groups of variations according to the three PV utilization levels: 25%. 70% and 90% of gross roof areas respectively:

Baseline (BL):	**70% Roof PV:**	**90% Roof PV Utilization**

- 25% Roof PV Utilization
- SRS Hulls
- GS Heatpumps
	- as BL
	- with thermal Flexibility of
	  - 0.5 K
	  - 2 K
	- w/ 50% wastewater recuperation
		- as before
		- 0.5 thermal flexibility

The Baseline scenario included *25% of roof utilization for PV,* as well as the thermal parameters stated above with a *groundsource heatpump system* for heating and cooling of the district.

The second scenario included PV utilization on 70% of the districts roof areas with 2 notable extensions:

1. Introduction of thermal flexibility: At times of excess renewables in the district, the setpoint temperature is raised during heating and lowered during cooling by a given delta (0.5 and 2 Kelvin respectively) to "save" some of the excess renewables from the PV system as heating/cooling in the very well insulated and thermally inert building mass via the HVAC system. As can be seen I the following diagram, even a thermal flexibility of just 0.5K, which is typically unnoticeable by users as it has minimal effect on indoor air temperature, can increase PV Self-consumption from 15.2 to 16.6 kWh/m²NFA and reduce the PV excess fed into the grid by a quarter
2. Recuperation of thermal energy of waste water, which in this model has an insignificant effect on the energy end use intensity.

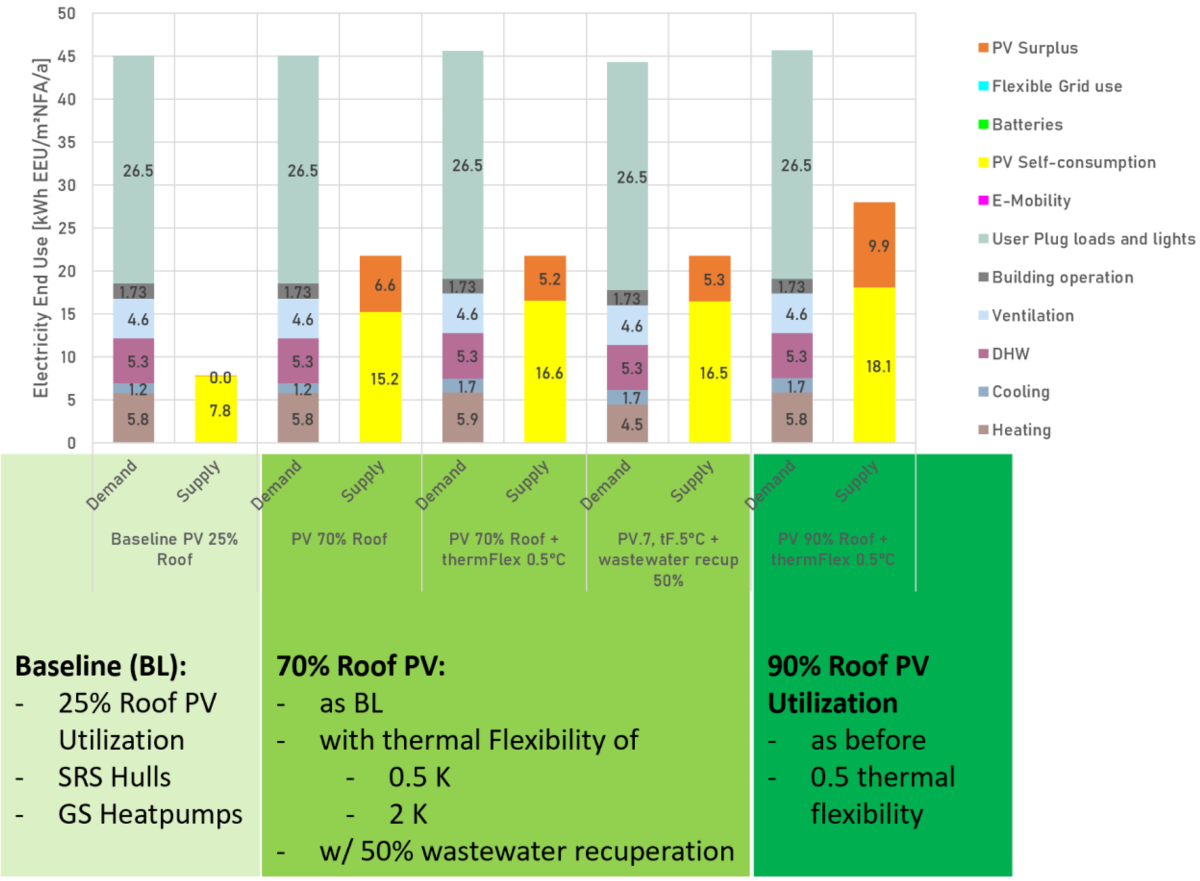


Figure 34 Electricity end use

As can be seen 70% PV roof utilization is sufficient to cover the district's HVAC energy demands, but insufficient in covering the user plug loads and lighting demands. The latter is actually not possible onsite at all with only roof mounted PV systems and heat pump systems.

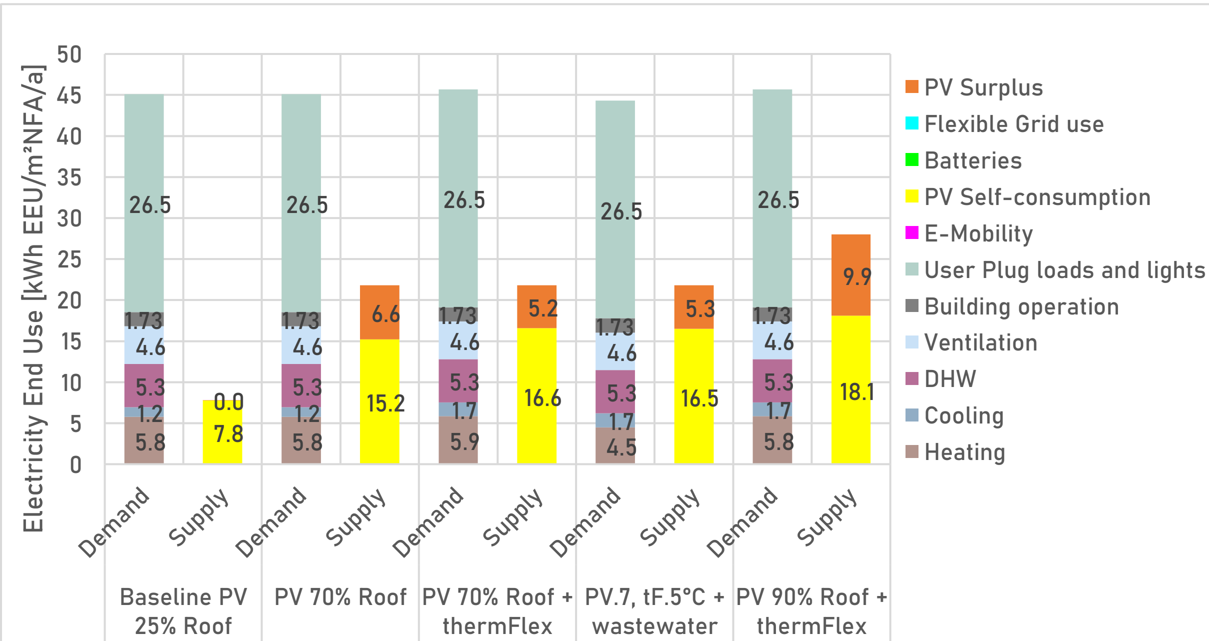


Figure 35 Energy End use balane Stockholm Royal Seaport

The following figure illustrates the resulting Primary Energy Balance, which needs to be in equilibrium between supply and demand to fulfil the PED requirement. On the right side of each scenario, the supply of the districts energy balance consists of three parts: the direct PV utilization on site (yellow), the credit of indirect PV utilization by PV feed in (orange, typically with a lower conversion factor during summer time) and the context factor due to district density (hatched red). Note that without the context factor, the energy balance cannot be positive with only roof mounted PV installation in any scenario. Even façade installation short of completely enveloping the buildings will not change this.

