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# The Benefits of Positive Energy Districts: Introducing Additionality Assessment in Évora, Amsterdam and Espoo

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**Abstract:** Positive Energy Districts (PEDs) are a promising approach to urban energy transformation, aiming to optimize local energy systems and deliver environmental, social and economic benefits. However, their effectiveness and justification for investment rely on understanding the additional value they provide (additionality) in comparison to current policies and planning methods. The additionality perspective is not used yet in current evaluations of PED demonstrations and pilots. Therefore, this paper introduces the concept of additionality in the evaluation of PEDs, focusing on the additional benefits they bring and the circumstances under which they are most effective. We discuss the additionality of PEDs in addressing the challenges of climate neutrality and energy system transformation in three European cities that are funded by the European Commission's H2020 Programme. It should be noted that given the ongoing status of these projects, the assessment is mainly based on preliminary results, as monitoring is still ongoing and quantitative results are not yet available. The paper discusses the drivers and barriers specific to PEDs, and highlights the challenges posed by technical complexities, financing aspects and social and legal restrictions. Conclusions are drawn regarding the concept of additionality and its implications for the wider development of PEDs as a response to the challenges of climate neutrality and energy system transformation in cities. We conclude that the additionality perspective provides valuable insights into the impact and potential of PEDs for societal goals and recommend this approach for use in the final evaluation of R&I projects involving PEDs using actual monitored data on PEDs.

**Keywords:** positive energy districts; citizen engagement; additionality; urban energy systems; sustainability

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## 1. Introduction

Many cities across Europe aim towards climate neutrality, in order to drastically reduce greenhouse gas (GHG) emissions to mitigate climate change [1]. Since energy production and consumption are responsible for major GHG emissions, green and digital transition efforts aim to transform the energy system to achieve significant reductions in environmental impact [2]. At the city level, this transformation requires a redesign of districts' energy systems, encompassing energy production, distribution and utilization. For this purpose, the concept of Positive Energy Districts (PEDs) has been introduced as one possible response for integrating energy systems locally and as an initiative to maximize the energy-performance-buildings sector on a larger scale [3]. PEDs are designed to generate more energy than they consume, with adaptability to market fluctuations and reduced reliance on centralized grids. This is achieved through decentralized solutions, renewable energy, storage technologies and enhanced management practices. The EU has proposed regulations to support the implementation of PEDs by 2050, with a target to plan 100 PEDs by 2025 [4,5]. Although still in the early stages, this project could significantly influence the global adoption of PEDs. The state of the art of its implementation and effective penetration into the current energy systems of European cities, according to the evidence provided by the literature [6], shows that fewer than half of the documents analyzed refer to actual case studies, 80% of which were funded as part of research projects.

A review of spatiotemporal urban energy system modeling for urban decarbonization strategy formulation [7] examines the complexity and effectiveness of various tools and concepts for supporting urban energy system transformation toward sustainable, low-carbon cities. The study presents a systematic screening and evaluation method, identifying 10 key modeling dimensions based on a literature review. These dimensions are used to assess 20 different urban energy system modeling frameworks, considering the needs of both the building sector and the mobility sector and the unique spatiotemporal characteristics of urban energy systems.

PEDs offer a range of potential benefits, including the optimization of energy systems beyond individual buildings, benefitting from solutions that have more impact or are easier to implement at a wider scale (district or neighborhood) [3]. The optimization of energy systems includes increased energy efficiency, higher density of renewable energy, flexibility and storage (considering congestion), as well as the integration of building energy systems with other city energy related infrastructures, such as electric vehicle (EV) charging points [8]. Additionally, these dynamic district-level energy systems are controlled in a smart way to optimize their positive impact withing the wider city-level energy systems and energy markets [9].

However, PEDs move beyond the traditional focus on buildings' energy consumption and climate impact. They are meant to achieve a broader range of environmental, social and economic benefits, aiming to foster inclusivity, citizen engagement, improved well-being and opportunities for local businesses [10]. Additionally, PEDs can be used to combat energy poverty in historic urban districts [11]. However, preserving historic structures while simultaneously promoting sustainable practices and addressing community needs presents a significant challenge [12,13]; therefore, many requirements must be considered to ensure that these structures can be securely adapted for new functions and uses [14].

The development of PEDs in European cities is the subject of many EU-funded research and innovation projects (R&Is), including POCITYF [15], ATELIER [16] and SPARCS [17]. These projects exploit the potential of PEDs by utilizing local energy systems, which typically combine multiple buildings, integrating external renewable energy sources and, in many cases, are designed to be governed by citizen-driven energy communities. Given the complex nature of PEDs, it is unsurprising that the potential drivers of and barriers to their design, implementation and operation are multifaceted.

The aim of this paper is to introduce the concept of additionality in the evaluation of PEDs, addressing the following fundamental question: "Do PEDs offer tangible additional benefits, and if so, under what circumstances and through which mechanisms?". To answer this question, we examine three PED developments in three different cities: Amsterdam, Évora and Espoo. These are lighthouse cities in the three aforementioned EU-funded projects, representing a range of city characteristics and contexts, as well as different PED designs.

## 2. PEDs and Additionality Concept

### 2.1. What Are Positive Energy Districts?

The PED concept is an emerging approach to achieving sustainable urban development and addressing the challenges of climate change and energy security; however, its definition is not unambiguous [8]. In broad terms, a PED can be considered as an urban area that aims to achieve a positive or net-zero energy balance by producing more energy from renewable sources than it consumes [18]. This is achieved by the installation and integration of renewable energy systems (RESs) (such as photovoltaics (PVs), battery energy storage systems (BESSs), etc.) and by optimizing energy consumption in buildings in the district. PEDs can be of any size, from a small neighborhood to a large city district, physical or digital, and address different aspects of the energy spectrum, such as use in buildings and transportation and energy-grid stability [3,19].

From an environmental standpoint, PEDs aim to reduce GHG emissions, playing a crucial role in mitigating climate change [11]. Moreover, they contribute to improved air quality, fostering healthier living environments and enhancing the overall well-being of communities [20]. Additionally, from an economic perspective, PEDs aim to serve as catalysts for local growth, increasing job creation and driving innovation in sustainable technologies [21]. It is worth noting that PEDs are expected to foster a sense of community unity by actively engaging residents in energy conservation practices and encouraging their participation in renewable energy production initiatives [22].

While PEDs are gaining traction, there are various factors that influence their progress, both positively (drivers) and negatively (barriers). Advancements in technology and RES penetration, political will and policy development, economic incentives, supportive governance, active community engagement and ongoing research and development efforts are key drivers of the wider development of PEDS as they promote and make them more viable and accepted [23–25].

On the other hand, barriers pose challenges that need to be addressed for the successful implementation and extensive adoption of PEDs. These obstacles include technical complexities, financing aspects, governance and legal restrictions, social impacts and difficulties in replicating successful models [26–29]. Understanding these major —and, in some cases, conflicting—categories of drivers and barriers is crucial for stakeholders aiming to promote the sustainable development of PEDs. For instance, RESs play a crucial role in achieving PED targets [30]; however, there are cases in which promising legislative frameworks aimed at promoting RESs have not been translated into comprehensive policy implementations [31].

Barriers to and drivers of PEDs have been studied and addressed in many research and innovation projects, such as, for example, in [9,32]. However, we observed that these projects often include aspects unrelated to the PED concept, meaning that they could also be applied to individual and unconnected buildings. For example, the barriers to energy efficiency in buildings are very relevant for policies and measures, but they are already being applied extensively without any associations with PEDs. This shows that addressing these barriers and enhancing drivers, including energy efficiency measures in PED projects, are not enough to accelerate energy efficiency.

### 2.2. Assessing the Additionality of PEDs

Additionality refers to the concept of causing a benefit that is additional to what would have occurred without the implementation of a specific project or initiative [33]. In the context of PEDs, additionality encompasses broader considerations of district-scale energy planning. It often relates to the additional energy savings, renewable energy generation and utilization, or GHG emission reductions that result from the implementation of sustainable energy projects within a district.

In this paper, our focus is on identifying the drivers and barriers specific to PEDs that can potentially be influenced by a PED approach.

Through this assessment, we aim to draw conclusions regarding the concept of additionality. Furthermore, ensuring that a specific project, initiative, or service genuinely contributes to the goals of PEDs is crucial. Therefore, establishing a baseline is necessary to determine whether the PED approach has resulted in any additional impact and is worth pursuing. It should be noted that additionality serves as a complementary, albeit distinct approach, for assessing barriers and drivers based on monitoring key impact indicators, a practice commonly employed by most R&I projects. This paper focusses on assessing the three main impact areas of PEDs [34], as presented in Figure 1. The PED areas selected for assessment (Figure 1) are analyzed below.

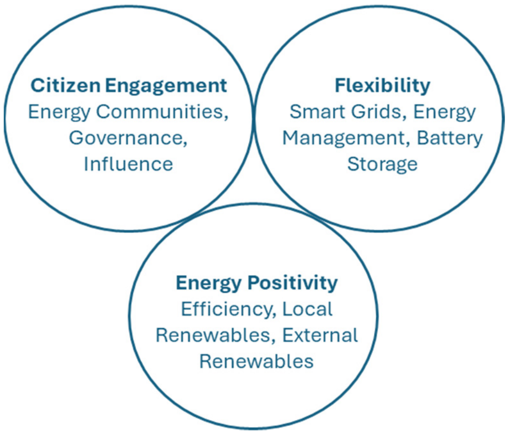


**Figure 1.** PED areas selected for assessment.

*Impact area 1: High energy efficiency and local renewable energy production to achieve energy positivity*

Energy positivity in PEDs can be achieved through increasing energy efficiency, local renewable energy production and integrating external renewable energy production into the PED energy system. This represents a demanding benchmark, even for new constructions, despite current regulations and practices already leading to near-zero-energy buildings at baseline. However, the PED energy balance may also include energy use from appliances and other sources not directly connected to the buildings. Achieving this benchmark is even more challenging in existing buildings, particularly through renovation.

*Impact area 2: Increasing the flexibility of the local energy system*

PEDs aim to increase energy flexibility by maximizing self-consumption and minimizing peak power demand through the installation of smart (micro) grids, energy management and battery storage. An energy system is flexible if it can meet (and reduce) peak load demand cost-effectively, reliably, and across all time scales. This means that the system must be able to balance supply and demand, even when there are fluctuations in variable renewable energy output. To achieve this, the system requires sufficient storage capacity, including both electricity storage and, through sector coupling, renewable heat and gas storage. This allows the system to balance periods of high variable renewable energy generation with periods of high demand, but low generation. In locations where the existing grid infrastructure is becoming a constraint on new connections and the growth of renewable energy production, increasing energy flexibility is particularly important. For example, in the city of Amsterdam, energy flexibility is crucial due to net congestion issues. Similarly, in the city of Espoo, the district heating and cooling system, as well as heating peak demands, are also critical considerations in achieving energy flexibility.

*Impact area 3: Citizen engagement in the governance of PEDs*

PEDs aim to involve citizens and other local stakeholders in governance and provide opportunities for residents to influence and interact with energy systems, particularly through energy communities. This is based on the hypothesis that increased involvement would enhance the benefits for citizens and increase the impact of PED's societal goals.

*The framework for assessing additionality*

In the context of PED developments in Amsterdam, Évora and Espoo, the question of additionality arises as follows: What is the realized impact of a demonstration PED project compared to the baseline if the R&I project had not been implemented? It is worth noting that impact is also correlated with cost-effectiveness; if a PED achieves the same impacts as the baseline but at a lower cost, this represents an added benefit. Figure 2 illustrates the systematic evaluation of the additional benefits derived from the PED approach. The workflow begins with identifying the key barriers and drivers within the three main impact areas relevant to PEDs. It then assesses whether these factors are influenced by the PED approach. Depending on this assessment, the analysis either considers the typical benefits derived from standard interventions or identifies the additional benefits that can be directly attributed to the PED approach. Finally, the overall benefit is determined by combining both typical and additional benefits.

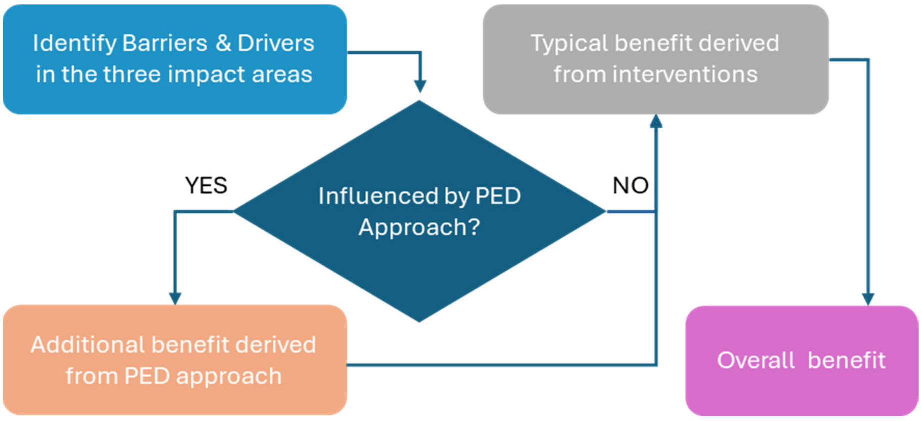


**Figure 2.** Flow diagram reflecting PED additionality.

The logical framework for addressing the additionality of PED cases is explained in Figure 3. For instance, the GHG emissions in an area after the implementation of the PED concept are calculated, partly based on measured energy production and demand data, and then compared to a baseline scenario without a PED. If these emissions are lower for the PED scenario, the PED can be considered as providing additional benefits for this specific impact.

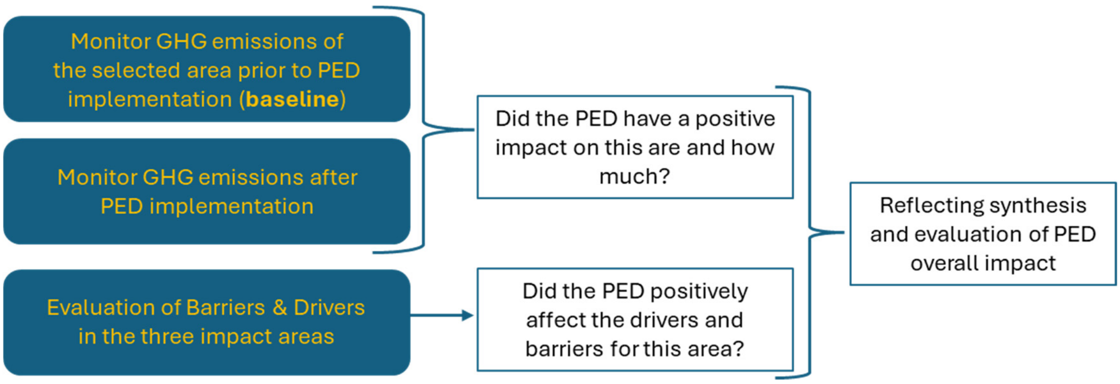


**Figure 3.** Example of addressing additionality framework.

*Objectives of the R&I projects and the role of PED demonstration cases*

The objectives of the three R&I projects, as presented in Figure 4, share a common goal: to explore and investigate the feasibility and design of PEDs and their impact, resulting in scientific insights and recommendations for policymakers, urban planners and other stakeholders. The primary R&I activity is related to the implementation and operation of actual PEDs, which undergo both ex ante and ex post monitoring and evaluation of their impacts. These demonstrations also contribute valuable input to research on business models, social aspects, governance structures, energy system optimization and replication.