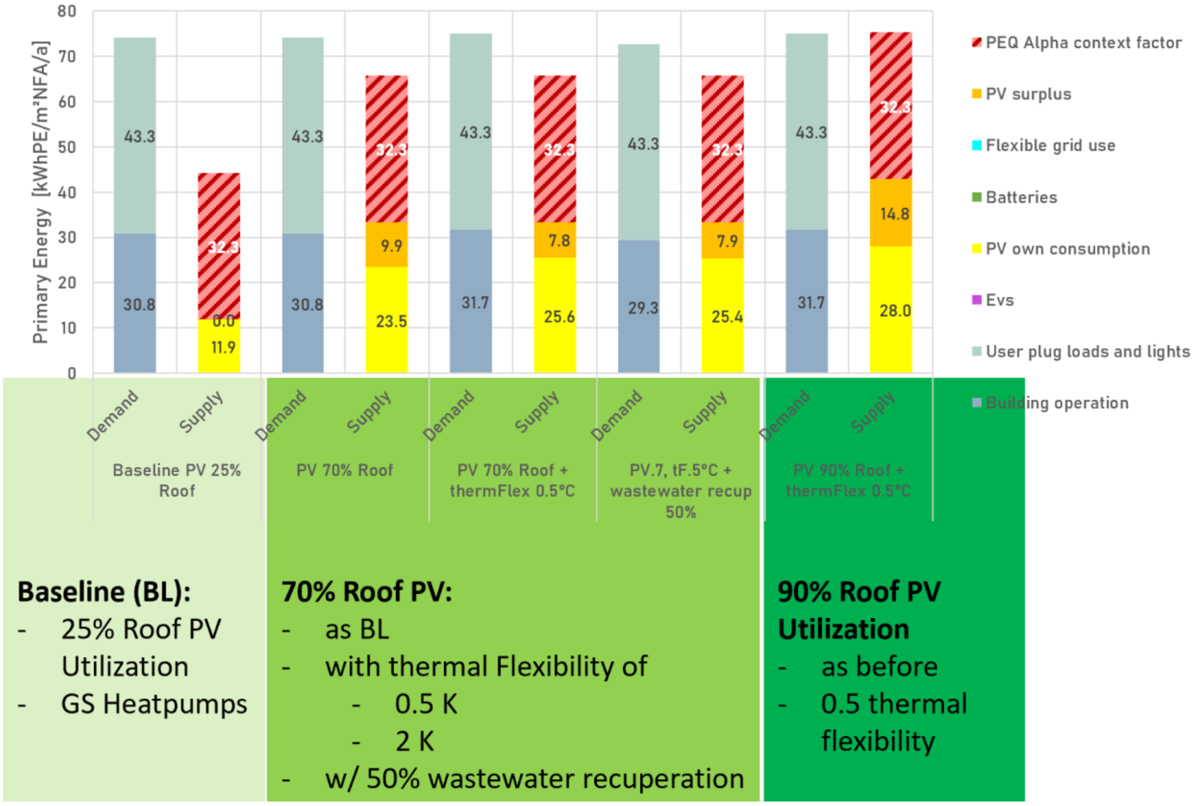


Figure 36 Primary energy balance for PED Alpha (Operation) Stockholm Royal Seaport

The conversion factors used are summarized here:

Table 13 Conversion factors Stockholm Royal Seaport

Conversion factors		
Average Electricity Primary Energy	1.6	kWhPE/kWhUE
Average Electricity GHG	0.146	kgCO2eq/kWhUE
District Heating var1	1.1	kWhPE/kWhUE
District Heating var2	0.33	kWhPE/kWhUE

Comparing the chosen HP system to a Supply via District heating depends on the chosen conversion factor: If the district heating conversion factor is below 0.4 kWhPE/kWhUE, the district heating has a slightly lower primary energy demand, above that it is higher. With typical factors of above one, the district heating scenario results in a doubling of primary energy demand.

Mobility

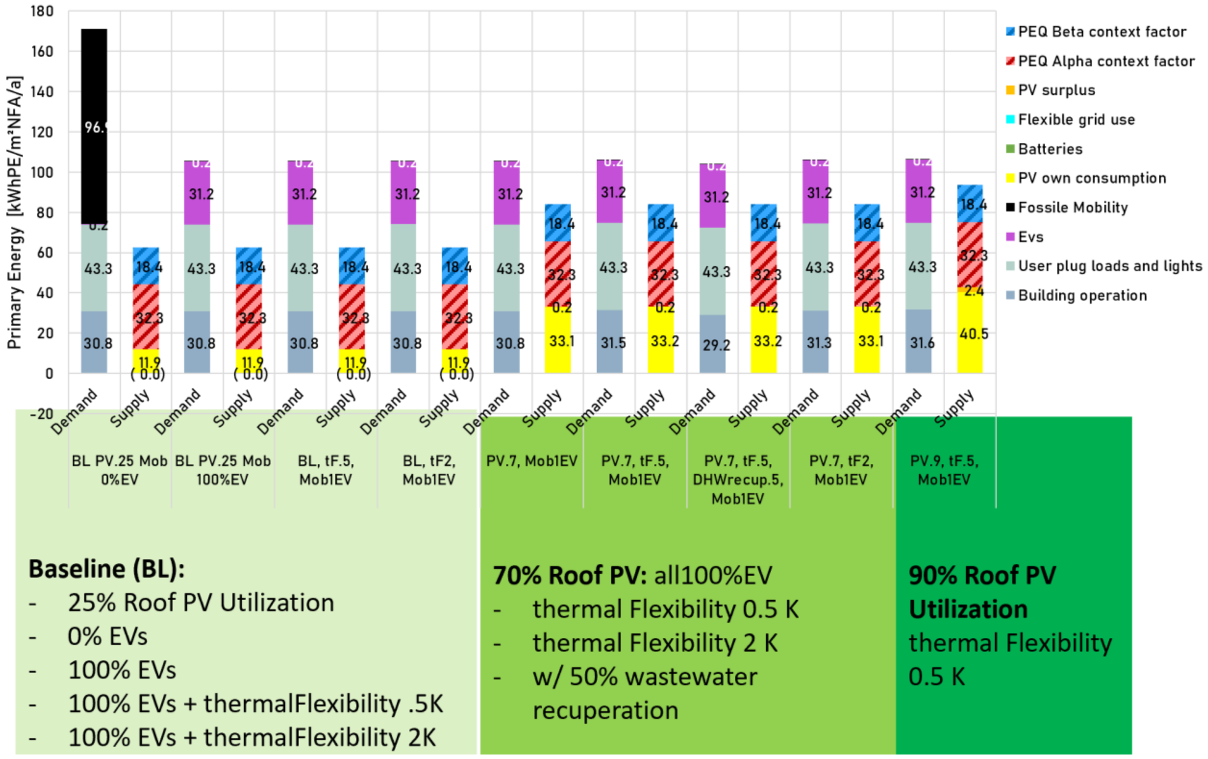
The results presented above were only considering the first layer of the PED definition operationalization covering District operation. In the following section, the approach is extended to include energy demand and supply context for everyday mobility in the district as well.