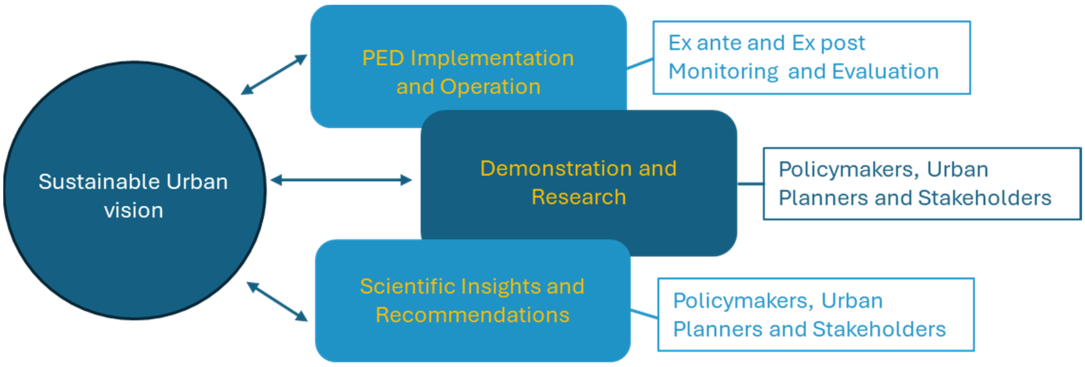


**Figure 4.** Objectives of the three R&I EU-funded projects.

At a broader level, cities are shaping their visions of a more sustainable future and decarbonizing urban environments. The expected impacts of these demonstrations are based on central hypotheses regarding the added value of the PED concept for relevant societal goals, compared to a baseline scenario without the PED approach and without the R&I project (as the baseline). The scope of impacts to be considered was specified in the terms of reference for the Horizon 2020 call for proposals [35], aligning with the R&I questions on PEDs stemming from emerging European policies aimed at the ambitious climate targets set by the European Union.

As PEDs vary in size and shape, the three PEDs studied have served as demonstration areas in three European research and innovation (R&I) projects. The assessment of the case studies is presented in the following sections.

## 3. Évora Case Study

*Description of the PED in Évora*

Évora holds national and international recognition for its recovery policies and heritage preservation. Since 2012, Évora has been implementing its Sustainable Energy Action Plan (SEAP), aiming at reducing its energy consumption, reducing carbon dioxide ($CO_2$) emissions by 20% in comparison with 1990 levels and promoting a sustainable use of energy. Energy efficiency has become a policy priority for Évora municipality due to its ability to address challenges such as reducing dependence on imported energy, reducing GHG emissions and improving economic competitiveness. The city is divided into three regions: the city center, a rural area and a technological and industrial park, where three PEDs are implemented. Different conditions enable testing different solutions in different environments, resulting in multiple conclusions and lessons learned, however, in this paper, only the city center will be analyzed in detail. The Évora PED is a pioneering project located in the historic city center of Évora, a World Heritage Site. The project incorporates eight municipal buildings, two parking lots and eleven residential and commercial clients, with the goal of achieving energy positivity while preserving the city's cultural heritage.

The PED's innovative solutions address the unique challenges of this location, where heritage preservation legislation mandates the careful consideration of energy efficiency and production. Key solutions include the installation of building-integrated photovoltaics (BIPVs) and building management systems (BMSs) in municipal buildings. The BIPV solutions that will be installed in the municipal buildings in the historical city center, namely PV glasses and PV shingles, will contribute to the positivity with 380 kWp of installed capacity estimated in 440 MWh of energy production yearly. This is aligned with the EU 2030 Climate and Energy Framework, which aims to cut GHG emissions by 40% compared with 1990 levels. A 5 MW community solar farm (CSF) has been established outside the city center, enabling citizens to invest in renewable energy production, as they are not permitted to install conventional PV panels on their rooftops. This solution allows city center residents to virtually participate in solar energy production, overcoming heritage-related barriers and promoting the goal of energy positivity. At the end of the project, this PED will have 117% of the total energy need covered by local RES, which mean not only that all the energy need will be met by renewable energy production, but also that it will have a surplus of 17%.

The PED project also features a range of cutting-edge technologies, including energy routers, smart inverters, EV chargers integrated with flexibility algorithms, smart lamp posts and a pay-as-you-throw (PAYT) system. These solutions demonstrate a multifaceted approach to enhancing energy efficiency and management, showcasing the potential for sustainable energy solutions in historic urban environments. With regard to residential clients, the introduction of a home energy management system (HEMS) offers a way for households to engage in energy conservation and optimization actively. These systems empower residents to manage their energy consumption better while contributing to the district's broader energy sustainability goals.

*Impact area 1: Barriers and drivers related to energy efficiency and renewable energy production in the PED*

When developing a PED, it is important to acknowledge that historical cities are under heavy European and national legislation, and so, to install solutions that can result in a positive energy balance, it is essential to obtain necessary authorizations. For this purpose, it is crucial to have the local municipality engaged, as they are the authorities that will have to interact with the local cultural agency. The municipality of Évora was required to prepare a comprehensive document to explain and guarantee that the solutions that would be installed would not interfere with the aesthetic appearance of the city. To achieve this, selecting technologies that can be discreetly installed, such as BIPVs, is important. In the case of POCITYF [15], manufacturing companies were involved in the project consortium. Alternatively, if companies are not part of the consortium, it is essential to research and identify companies that offer these technologies and ensure that their availability aligns with the project timeline. The municipality of Évora prepared a comprehensive document, which was submitted to the Cultural Regional Agency (in Portuguese, Direção Regional da Cultura); however, the authorization was only given after a second round of interaction, almost two years after the beginning of the process.

Given the time-consuming nature of these processes, it is crucial to initiate the authorization process at a very early stage of the PED project. Failure to do so may jeopardize the project timeline, particularly during the lengthy monitoring phase. Following the authorization phase, if the solutions are to be installed in municipal buildings, public tenders must be prepared. Similarly, the tender process is also time-consuming. However, if the municipality recognizes the benefits of these solutions for the city, it is easier to move through that process.

The development of this PED has faced two major challenges: the legislative obstacles surrounding BIPV installation and the limited availability of injection points. The PED's objectives are multifaceted, aiming to achieve energy positivity, navigate regulatory challenges related to its World Heritage Site status, boost local energy generation, deploy EV chargers with flexible algorithms, integrate smart waste management within the PAYT system and promote citizen engagement through mobile apps and HEMS. This holistic approach tackles the pressing issue of urban energy management while encouraging community participation and engagement in sustainable practices.

Table 1 presents the main drivers of, and Table 2 presents the barriers that may be faced by, the PED approach in the city center of Évora.

**Table 1.** Drivers of energy efficiency and RES, and observations on the impact of the PED approach in Évora.

| Drivers | Relevance to PED Approach | Has the PED Strengthened This Driver? |
|---|---|---|
| EU Funding and Legislation:<br>EU-funded projects | Yes. For historical cities, it is necessary to have innovative solutions, such as BIPV, which are still very expensive, to reach positivity (or at least, contribute to local production). | Yes. The grants made additional solutions installation possible. |
| Sustainability Goals and Urban Transformation:<br>Urban environment and climate change goals | Yes. Possessing a proven track record of efforts to meet the European Union's goals for building a resilient energy system and implementing a bold climate policy is crucial for ensuring security, sustainability, competitiveness and affordability to achieve a PED. | No. These goals were already set before inclusion of the buildings in the PED. |
| EU Funding and Legislation:<br>Changes to existing legislation to realize the full potential of sustainable technologies | Yes. The objective is to have more production than consumption within the city center, taking advantage of current technologies to reduce GHG emissions and increase citizens wellbeing. | Yes. The project created solutions to overcome this type of inequality. |

**Table 2.** Barriers to energy efficiency and RES and observations on the impact of the PED approach in Évora.

| Barriers | Relevance for PED Approach | Has the PED Reduced This Barrier? |
|---|---|---|
| Regulatory and Contractual Barriers:<br>European Legislation | High. The installation of the RES in the city center is necessary to reach positivity. | No. The PED approach did not contribute to the reduction of this barrier. |
| Technical Barriers and Grid Integration:<br>Injection-point unavailability | High. To have more production in a certain area, it is important to have availability of the grid to install these technologies. | No. The PED approach did not contribute to the reduction of this barrier. |
| Resident and Community Engagement Challenges:<br>Citizens' engagement | High. Contributes to achieving energetic positivity for the area, and fosters a sense of community ownership and participation in sustainable practices. | Yes. The PED approach contributed to the reduction of this barrier. The CSF offered a solution, enabling citizens residing in the city center to participate in solar energy production virtually, as if the panels were installed on their own rooftops. |

Significant drivers are EU-funded projects, which align with the EU's 2030 targets by utilizing funds to accelerate the energy transition, particularly through the adoption of expensive technologies. Urban environment and climate change goals present opportunities for historical cities. However, these cities struggle to meet climate change and energy transition goals due to existing legislation, which hinders the achievement of EU targets. Changes to existing legislation to realize the full potential of sustainable technologies are also drivers as revising current laws could allow for the installation of RESs in historical cities, creating opportunities for technologies that respect cultural heritage.

Several challenges hinder the energy transition in historical cities. One major obstacle is European legislation, which restricts the installation of RESs in historical city centers, such as Évora, which is listed on the World Heritage List. This protective legislation, while essential for preserving cultural heritage, makes it difficult to deploy sustainable technologies in areas that need energy upgrades the most.

Another significant barrier is the injection-point unavailability in the electrical grid. The grid in Portugal was originally designed for centralized energy production, and with the increased penetration of renewables, grid congestion is becoming a problem. This lack of capacity to integrate more renewable energy, like solar PV plants, creates bottlenecks, slowing down the expansion of clean energy infrastructure.

Citizens' engagement is also crucial, but challenging. Involving the public in the energy transition is essential to ensure they are at the center of the process. Building trust and maintaining open communication with citizens are necessary to encourage their active participation in and acceptance of sustainable projects. Without this engagement, local support may falter, affecting project outcomes.

***Impact area 2: Barriers and drivers related to flexibility of the energy system***

Within the PED are installed three EV chargers, each with a capacity of 7.2 kW, alongside three batteries, each with a storage capacity of 30 kWh. As part of the initiative for decarbonization, one EV charger and battery will be deployed within the Living Laboratory for Decarbonization (LVpDÉ), with an additional two EV chargers and two batteries to be installed at the City Hall.

These assets are planned for integration into the EV Management Platform, where flexibility algorithms will be employed to optimize self-consumption and enhance cost savings. Moreover, the implementation of BMS across all eight municipal buildings offers users the ability to monitor energy consumption and production in real-time. This data-driven approach facilitates optimization strategies, empowering active user participation in energy management initiatives. The main drivers of energy flexibility are EU project financing to cover equipment costs, such as batteries and EV chargers, and installation expenses. Another positive factor is the limited availability of available solutions to increase savings due to legal restrictions on installing RESs. However, since these solutions were installed in municipal buildings, it was necessary to launch public procedures for the installations, which proved to be very time-consuming.

The following tables present the main drivers (Table 3) and barriers. One important driver is financing from EU projects, which plays a crucial role in supporting the development of sustainable technologies. Since many of these technologies remain costly, EU funds are essential in boosting their advancement. Another key factor is the limited range of options for increasing self-consumption. Technologies that are compatible with the preservation of cultural heritage are both limited and expensive, making it difficult for historical cities to fully participate in the energy transition.

**Table 3.** Drivers of energy system flexibility and observations on the impact of the PED approach in Évora.

| Drivers | Relevance to PED Approach | Has the PED Strengthened This Driver? |
|---|---|---|
| EU Funding and Legislation: Financing from EU projects | High. | Yes, PED development is a critical component in the context of sustainable cities, as it increases the possibilities of funding for such initiatives. PEDs are being developed as key components for energy-efficient environments, recognizing the significant role of cities in the energy transition. |
| Local Renewable Energy and Efficiency: Limited options to increase self-consumption | High. Storage and RES equipment increases self-consumption, helping to compensate for the low capacity installed in the buildings. | Yes, increasing self-consumption is critical to decrease dependency on the grid and reach positivity. |

Table 4 shows how energy system flexibility may be impacted by the PED approach in the city center of Évora.

**Table 4.** Barriers to energy system flexibility and observations on the impact of the PED approach in Évora.

| Barriers | Relevance to PED Approach | Has the PED Reduced This Barrier? |
|---|---|---|
| Regulatory and Contractual Barriers: Public tenders | High. Without the public tenders, the systems could not be installed. | No, this procedure is mandatory given that the municipalities were responsible for installing the solutions, and the PED approach did not influence it. |

One important driver is financing from EU projects, which plays a crucial role in supporting the development of sustainable technologies. Since many of these technologies remain costly, EU funds are essential in boosting their advancement. Another key factor is the limited options for increasing self-consumption. Technologies that are compatible with the preservation of cultural heritage are both limited and expensive, making it difficult for historical cities to fully participate in the energy transition.

Public tenders in Portugal present a barrier due to lengthy bureaucratic processes. The internal inertia within municipalities causes significant delays in decision-making and implementation. These time-consuming processes slow down the development of critical energy transition projects and add layers of complexity to an already challenging process.