Table 14 Mobility Parameters

Mobility parameter		
Residents	10334	PAX
EVs (on site, domestic and incoming)	3000	
Annual individual motorized mobility	11000	Person-km/a

The following figure presents the same scenarios as discussed above, with the addition of energy demand of motorized individual mobility in two variations:

- Only first, leftmost demand: All individual motorized mobility is realized with fossile fuels
- All other variations utilize 100% Eletric vehicles (purple)



The blue bar on the supply side is the context factor for mobility, that can be derived from analyzing the surrounding Swedish energy system and allocating renewable energy budgets to the sectors industry, public transport from centralized sources (Wind, Water, biomass), resulting in a credit per floor area for district mobility coverage. Note that in this allocation approach, mobility of both public transport as well as industry and commerce is already accounted for in the corresponding sectoral allocation. One motivation for this is that the district is not the main beneficiary or cause of this type of mobility.

3.2.2 Brussels North District

The Austrian simulation model and definition framework was tested on the Brussels case in a simplified assessment, using four example blocks representing major typologies present at the district. They show the quantitative differences in the primary energy balance between the Austrian green field developments and the possible decarbonization paths of the Brussels North District. It can be used as a starting point for an operational definition of the energy and emissions quantification within the Brussels definition.

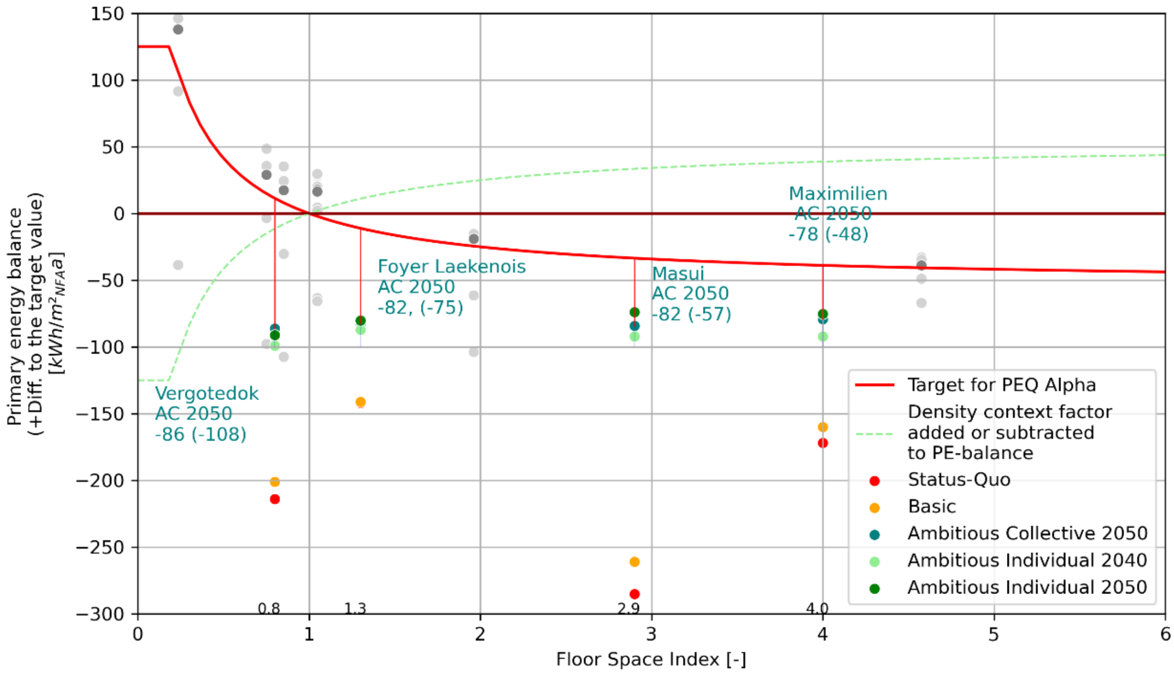


Figure 37 Primary Energy Import-Export Balance for four homogeneous areas of the Brussels North district as a function of the area density (lower to higher from left to right).

The red vertical line and numbers in brackets denote the difference from reaching the "PED Alpha" Definition of a PED, including only building operation and user electricity, excluding mobility and embodied energy. It can serve as a first indication of a possible context-factor of "heritage" as an allocated budget, offsetting the diminished energy balance potential due to the nature of the brown field development.

3.2.3 Vienna Seestadt Aspern

Following illustration gives a bird eye view of the Vienna Seestadt Aspern North District (grey). The example plot F12 investigated in this assessment is colored in white.

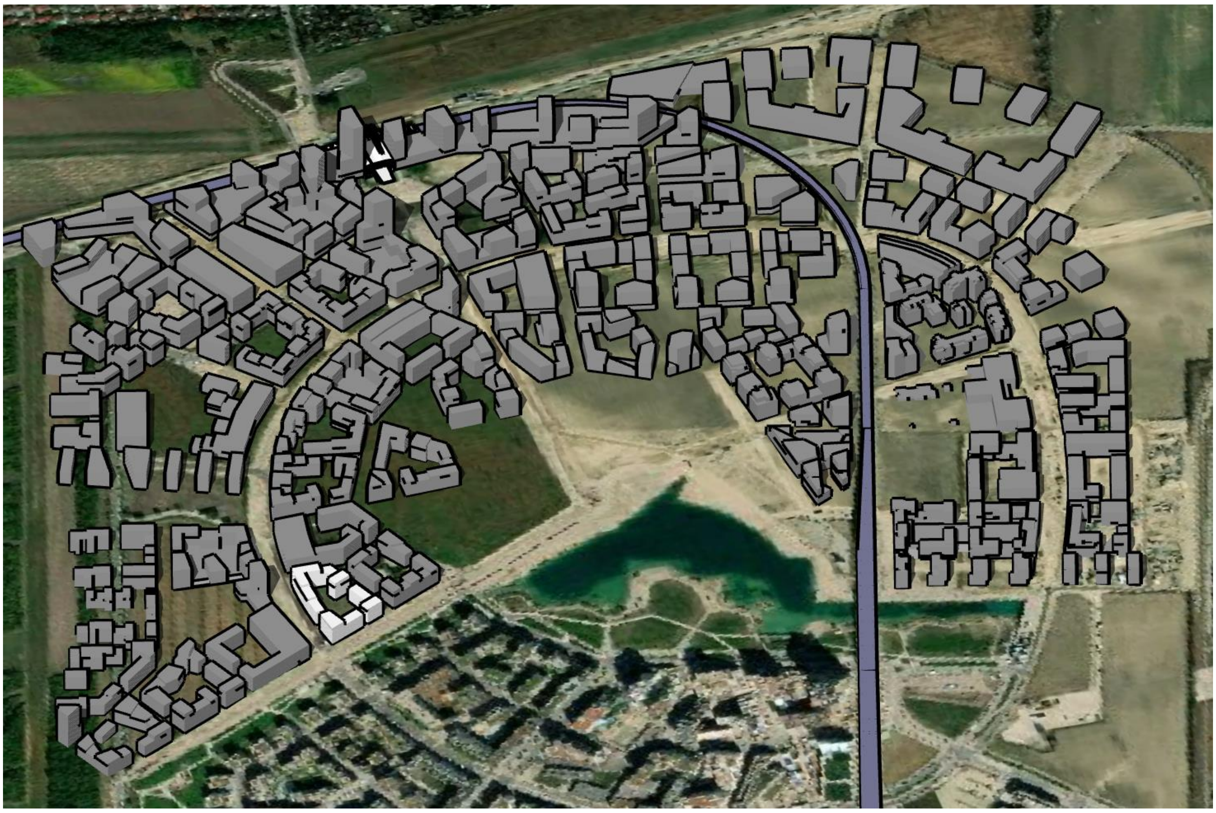


Figure 38 Vienna Seestadt Aspern North District (grey).

It is important to distinguish the buildable plot area from the total district area, that also includes spaces for traffic and green and blue infrastructure, which is typically not available for renewable solar energy generation. The district characteristics are summarized in the following table:

Table 15 District characteristics

Reference Areas		
District Area	102	ha
Gross Floor Area	1 909 056	m²
District Plot Area	759 345	m²
Building Storeys (avg)	5.3	-
Floor Area Ratio [FAR]	2.70	-
Net to Gross Floor Ratio	85%	-

As can be seen, the district is predominated by two parts residential and one-part office and residential usages, with the remaining ten percent mostly used by retail. The entire district is comprised of almost two million square meters gross floor area. The density of the district is rather high with a FAR of 2.7 and an average building storey of just over five.

As the entire district is too large to be evaluated with the existing PED assessment operationalization, only one block – F12 – is modelled instead pars pro toto. It has the same FAR and compactness as the entire district and can represent the district's envelope and shape most suitably. The block is modelled to have the same usage share as the entire district. The results obtained as such are related to the gross/net floor area and can serve as an estimate for the entire district. The Distribution of plot densities in Seestadt Aspern Nord measured as floor area ratio (i.e. gross floor area over buildable plot area) are also shown in the following figure. As can be seen, most blocks congregate between 2 and 3.5 FAR. The average FAR for the entire district is 2.7.

Table 16 District Usages

District usage	Share		Aspern Nord Total	Representative Block F12	
Residential	60.1%		1 146 475	14 570	m² GFA
Office and Commercial	31.1%		594 648	7 557	m² GFA
Primary School	0.9%		17 303	220	m² GFA
Secondary School	0.0%		-	-	m² GFA
Retail Supermarket	2.4%	30%	45 189	574	m² GFA
Retail other	5.5%	70%	105 441	1 340	m² GFA
Total	100.0%		1 909 056	18809	m² GFA
Density (FAR)			2.7	2.7	-

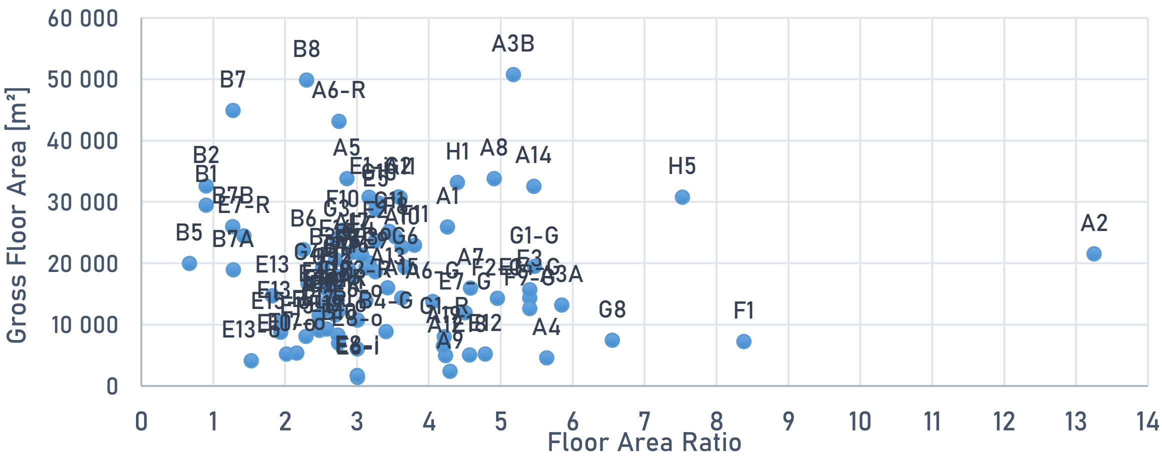


Figure 39 Distribution of plot densities in Seestadt Aspern Nord

The following table shows the density context factor of the district. According to the example definition operationalization, this factor needs to be included in the primary energy balance of the district to assess whether it achieves a PED positive energy balance. Another way to think about this is that due to its density, the district needs to only achieve a primary energy balance of negative -27.2 kWh PE per square meter gross floor area. Note that this is only the case for dense urban districts. For neighbourhoods with low density (with FAR < 1) the density context factor is negative, meaning their energy balance must be that much more positive.

Table 17 Density context factor Vienna Seestadt Aspern

PED Alpha	
Context Factor due to Density	
27.2	kWh/m²GFAa
32.1	kWh/m²NFAa

As introduced in Section 3.1 in principle and 3.1.6 in particular, this context factor represents an effort-sharing allocation from low-density districts to high-density districts, reducing the energy balance target of the latter by the given amount of primary energy.

PV Model

The PV Modelling was carried out in 2 steps: First, a theoretical PV system application with a maximum (100%) utilization of the available roof areas was modelled as can be seen in the figure below. Second, the resulting yields were incorporated in the district energy simulation in 3 variations, each scaling the yield of the 100% example roof to the total district roof area with a given utilization rate: The analyzed variations were:

- 25% of district roof areas utilized by PV Systems
- 70% of district roofs areas, or façade mounted PV with equivalent yield
- 90% of district roofs areas, or façade mounted PV with equivalent yield
- 105% of district roof areas, implying additional façade mounted PV with equivalent yield
- 120% of district roof areas, implying additional façade mounted PV with equivalent yield

PED Assessment Results

Results were obtained for both assessment boundaries Alpha (district operation and use) and Beta (also including individual private mobility) separately in a number of variating system configurations. The configurations are shown in the following table and can be characterized by four main differences:

- PV Utilization ("PV")
- Thermal Flexibility; characterized by the permitted indoor temperature("ΔT")
- "Flexible use of offsite RES"
- "Other Features"; specified individually

Table 18 Investigated system configurations

Variation Name	PV[8]	ΔT[9]	Flexible use of offsite RES	Other features
Baseline PV 25% Roof	25%	0	-	
BL + thermFlex 2°C	25%	2K	-	
BL + 2°C + WPS	25%	2K	✓	
BL + thermFlex 0.5°C	25%	0.5K	-	
BL + 0.5°C + WPS	25%	0.5K	✓	
PV 70% Roof	70%	0	-	
PV 70% Roof + thermFlex 2°C	70%	2K	-	
PV 70% Roof + 2°C + WPS	70%	2K	✓	
PV 70% Roof + thermFlex 0.5°C	70%	0.5K	-	
PV 70% Roof + 0.5°C + WPS	70%	0.5K	✓	
PV.7, tF.5°C + wastewater recup 50%	70%	0.5K	-	50% wastewater heat recuperation
PV.7, tf.5°C + 0.3kWh/kWp Battery	70%	0.5K	-	Electric Battery: 0.3 kWh/kWp
PV 90% Roof + thermFlex 0.5°C	90%	0.5K	-	
PV 105% Roof + thermFlex 0.5°C	105%	0.5K	-	

[8] Percentage of Gross Roof Area coverage with East-West facing 15° inclined modules

[9] Thermal Flexibility provided by pre-heating or pre-cooling to 0.5 or 2 Kelvin above/below the minimum required setpoint temperature of 22°C in winter and 25°C in summer. Note that this control always overfulfils the setpoint, and never undershoots the desired setpoints (warmer than set in winter, and summer vice versa)

PV 120% Roof + thermFlex 0.5°C	120%	0.5K	-

The Baseline scenario included *25% of roof utilization for PV*, as well as the thermal parameters stated above with *a ground source heat pump system* for heating and cooling of the district.