*Impact area 3: Barriers and drivers related to citizen engagement in PED governance*

The citizen engagement aspect emerged as a key factor in realizing the objectives of Évora's PED project, which was primarily aimed at placing citizens at the forefront of the energy transition. Central to this approach were three distinct engagement campaigns:

1. Targeting city center residents equipped with PV panels—installed prior to the legislation forbiting their installation—where the installation of HEMS was essential in enhancing energy efficiency through behavioral changes. This initiative was crucial in enhancing energy efficiency through behavioral changes, fostering a culture of sustainability among residents.
2. Engaging clients to participate in testing the PAYT solution underscored our commitment to innovative waste-management practices. This approach not only promoted efficient waste management but also encouraged citizens to take an active role in reducing waste and promoting a cleaner environment.
3. The utilization of digital applications developed within the project framework constituted a third avenue of engagement. These applications included a tourist app incentivizing exploration through point accrual, a city information platform offering access to pertinent urban data such as weather, traffic and energy community presence, as well as a cultural experience marketplace facilitating access to events while rewarding citizen participation.

These engagement campaigns were critical in realizing the objectives of Évora's PED project, as they placed citizens at the forefront of the energy transition, empowering them to make behavioral changes that enhance energy efficiency and contribute to the societal objectives of PEDs (Table 5).

**Table 5.** Drivers of citizen engagement and observations on the impact of the PED approach in Évora.

| Drivers | Relevance to PED Approach | Has the PED Strengthened This Driver? |
|---|---|---|
| Sustainability Goals and Urban Transformation: Include citizens in the transformation of the city | High. Needed for the wide penetration of PEDs. | Yes, through the changes in citizens' behavior, it is possible to increase self-consumption and decrease the amount of energy purchased from the grid. |

A key driver is the need to include citizens in the transformation of the city. In Portugal, public tenders often face significant delays due to internal inertia within municipalities, where bureaucratic processes and administrative inefficiencies slow down decision-making and implementation. This hampers the ability to involve citizens effectively in urban transformation efforts, which is essential for achieving energy transition and sustainability goals.

On the other hand, another hurdle is the interest of citizens to be active throughout the project. While initial enthusiasm may be high, maintaining this engagement over the duration of the project is difficult. Building trust can take time, and the lack of technical knowledge among citizens often hinders their full understanding of the project's benefits, which in turn diminishes their motivation and involvement over time.

Table 6 presents the drivers of citizen engagement that may be impacted by the PED approach in Évora.

**Table 6.** Barriers to citizen engagement and observations on the impact of the PED approach in Évora.

| Barriers | Relevance for the PED Approach | Has the PED Reduced This Barrier? |
|---|---|---|
| Resident and Community Engagement Challenges:<br>Interest of the citizens in being active throughout the project | High. Needed for energy positivity. | Yes, it is essential to develop strategies for realizing participatory processes that involve citizens from the beginning phase. Building trustful and reliable relationships between citizens and local authorities is critical to the success of PEDs. |

In Évora, the concept of additionality is clearly demonstrated through the PED project's tangible impacts, which would not have occurred without its implementation. The PED has driven technological innovation, policy alignment and stakeholder engagement, while overcoming barriers like regulatory constraints and financing challenges. It has also fostered energy communities that reduce energy costs, increase local production and promote social cohesion. The project's financial benefits are clear, with BIPV systems installed at no cost to the municipality, leading to long-term energy savings. These outcomes showcase the PED's role in accelerating Évora's sustainable energy transition.

## 4. Amsterdam Case Study

*Description of the PED in Amsterdam*

Amsterdam is undertaking the transformation of a former industrial neighborhood, Buiksloterham, into a sustainable area featuring a blend of residential and commercial spaces. Within this development, two new building blocks in separate locations totaling 22,000 $m^2$ are being constructed to become part of a PED. The first block, named República, consists of 55 apartments alongside various utility buildings, such as a hotel, restaurants and a shared office space, totaling six structures [36]. The second block, "Poppies", comprises 100 apartments.

It is envisaged that these will be complemented by an external PV plant outside the actual PED area. This additional PV production is necessary, because the two blocks cannot be made energy-positive, as a result of the limitation on integrating more PVs or other forms of renewable energy production (lack of roof space, grid congestion and unfavorable business case). Additionally, a biogas plant using the waste streams from the PEDs is planned.

All three PED components will be integrated into a local energy market, with an energy storage battery installed at the República site.

The construction phase of the PED in Amsterdam has now been successfully completed, marking the beginning of the official monitoring period. This monitoring phase, which is critical for gathering data on the district's performance and impacts, will continue until the end of 2025. After the conclusion of the monitoring, a comprehensive evaluation will be conducted to assess the actual impacts of the PED. As the monitoring has just started, no concrete results are available at this time. Therefore, the current assessment of additionality presented in this document is based on preliminary estimates and is intended to serve as an illustrative example of how the additionality concept will be applied in future evaluation processes.

*Impact area 1: Barriers and drivers related to energy efficiency and renewable energy production*

A wide range of energy efficiency measures and RES integrations have been implemented in the two building blocks of the PEDs, incorporating a range of cutting-edge technologies. These measures include the following:

- Greater-than-building-standards insulation to minimize heat loss and enhance thermal efficiency.
- A centralized heat pump plant for heating, complemented by distributed booster heat pumps. These are combined with subsoil Aquifer Thermal Energy Storage (ATES) to increase the coefficient of performance for both heating and cooling.
- Extensive coverage of the building roofs with the integration of 191 high-performance PV panels.
- Heat recovery systems to capture and recycle waste heat.
- Additional thermal storage buffers to afford flexibility in controlling heat pumps.

As a result, the level of energy efficiency and RES production in the PED building blocks was higher than the baseline, as reflected by the relevant regulation. However, this was not enough to achieve energy positivity, although this technically would have been possible [37,38].

The primary drivers behind the project's sustainability standards were the initial developer-set standards and additional financing from the R&I project. The PED approach's potential drivers of energy efficiency and RES did not have a verifiable impact. In contrast, the second building block of the Amsterdam PEDs, where the municipality owned the land and initiated a tender with high energy performance demands, showed a different outcome.

The additionality of external RES production is debatable. For the Amsterdam PED demonstration, the project requirement for energy-positive buildings was the main driver. The PED approach enabled the integration of buildings and infrastructure, including a largely RES-based heating system. The connection to local PED grids and potential financial benefits could improve the business case for external RES production, but this will not be demonstrated in the Amsterdam project due to construction and sourcing delays (Table 7).

**Table 7.** Drivers of energy efficiency and RES and observations on the impact of the PED approach in Amsterdam.

| Drivers | Relevance to PED Approach | Has the PED Strengthened This Driver? |
|---|---|---|
| EU Funding and Legislation: Changes to existing legislation to realize the full potential of sustainable technologies | Current building regulations in the Netherlands require new buildings to become close to zero-energy. | Regulation is part of the baseline and is not influenced by a PED approach. Furthermore, the baseline is dynamic, as regulation of building performance is becoming strict, reducing the difference between baseline and PED. |
| Sustainable Building Projects: Quality standards for buildings set by project developers and/or the municipality | High energy efficiency and RES standards are needed to achieve energy positivity. In some cases, the standards are set at a higher level by the developers and/or the municipality (selling the land). | These standards were already set before inclusion of the buildings in the PED. However, by demonstrating the viability of the concept, they could move the baseline forward in the long term. |
| EU Funding and Legislation: EU-funded projects | Additional energy efficiency and RESs are needed to achieve energy positivity. | The grants made additional EE and RES measures possible. Some of the EE and RES measures in the PED were covered by the EU grant. |

A range of factors propel the energy transition in historical cities. EU funding and legislation remain pivotal, with EU funding projects aligned with the European targets for 2030 aimed at boosting the energy transition through the adoption of expensive, yet essential technologies. Additionally, changes to existing legislation to realize the full potential of sustainable technologies are critical; by updating laws, the EU can remove barriers and facilitate the integration of renewable energy systems in historical contexts. Quality standards for buildings set by projects ensure that new developments meet stringent sustainability criteria, promoting energy-efficient construction while preserving cultural heritage. Table 8 presents a summary of the barriers related to energy efficiency and renewable energy production.