The second scenario included PV utilization on 70% of the districts roof areas with 2 notable extensions:

- Introduction of ***thermal flexibility***: At times of excess renewables in the district, the setpoint temperature is raised during heating and lowered during cooling by a given delta (0.5 and 2 Kelvin respectively) to "save" some of the excess renewables from the PV system as heating/cooling in the very well insulated and thermally inert building mass via the HVAC system. As can be seen I the following diagram, even a thermal flexibility of just 0.5K, which is typically unnoticeable by users as it has minimal effect on indoor air temperature, can increase PV Self-consumption from 17.7 to 9.4 kWh/m²NFA and reduce the PV excess fed into the grid in half. A larger thermal flexibility of 2K has no significant further increase in self utilization, as it is already with 0.5K at 90% at a very high ratio.
- Introduction of ***flexible use of offsite RES***: Leads to a further decrease of regular grid electricity from around 27 kWh/m²NFA/a by a quarter (7-8 kWh/m²NFA/a in flexible grid use, shown in the following diagram in cyan).

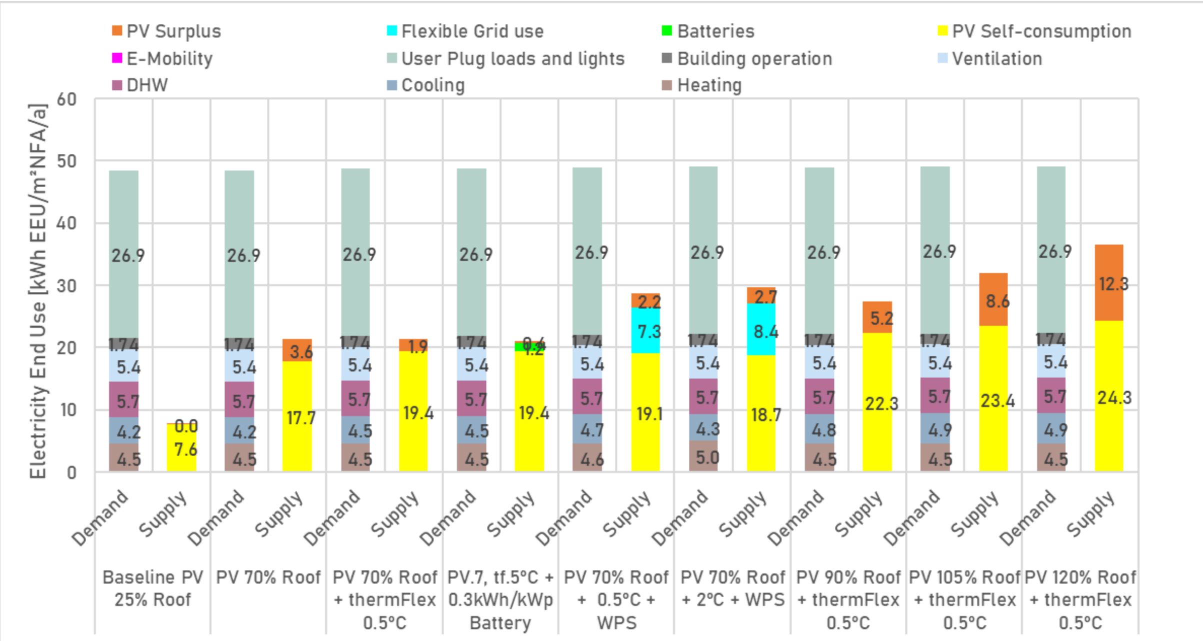


Figure 40 Electricity end use Vienna Seestadt Aspern

As can be seen 70% PV roof utilization is sufficient to cover the district's HVAC energy demands, but insufficient in covering the user plug loads and lighting demands. The latter is actually not possible onsite at all with only roof mounted PV systems and heat pump systems. Additional façade mounted PV systems amounting to approx. 13 kWh/m²NFA/a would be necessary.

The following figure illustrates the resulting Primary Energy Balance, which needs to be in equilibrium between supply and demand to fulfil the PED requirement. On the right side of each scenario, the supply of the districts energy balance consists of three parts: the direct PV utilization on site (yellow), the credit of indirect PV utilization by PV feed-in (orange, typically with a lower conversion factor during summer time) and the context factor due to district density (hatched red). Note that without the context factor, the energy balance cannot be positive with only roof mounted PV installation in any scenario. Even façade installation short of completely enveloping the buildings will not change this.

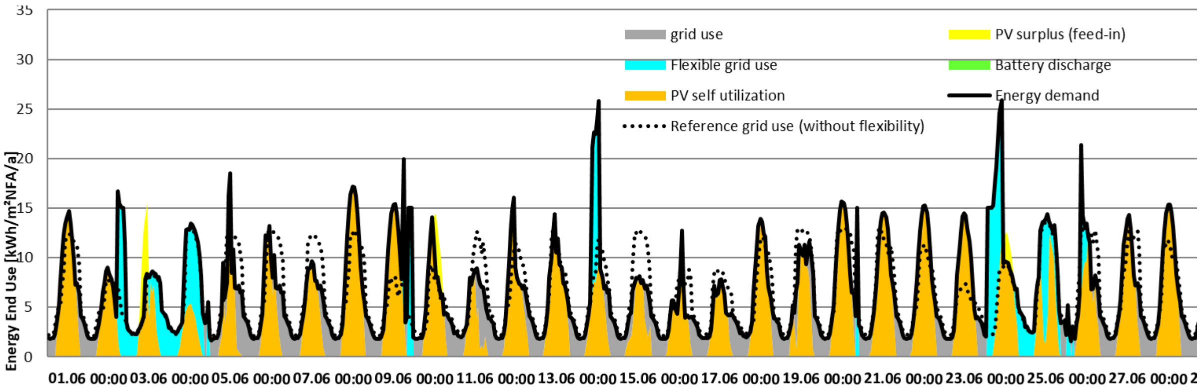


Figure 41 Temporal Illustration of electricity energy end use in June.

The above figure illustrates the flexibility of the PED in action during a sunny summer month: Flexible grid support events, where the PED uses additional offsite RES such as wind peaks to reduce energy demand relative to a reference (dotted line) later are shown in cyan. The thermal flexibility also enables higher direct utilization rates of PV (in orange) compared to the baseline (dotted line), as can be seen e.g. on the 6th, 22nd and 23rd of June Both onsite (PV in orange) and offsite (wind peaks in cyan). RES is flexibly used and mostly stored thermally in the building mass, consequently reducing the energy demand down the line (compared to the reference energy demand indicated as a dotted line). As can be seen, with this flexible control even in clear sunny conditions and high roof utilization rates of 70%, the PV surplus can be held to a minimum.