**Table 8.** Barriers to energy efficiency and RES and observations on the impact of the PED approach in Amsterdam.

| Barriers | Relevance to PED Approach | Has the PED Reduced This Barrier? |
| --- | --- | --- |
| Market and Financial Barriers: Integrating energy efficiency and RES in the building design | Both are crucial to achieve energy positivity, beyond current (regulated) practice in new buildings in the Netherlands. | In the Amsterdam PED, there is no indication that the PED approach has directly contributed to the building design, as a result of (1) a mismatch in time (the design was almost finished before the PED project started) and (2) the lack of a business case or other arguments for subsequent modifications to the design. |
| Regulatory and Contractual Barriers: Additional costs of energy efficiency and RES | Needed to achieve energy positivity. Currently, in most cases, the business case for EE and RES beyond regulation is not positive. | The business model of the developers did not allow for enough energy efficiency and RES to achieve energy positivity. The PED approach did not provide additional drivers for an improved business case for EE and RES. |
| Regulatory and Contractual Barriers: Barriers to the implementation of energy efficiency and RES measures | In the Netherlands, new buildings, in almost all cases, comply with regulation. Investments in additional energy efficiency and RES is rare. | The experiences with implementation of energy efficiency and RES measures in the PED has provided insight into ways to address these barriers. |
| Technical Barriers and Grid Integration: Difficulties in the building development and design process and the PED project | High. The PED approach should be able to influence the design of buildings from the start. | Partly. The development and project design had started before a PED approach was adopted. |

Various barriers complicate the implementation of energy efficiency and RES cities. Integrating energy efficiency and RES in the building design can be challenging, as aligning sustainability goals with architectural standards may be complex. Moreover, the additional costs of energy efficiency and RES measures increase the financial burden on projects, making them less attractive for investors and building owners. Furthermore, the difficulties in the building development and design process and the PED project add another layer of complexity, as balancing sustainability with architectural preservation often creates design challenges that slow down project progress.

***Impact area 2: Barriers and drivers related to flexibility of the energy system***

The PED in Amsterdam features a centralized battery system, smart EV chargers and distributed smart-grid-ready heat pumps, managed by an advanced EMS to optimize self-consumption and minimize peak power demand. However, the project faced challenges in legal and organizational aspects, including contract establishment and asset integration. Delays were caused by issues with billing, tax application and the integration of the battery into the management system. An unforeseen barrier emerged due to congestion in the electricity grid, limiting energy system usage. The local flexible energy market is crucial, but current congestion issues pose challenges.

The main drivers of energy flexibility are the strategic and commercial interests of private sector parties developing flexibility technologies for local grids, the urgency of congestion management in the city and the project financing available for measures such as the battery and development costs (Table 9). In the city, a growing number of R&I projects address energy flexibility; however, there is no evidence yet that the integration of energy flexibility within a PED has strengthened these drivers or reduced the existing barriers (Table 10), beyond the availability of project resources.

**Table 9.** Drivers of energy system flexibility and observations on the impact of the PED approach in Amsterdam.

| Drivers | Relevance to PED Approach | Has the PED Strengthened This Driver? |
|---|---|---|
| Local Renewable Energy and Efficiency: Increasing congestion bottlenecks in the city | PED aims for increased flexibility to allow higher densification of RES in the PED and to become a source of income (selling services to the grid). This strongly depends on the location. | In the Amsterdam PED, the flexibility system is not yet operational, so its impacts have not been demonstrated yet. The project faces both technical and financial obstacles, so that both technical feasibility and a positive business case, crucial for upscaling and replication, cannot yet be demonstrated. |
| Sustainable Building Projects: Increasing markets for products and services in energy flexibility | R&I projects on PEDs aim to bring these products and services closer to the market to speed up implementation. | The Amsterdam PED was only one of many R&I projects over recent years that addressed flexibility in energy system. None of these projects were part of an overall PED approach. |
| EU Funding and Legislation: Grant financing for investments and development of systems | To date, the majority of PEDs have been implemented with grant support from R&I projects. | The grants were essential in covering the additional costs of these measures (such as the battery and the energy management system). |

**Table 10.** Barriers to energy system flexibility and observations on the impact of the PED approach in Amsterdam.

| Barriers | Relevance to PED Approach | Has the PED Reduced This Barrier? |
|---|---|---|
| Technical Barriers and Grid Integration: High R&I costs for system development | The assumption is that the PED approach would improve the affordability and business case for flexibility-related products and services that are needed to allow more RESs. | The PED project has brought these systems to a higher TRL level. However, there are no clear signs that a significant market share with significant impact can be achieved soon. |
| Technical Barriers and Grid Integration: Affordability of flexibility systems for PEDs | Without affordable systems, flexibility options cannot be included in the PED. | To date, there is no evidence of products that would be affordable for potential users. Business models remain immature. Furthermore, development times are still too long. However, demand may increase with increasing congestion problems in Amsterdam. |
| Technical Barriers and Grid Integration: Lack of uptake of smart EMS by building owners and users | These systems are necessary to introduce energy flexibility in local energy systems. In PEDs, it is assumed that residents and other stakeholders take ownership of these systems and benefit from the advantages. | The main drivers of smart buildings are not specific to PEDs, the developing regulation on building management systems for utility buildings, or the increasing insights into costs and benefits. |
| Technical Barriers and Grid Integration: Lack of quantitative knowledge on the benefits impact of flexibility measures | Energy flexibility is assumed to be a key innovation in PEDs. In the EU, in the Netherlands and in Amsterdam, many R&I projects are ongoing, exploring and demonstrating the feasibility, impact and benefits of flexibility measures at building and district level. | The project has brought together researchers, product developers and other stakeholders. The investigation of grid balancing services was new. The project has provided insight into the business case for energy communities in PEDs to invest in flexibility measures. However, the final evaluation on technical and economic feasibility is still outstanding. |
| Technical Barriers and Grid Integration: Connection restriction due to congestion | The assumption is that the PED approach would improve the affordability and business case for flexibility-related products and services that are needed to allow more RESs. | The PED project has brought these systems to a higher TRL level. However, there are no clear signs that a significant market share with significant impact can be achieved soon. |

Sustainability goals and urban transformation push cities to adapt to climate change targets, although historical cities often face challenges due to restrictive legislation. To overcome this, revisions in legislation are being considered to enable the installation of renewable energy systems compatible with cultural heritage. Financing from EU projects plays a crucial role in supporting the development of sustainable technologies, as many remain costly, and EU funds are essential in advancing their implementation. The limited options for increasing self-consumption highlight the need for more affordable and culturally compatible technologies to allow historical cities to participate fully in the energy transition.

High R&I costs for system development present a significant financial hurdle for the research into and development of advanced systems for PEDs. Similarly, the affordability of flexibility systems for PEDs remains a concern, as these systems are often costly to install and maintain, limiting widespread adoption. Additionally, the lack of uptake of smart EMS by building owners and users hinders the integration of smart technologies, largely due to unfamiliarity with their benefits. The lack of quantitative knowledge on the benefits and impact of flexibility measures further impedes progress, as stakeholders are often unsure about the tangible value these systems provide. Finally, connection restrictions due to grid congestion represent a physical limitation, as the outdated grid infrastructure struggles to accommodate the increased energy flow from renewable sources.

*Impact area 3: Barriers and drivers related to citizen engagement in PED governance*

The Amsterdam PED demonstration aims to establish this governance structure for the full local system and its assets, including not only renewable energy production, but also the use of energy storage and energy trading, both internally and externally. Alternative juridical models for this energy community have been investigated. The PED residents and other legal entities that occupy property in the PED, such as hotel, office space and food and beverage operators, which will become members of the energy communities, have been engaged and consulted. It is likely that residents would not have organized an energy community without the project developers' and R&I project's initiative and support.

The drivers contributing to the development of participatory governance in local energy systems include political and policy support at both national and local levels, including the municipality of Amsterdam (presented in Table 11). Additionally, many research and innovation projects are supporting the establishment of local energy communities. Strong motivation among a segment of the population to take initiatives is also a key factor. Furthermore, ongoing legal reform is aimed at facilitating the development of energy communities.

**Table 11.** Drivers of citizen engagement and observations on the impact of the PED approach in Amsterdam.

| Drivers | Relevance to PED Approach | Has the PED Strengthened This Driver? |
|---|---|---|
| Sustainability Goals and Urban Transformation:<br>Growing political and societal support for local governance of energy systems | In this initial phase, PED development in Amsterdam is strongly reliant on this support. The city of Amsterdam is project coordinator of the PED project, indicating their initial interest in PEDs. | There are no indications that this momentum is influenced by holistic approaches in PEDs in Amsterdam. PEDs are still very unknown to both politicians and civic society. In Amsterdam, the municipality has had a very limited role in the implementation of the PED project, which is indicative of the barriers to embedding the results of the R&I project into the city's policies and planning. |
| Local Renewable Energy and Efficiency:<br>Foreseen economic benefits of self-production, consumption and energy sharing/trading | In Amsterdam, commercial parties, including SMEs, play a key role in initiating local energy projects, including PEDs, based on their expectations of positive future business cases. At the same time, a further hypothesis is that PED residents will profit financially from these new energy services. | The first indications, to be substantiated on the basis of final monitoring results, are that the business case for commercial parties offering products and services for PEDs are less favorable than initially expected. From the residents' perspective, the additional PED measures and investments in PV were not reflected in $m^2$ purchase price for their apartment. It is not yet clear how satisfied residents are with the energy bills, which were initially higher than expected. |

On the other hand, several hurdles have been identified in the functioning of the energy community (presented in Table 12). These include low resident knowledge or interest, a lack of feelings of ownership and the different statuses of residents, such as renters, owners and commercial parties. Administrative challenges without a dedicated budget also pose a problem, as does the option for residents to opt out of the concept.

**Table 12.** Barriers to citizen engagement and observations on the impact of the PED approach in Amsterdam.

| Barriers | Relevance for the PED Approach | Has the PED Reduced This Barrier? |
| --- | --- | --- |
| Resident and Community Engagement Challenges: Lack of knowledge/motivation among residents | The energy community governing the PED strongly depends on voluntary contributions from the residents and other inhabitants of the PED. | The residents in the PED demonstration have been informed by project researchers. It remains to be seen whether they are motivated enough to engage in PED governance in the longer term. Not everyone is prepared to dive deep into energy systems. Research into their motivation is ongoing. |
| Resident and Community Engagement Challenges: Lack of opportunities for residents to become engaged and interact with the energy systems and markets | The influence of residents on their living environment is considered an important pre-requisite for a successful PED. | In República, the energy community members have been able to influence the operation of the energy community. However, many decisions on the design of the Amsterdam PED and the community were made before residents moved in and offered their views. This has restricted the engagement. |
| Regulatory and Contractual Barriers: Complex and restrictive regulations for (energy) contracting | Without an enabling regulatory environment, the flexibility of the PED energy system cannot be achieved. | Options for (legal) governance were explored in the project, but systemic barriers remain. This is subject of future energy law reform that is debated at EU and national level. It cannot be influenced by developments on a local level, such as PEDs. |
| Resident and Community Engagement Challenges: Strong dependence on the project support in involving residents and setting up the energy community organization | The majority of PEDs have been implemented in the Netherlands with grant support from R&I projects. | It is unlikely that it is possible to establish a new energy community for PEDs and have the necessary systems in place for them to interact with the energy systems and markets in a future PED with any additional project support. This seriously restricts replication in the short term. |

Growing political and societal support for the local governance of energy systems empowers local authorities and communities to manage their energy resources, fostering initiatives such as self-production, consumption and energy sharing or trading. The foreseen economic benefits of self-production, consumption and energy sharing/trading motivate stakeholders to invest in decentralized energy systems, enhancing economic resilience and reducing energy costs.

The lack of knowledge and motivation among residents acts as a barrier, as many citizens are unaware of how they can contribute to or benefit from energy systems and markets. Additionally, there is a lack of opportunities for residents to become engaged and interact with the energy systems and markets, which limits their involvement in energy-saving initiatives. Complex and restrictive regulations for energy contracting further complicate participation, making it difficult for citizens and local businesses to engage in energy-sharing or other market-based systems. The strong dependence on project support in involving residents and setting up energy community organization emphasizes the challenge of building a self-sustaining community without continued external backing.

## 5. Espoo Case Study

The Espoonlahti district in Espoo, Finland, has recently undergone significant development, with the addition of a new shopping center and central services block. This dense mixed-use area is supported by a geothermal heating and cooling plant aimed at optimizing energy use. The block spans a heated floor area of approximately 150,000 $m^2$ and includes 550 residential apartments, a senior house with around 120 apartments and a shopping center with a leasable gross area of 44,000 $m^2$.

The development incorporates renewable energy solutions, including geothermal energy, solar PV panels and battery storage, in an effort to provide a more sustainable energy supply. Public transportation access, including a new metro line and bus terminal, has been expanded to encourage reduced reliance on personal vehicles. The buildings and infrastructure in the area have been designed to focus on energy efficiency, with an emphasis on minimizing energy consumption.

Community engagement has been part of the development process, with input from local residents considered in the planning stages. However, like with many large-scale urban projects, the success of these initiatives in meeting the community's long-term needs and sustainability goals will depend on continued monitoring and adjustments.

*Impact area 1: High energy efficiency and local renewable energy production to achieve energy positivity*

The RES production on the demonstration site in Espoo includes a 4.4 MW regenerative ground source heat pump plant, with approximately 50 kilometers of bore holes. The regenerative geo-energy system also supplies 100% of the cooling demand and most of the heating demand for the center with the stores and public services, as well as the residential buildings. During the monitoring period (2 years at the time of writing) in which the building has been in operation, practically no external heat has been needed from district heating, even during the cold winter days, although the system was designed to use heat from the district heating grid in cases of prolonged cold weather. An electric boiler also exists as a reserve system. Excess heat recovered during summer from air conditioning and from the refrigeration systems of grocery stores is injected into the geo-energy field, increasing the capacity and efficiency of the system. In essence, this means that the geo-energy system is used for seasonal thermal energy storage. The building block has PV panels on the roof and building façades, with peak power of 634 kWp. The panel area is 2400 $m^2$.