A positive energy balance for operation (PED Alpha) can be achieved in two main ways:

- 105% of roof PV utilization or higher (or equivalent façade mounted systems)
- 70% roof PV Utilization and flexible grid use

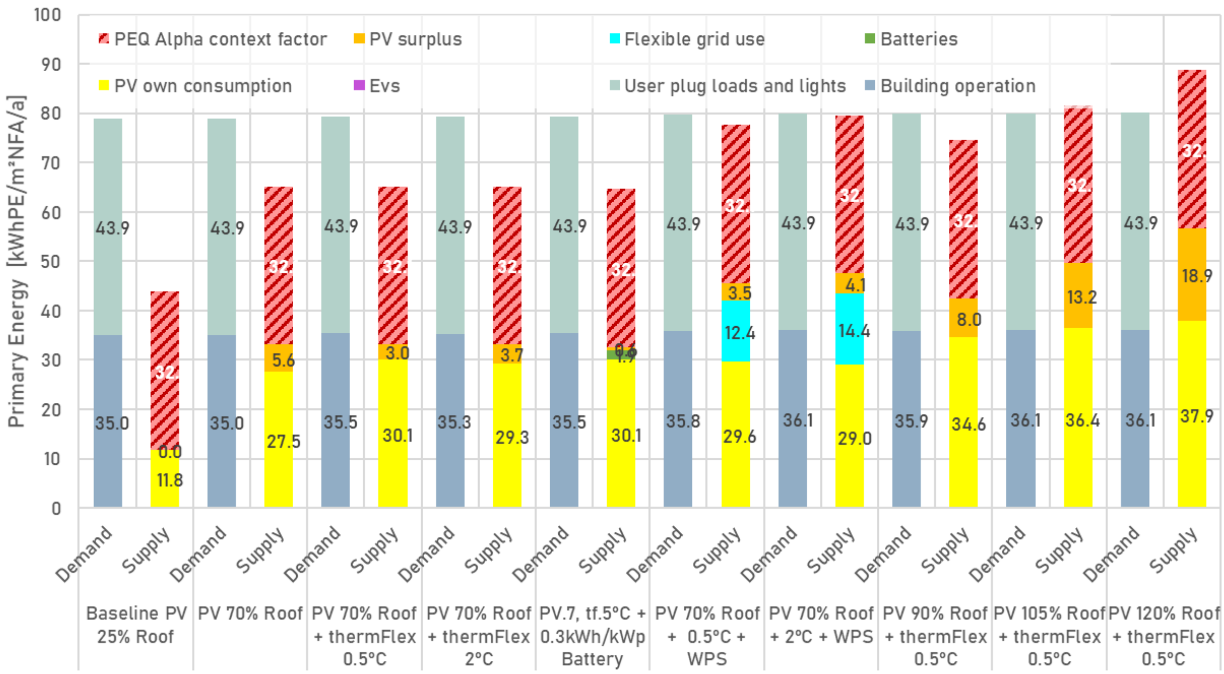


Figure 42 Primary Energy Balance Alpha (Operation) for selected system configurations

The conversion factors from energy end use to primary energy, as well as the context factors used for the balance are summarized in the following table:

Table 19 Conversion and Context Factors used in the Primary Energy Balances Alpha and Beta

Conversion factors		
Electricity Primary Energy (annual average [10])	1.630	kWhPE/kWhUE
Electricity GHG (annual average)	0.231	kgCO2eq/kWhUE
Context factors		
Alpha (Density)	32.06	kWh/m²NFA
	27.25	kWh/m²GFA
Beta (Mobility)	23.87	kWh/m²NFA
	20.29	kWh/m²GFA

Mobility

The results presented above were only considering the first layer of the PED definition operationalization covering district operation (PED Alpha). In the following section, the approach is extended to include energy demand and supply context for everyday mobility in the district as well. The following figure presents the same scenarios as discussed above, with the addition of energy demand of motorized individual mobility in two variations:

- All individual motorized mobility is realized with fossil fuels (in black; only for the first, leftmost configuration)
- 100% Electric vehicles (purple)
- 50% Fossil (black), 50% EV (purple) split (rightmost configuration)

The following figure illustrates the feasibility of achieving a PED including mobility with fossil and electric motorized individual traffic and a mix. Note that apart from cutting primary energy demands more than in half due to higher vehicle efficiency, the use of EVs has the additional advantage of providing large amounts of grid flexibility through their battery charging (cyan): If the pool of EVs in the district is large enough, they can be almost exclusively charged at times of renewable oversupply in the grid.

[10] The assessment is carried out using monthly conversion factors

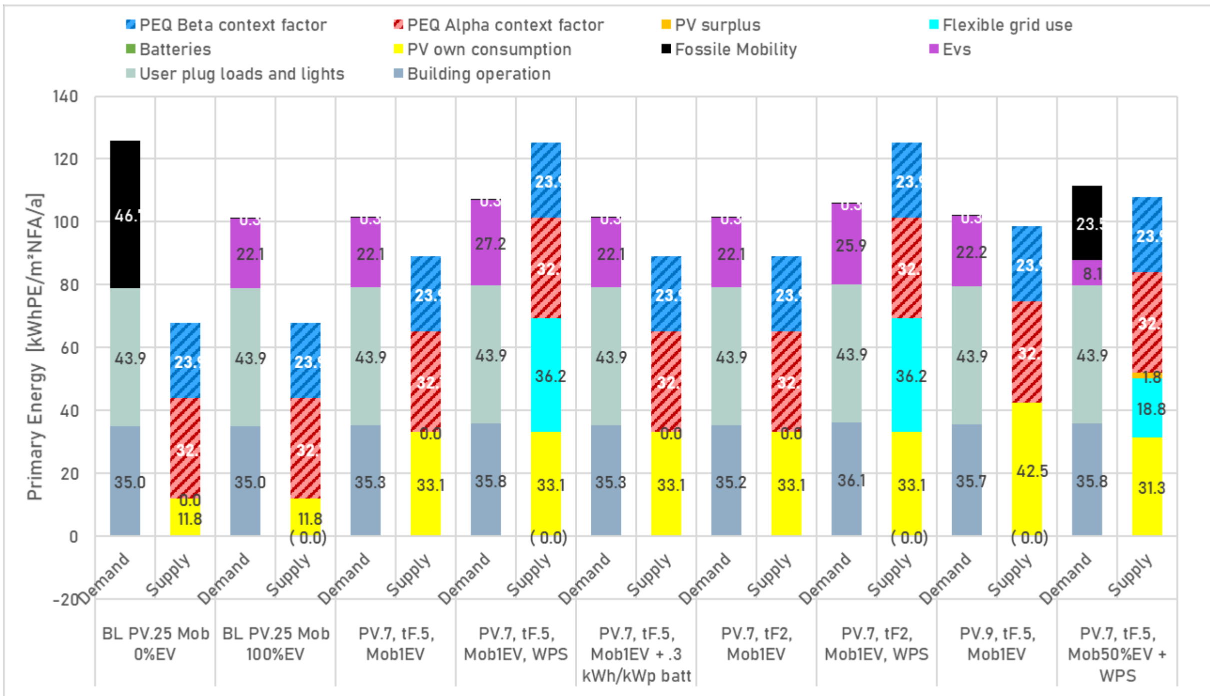


Figure 43 Primary Energy Balance Beta (Operation and Mobility) for selected system configurations

The model shows that with the very highly efficient system configurations a positive energy balance can only be achieved with EV shares of 60% or higher without additional measures such as reducing the annual volume of motorized individual mobility, efficient user appliances, other forms of onsite renewable generation such as waste water recuperation, etc.

The blue hashed bar on the supply side represents the context factor for mobility, that was derived from analyzing the surrounding Austrian energy system and allocating renewable energy budgets to the sectors industry, public transport from centralized sources (Wind, Water, biomass), resulting in a credit per floor area for district mobility coverage[11]. Note that in this allocation approach, mobility of both public transport as well as industry and commerce is already accounted for in the corresponding sectoral allocation.

[11] As described in (Schneider et al., 2023)

4 Observations

This section aims to give an overview of the discussions around PED definitions and the observations on selected key questions raised.

4.1 Which districts readily achieve a positive energy balance without context factors?

The previous example section illustrates that all three districts do not achieve either a positive primary energy balance or balance of energy end use and local supply, whether mobility is included or not. This is mostly due to the high density and as many stakeholders agree this needs a mechanism to allow dense urban districts to achieve a PED. As discussed at length in (Schneider et al., 2023), here is a rundown of the most common perspectives. It mostly comes down to your idea of general achievability of "PED". Which districts should achieve it?

If common balances must simply be positive -> generally mostly low density green field developments

With the example assessments of the previous section it is safe to subsume that in the absence of uncommon local potentials, only green field developments with low density can achieve a positive energy balance of their space use. Mobility is typically too energy intensive to be included in the balance without offsetting considerations.

This holds also true for the inclusion of embodied energy, for both green and brown field developments, although in direct comparison the latter can significantly close the gap to the former, or even perform better, depending on how renewable building materials are accounted for (i.e. how much carbon they can offset due to storage effects).

This illustrates the paradox of the arbitrary positive balance: Even though including embodied energy into the assessment would be desired as it more accurately measures what we care about – climate neutrality -, in practice it can not be done because it seems unattainable or required customized tricks.

Districts that unlock their unique potential

Many PED demo sites pursue ambitious plans to maximize the utilization of local renewable energy - as they should, which leads to innovative measures such as using industrial waste heat or residual heat from waste water as free energy source that enables a positive energy balance. (Hedman et al., 2021) As these measures are not typically generalizable and readily available for districts that are not situated in proximity to a heaty industry or a main collection sewer, they are also excluded from reaching the same energy balance, even though they apply the same solar utilization and efficiency measures.

This might just be a labelling issue, but from the perspective of a zero carbon mission it seems counterproductive to offer a special label "PED" to districts that unlock their unique potentials and deny it to those that just do the "regular" measures very ambitiously but ultimately not to the same balancing effect.

But it can also be argued the other way around: That it is important to utilize these unique local energy potentials and awarding districts that do so the district PED label.

In terms of climate neutrality on the scale of the building sector in general however, it is clear that doing "the existing boring measures" such as insulation and PV ambitiously on large scale has a much bigger effect than realizing situational potentials.

If all built environments should have a way of achieving PED

Although not all or even many stakeholders agree, there is an argument to be had that a PED definition should encapsulate the effort sharing for the entire building sector with Paris-compatible quantitative targets for all typologies within in. There are two ways in which this can be achieved:

1. Appropriately parameterized context factors that encode achievability and "set in context quantitatively"

Or

2. Individual goal setting on a district by district level, i.e. some form of processual approach and definition

The fact, that this requirement is not typically present at the start of a PED definition process, but rather emerges organically with the question on PED definition purpose and overarching goals. This indicates that the initial PED definition framework (JPI Urban Europe, 2019) is only really viable for frontrunner lighthouse projects but not suitable for follow-up replication and wide-spread application.

4.2 The PED as a Process

The development of a district is a delicate and complicated process. The care going into planning and organizing this process is one of the biggest predictors of a successful development. It is therefore important to not let arbitrary definitions dictate goals while losing track of the process itself.

It is however also important to not pit dynamic process design and normative goal setting against each other. Instead, they should be seen as two separate areas that both play important roles, but differently so in the interface between the various stakeholders:

When developers and planners interface with users, inhabitants and stakeholders of a certain district, quantitative energy goals, with their scientific derivations on positivity and climate neutrality are often not just unimportant but an outright obstacle in communicating vision and onboarding key participants.

This changes when you consider the interface between city and state administrations, legal bodies and district developers: Communicability of achievements is still important and should not be obfuscated by elaborate definitions. But it is also important to connect districts achievements and aspirations to energy and climate goals on a higher level in preparation for legislative normalization and certification. This need not concern the district developers "on the ground", but incidentally they are the ones currently involved in the PED projects explored to date.

4.3 Why different and open definition aspects is a good thing

If one thing has become clear about PED definition it is that there is no one uniform definition that can satisfy all stakeholder needs. Rather, PED definition must reflect the different areas and levels of target design and district planning. It seems clear now, that striving for a common definition is not a viable way forward. Instead, the differences in definition needs and perspectives must be embraced and studied in terms of classification: Different aspects of PED definition have already underwent this scrutiny, such as system boundaries and calculation methodology of the energy and emission balances and the categorization of KPIs into thematical groups such as environmental, societal, economic, legal, etc.

It seems useful to expand this research onto perspectives of regionality and as instruments of normative goals such as the Paris Agreement and their national, regional and municipal interpretations.

4.4 What about…

Comparing this document with existing research and project reports on PED definition, the main focus of this report is obviously on the observations on the PED definition approach itself and a quantitative definition of PEDs through a positive energy balance. This is to not reiterate already established findings and work but rather contributing new aspects to the discussion. Nevertheless, there are a number of key topics that we want to address here in all brevity:

4.4.1 …Economic aspects

Although important for project feasibility and implementation, both resource and cost efficiency were never explicitly discussed within the Cities4PEDs project PED definition discussion. In hindsight it might have been beneficial to include this dimension into the considerations as it could give directions and thresholds of ambitions defined by cost or resource efficiency.

4.4.2 …Qualitative Aspects

The quality of district development is hardly defined by its energy performance. As such, there is also an argument for the definition of PEDs to be centered on the assessment of KPIs regarding quality of life and other social and inclusivity aspects, as other projects have shown. Although a valid approach, one must keep in mind that there is a difference between taking certain aspects into assessable account in the development of a specific district on one side, and taking that aspect as a definitory criterion into the definition itself that should be imposed on all districts.

4.4.3 …Existing buildings and renovation

The renovation sector was largely excluded from the analysis, although it will of course play the most important role in the coming years. In principle, the definition and operationalization presented here can also be applied to refurbishment of existing buildings and, as initial studies show, can sometimes be achieved. However, it is clear that especially the PEQ Alpha system boundary with the relatively high implicit requirements for energy efficiency and local renewable energy production will not be easily - if at all - achievable for all existing quarters. Here, apart from the building density, the credit must also be examined and, if necessary, parameterized depending on additional parameters such as the building age or the settlement typology.

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8 Appendix

8.1 PED Concept Stakeholder Interview Questions

Question 1

Fill in the Answer of your interview partner

As a *role/profession* **the PED concept is useful to me** because…
if…

Question 2

The role / profession of your interview partner

As a *role/profession* **, i expect from a PED definition that because** *fill in the answer of your interview partner*
…

Question 3

I will stop using or pursuing the PED concept if …

Question 4

My greatest pain dealing with PEDs right now is …

8.2 Assessment model parametrization

8.2.1 Stockholm Royal Seaport Loudden

PV Model

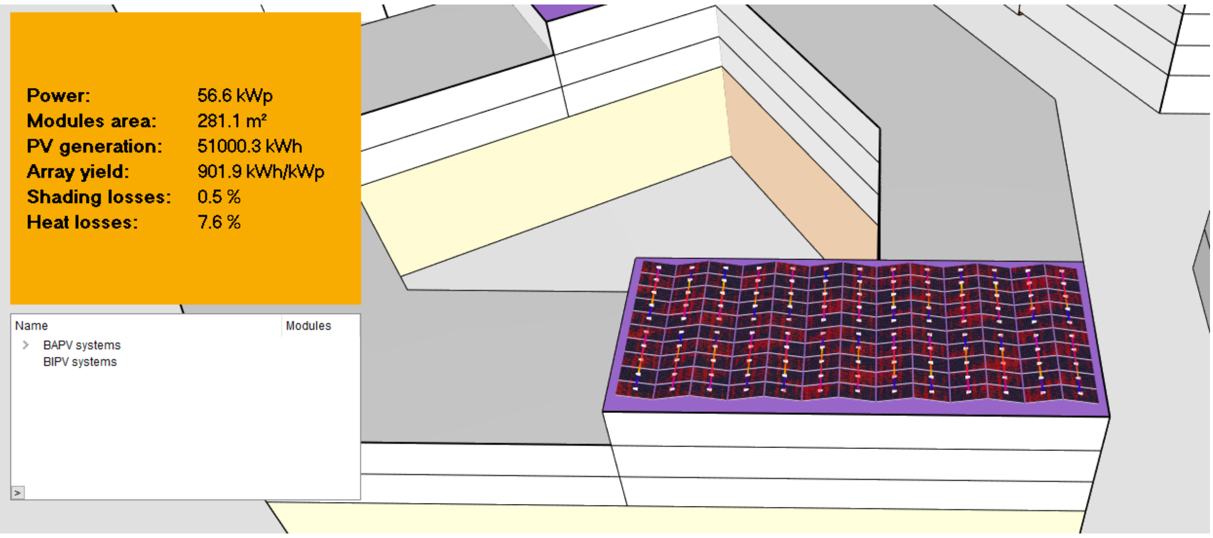

Figure 44 Example of a PV system application with a **100%** roof utilization using east-west oriented modules with 15° of inclination.

Table 20 PV system configuration and parametrization

Parameter		
Available Roof Area	124.313	m²
Weather	Stockholm Bromma 2020	
Source	meteonorm 8	
Annual Global Horizontal Irradiation	988	kWh/m²
Module	Sunpower SPR-435	
	1046 x 2067	mm
Annual Yield	901	kWh/kWp
Max Utilization (100% Roof areas)	19	MWp
	138	kWh/m²Roof
	26.5	kWh/m²GFA
Actual Utilization	25%	
Installed Power	4.754	MWp
PV Yield	6.6	kWh/m²GFA
	7.8	kWh/m²NFA

Energy Model Parameters

The following tables give an overview of the assumed properties of the buildings and the energy system used in the thermal and electric energy system simulation:

Table 21 Model parameters Stockholm Royal Loudden

Thermal Hull				
Thermal Transmittance		Wall	0.15	W/m²K
		Windows	0.87	W/m²K
		Roof	0.1	W/m²K
		Floor	0.16	W/m²K
Visible Transmittance			0.7	-
Thermal active mass			204	Wh/m²K
Ventilation				
Heat recovery			90%	
Energy Supply	Heat Pump (ground source, water)			
Heating	COP		4.25	
	Transmission losses		5%	
	Temp Set Point		22	°C
Cooling	COP		4.75	
	Transmission losses		5%	
	Temp Set Point		25	°C
DHW	COP		3	
Energy Use				
Heating			**23.2**	kWh/m²a
Cooling			**5.4**	kWh/m²a
DHW			**11.1**	kWh/m²a
Plug Loads	District avg		**26.5**	kWh/m²a
(per usage)	Residential		26.7	kWh/m²a
	Office		19.4	kWh/m²a
	Secondary and tertiary education		14.1	kWh/m²a
	Primary education and Kindergarten		6.1	kWh/m²a
	Retail Supermarket		30.8	kWh/m²a
	Retail		4.4	kWh/m²a

8.2.2 Vienna Seestadt Aspern

PV Model

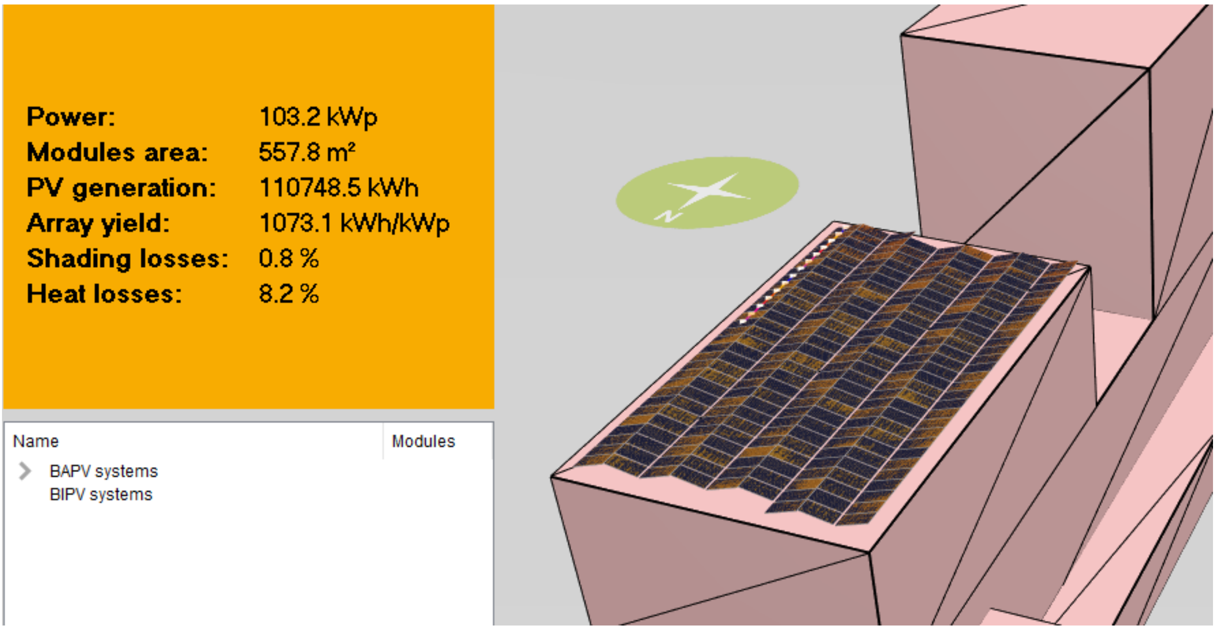

Figure 45 Example of a PV system application with a **100%** roof utilization using east-west oriented modules with 15° inclination.

The following table summarizes the PV system modelling parameters and resulting yields

Table 22 PV System parameters

PV Parameter		
Available Roof Area	311 394	m²
Weather	Vienna Hohe Warte 2020	
Source	meteonorm 8	
Annual Global Horizontal Irradiation	1199	kWh/m²
Module	Sunpower SPR-435	
	1046 x 2067	mm
Annual Yield	1071.85	kWh/kWp
Max Utilization (100% Roof areas)	45	MWp
	155	kWh/m²Roof
	25.7	kWh/m²GFA
Actual Utilization	25%	
Installed Power	18	MWp
PV Production	6.32	kWh/m²GFA
	5.37	kWh/m²NFA

Energy Model Parameters

The following tables give an overview of the assumed properties of the buildings and the energy system used in the thermal and electric energy system simulation:

Table 23 Model parameters

Thermal Hull			
Thermal Transmittance	Wall	0.15	W/m²K
	Windows	0.87	W/m²K
	Roof	0.10	W/m²K
	Floor	0.16	W/m²K
Visible Transmittance		0.7	-
Thermal active mass		204	Wh/m²K
Ventilation			
Heat recovery		90%	
Energy Supply	**Heat Pump (ground source, water)**		
Heating	COP	4.25	
	Transmission losses	5%	
	Temp Set Point	22	°C
Cooling	COP	4.84	
	Transmission losses	5%	
	Temp Set Point	25	°C
DHW	COP	3	
Energy Use			
Heating		18.2	kWh/m²a
Cooling		20.4	kWh/m²a
DHW		11.9	kWh/m²a
Plug Loads	District avg	24.7	kWh/m²a
(per usage)	Residential	26.7	kWh/m²a
	Office	19.4	kWh/m²a
	Secondary and tertiary education	14.1	kWh/m²a
	Primary education and Kindergarten	6.1	kWh/m²a
	Retail Supermarket	30.8	kWh/m²a
	Retail	4.4	kWh/m²a