In thermal energy, a positive energy balance can technically be achieved in this demonstration site, but with the current pricing of the district heating, it is not economically viable in practice to sell heating energy outside of the demonstration block. The drivers of and barriers to energy efficiency and local RES are summarized in Tables 13 and 14.

**Table 13.** Drivers of energy efficiency and local renewable and observations on the impact of the PED approach in Espoo.

| Drivers | Relevance to PED Approach | Has the PED Strengthened This Driver? |
|---|---|---|
| Sustainable Building Projects:<br>Building owners targeted to build a new shopping center, with public services, to be as sustainable and efficient as possible | High. Building a new shopping center within a PED framework can provide numerous benefits, including increased energy efficiency, reduced environmental impact, enhanced community engagement and economic development. By aligning with PED principles, the shopping center can contribute to a more sustainable and resilient future. | No. Some integrated energy system advances were made, but on the other hand, the building would also have been at Gold LEED (Leadership in Energy and Environmental Design) level [39] without the PED approach. |
| Local Renewable Energy and Efficiency:<br>Increase the use of local RES | High. Increasing the use of local RES is a crucial component of achieving the goals of PEDs. By harnessing renewable energy resources, PEDs can become more sustainable, resilient and economically viable communities. | Partly (for the dimensioning of the PV plant). Additional RES sources were studied, but the choices for the RES production were made without the PED driver. |

**Table 14.** Barriers to energy efficiency and local renewable energy production and observations on the impact of the PED approach in Espoo.

| Barriers | Relevance to PED Approach | Has the PED Reduced This Barrier? |
|---|---|---|
| Market and Financial Barriers: Business case not profitable for selling excess heat outside of PED, to the district heating grid | High. Selling excess heat to the grid can still be a valuable strategy for PEDs in certain circumstances. | No. |
| Regulatory and Contractual Barriers: Contractual difficulties: not possible to make an electricity-buying contract with a specific plant that the operator owns (outside of the PED demonstration area) | High. Without a direct contract, PEDs may be exposed to fluctuations in energy prices, which can impact their financial viability. | No. Practically, being able to have such a contract does not directly increase local RES production. Achieving energy positivity balance purely by using local RES sources does not seem feasible in the dense urban environment in Finland. |

Building owners targeting sustainable and efficient developments, such as new shopping centers with public services, drive the integration of sustainability into urban planning. Efforts to increase the use of local RES reduce dependence on external energy supplies and support local economies.

Economic and contractual barriers play a role in delaying the energy transition. Business cases not being profitable for selling excess heat outside of PEDs to district heating grids limit financial incentives for developers. In many cases, the economic model does not support selling surplus energy to broader networks, reducing profitability. Additionally, contractual difficulties, such as not being able to make an electricity-buying contract with a specific plant owned by the operator outside of the PED demonstration area, create legal and logistical challenges, stalling efforts to scale up energy sharing across different regions.

*Impact area 2: Increasing flexibility of the local energy system*

Electric batteries, together with smart energy management systems, are used to optimize and control the energy systems of the building block in the Espoo PED case. In Nordic countries, newly built complex building entities typically already have very good energy efficiency, which often requires rather advanced energy management systems. With the electric battery, this demo site has large enough energy flexibility capacity to make it possible to participate in the national electricity grid's flexibility markets. Minimized electricity costs are drivers that provide financial incentives for adopting energy-saving measures, making sustainable investments more attractive (Table 15).

**Table 15.** Drivers of energy flexibility and observations on the impact of the PED approach in Espoo.

| Drivers | Relevance to PED Approach | Has the PED Strengthened This Driver? |
|---|---|---|
| Local Renewable Energy and Efficiency: Minimized electricity costs | High. By implementing energy-efficient strategies and promoting renewable energy, PEDs can achieve significant savings for residents and businesses, while also contributing to a more sustainable and resilient future. | Yes. Based on the results, building owner decided to invest in battery storage and join Nordpool's reserve market. R&Is create the ground by showing the possibilities (as well as though sharing experiences from similar demonstrations). |

*Impact area 3: Citizen engagement in the governance of PEDs*

The central block is an important mobility hub, connecting the metro station, bus terminal and facilities for cycling and e-mobility. The citizen engagement activities for engaging people in the PEDs were highly focused on sustainable mobility, including how to optimize people flow and user experience. Activities included studies on micro mobility and shared mobility, a 1.5-degree workshop, a mobile ethnographic user study in

Espoonlahti, test days for electric vehicles and engagement activities with local "buddy families", users of the shopping center and school children.

Citizens, particularly youths, have been engaged in the co-creation of the new shopping center. Additionally, a collaboration has taken place with a local elementary school class, with the students studying specific sustainability themes promoting sustainable lifestyles and energy solutions. The drivers and barriers are presented in Tables 16 and 17, respectively.

**Table 16.** Drivers of citizen engagement and observations on the impact of PED in Espoo.

| Drivers | Relevance for PED Approach | Has the PED Strengthened This Driver? |
|---|---|---|
| Sustainability Goals and Urban Transformation:<br>City wants to be a pioneer of sustainable lifestyle | Medium. Supporting sustainable lifestyle in the district by engaging people in the planning of their local mobility solutions. | Yes: by bringing resources and new tools for sustainable mobility development. |

**Table 17.** Barriers to citizen engagement and observations on the impact of PED in Espoo.

| Barriers | Relevance to PED Approach | Has the PED Reduced This Barrier? |
|---|---|---|
| Resident and Community Engagement Challenges:<br>Behavioral change is difficult | Medium. By understanding the factors that make behavioral change difficult and implementing effective strategies, individuals can overcome obstacles and achieve their goals. | The project provided additional resources and channels for raising awareness of the behavioral changes, yet there is no information on whether this really changed the citizens' behavior. |

The city's ambition to be a pioneer of a sustainable lifestyle drives a significant shift in urban planning and policymaking. Cities that aim to lead in sustainability often adopt policies that prioritize renewable energy, green transportation and resource-efficient infrastructure. Public awareness campaigns, green certifications and sustainability awards can further motivate citizens to adopt eco-friendly practices in their daily lives.

On the other hand, behavioral change is difficult and presents a significant barrier to the adoption of new energy-efficient practices. Even when the technology and infrastructure are in place, residents and businesses may resist changing long-standing habits, requiring ongoing education, incentives and engagement to achieve meaningful shifts in behavior toward more sustainable practices.

In the case of Espoo, the concept of additionality is demonstrated through the integration of renewable energy systems and sustainable urban development. The development incorporates advanced energy solutions, such as geothermal energy, solar PV panels and battery storage, optimizing energy use in this densely built environment. Additionally, expanded public transportation and ongoing community engagement are expected to drive behavioral shifts, encouraging reduced car usage and greater participation in local energy initiatives. Combined with energy-efficient building designs, these efforts are projected to yield long-term benefits, such as reduced energy costs and increased local energy resilience, clearly illustrating the future additionality of Espoo in promoting urban sustainability.

## 6. Discussion

This section delves into the concept of additionality within PEDs based on the case study findings. We note that the analysis is based on preliminary monitoring results, as these projects are still ongoing. The aim is to investigate whether the additionality perspective can potentially be of benefit in PED impact evaluations.

By analyzing these factors, we can identify the unique contributions of the PED approach and the extent to which it moves beyond "business as usual" practices. Additionally, we discuss broader drivers and barriers that can affect PED implementation and impact across different areas. Figure 5 summarizes the levels of additionality per impact area for both drivers and barriers.

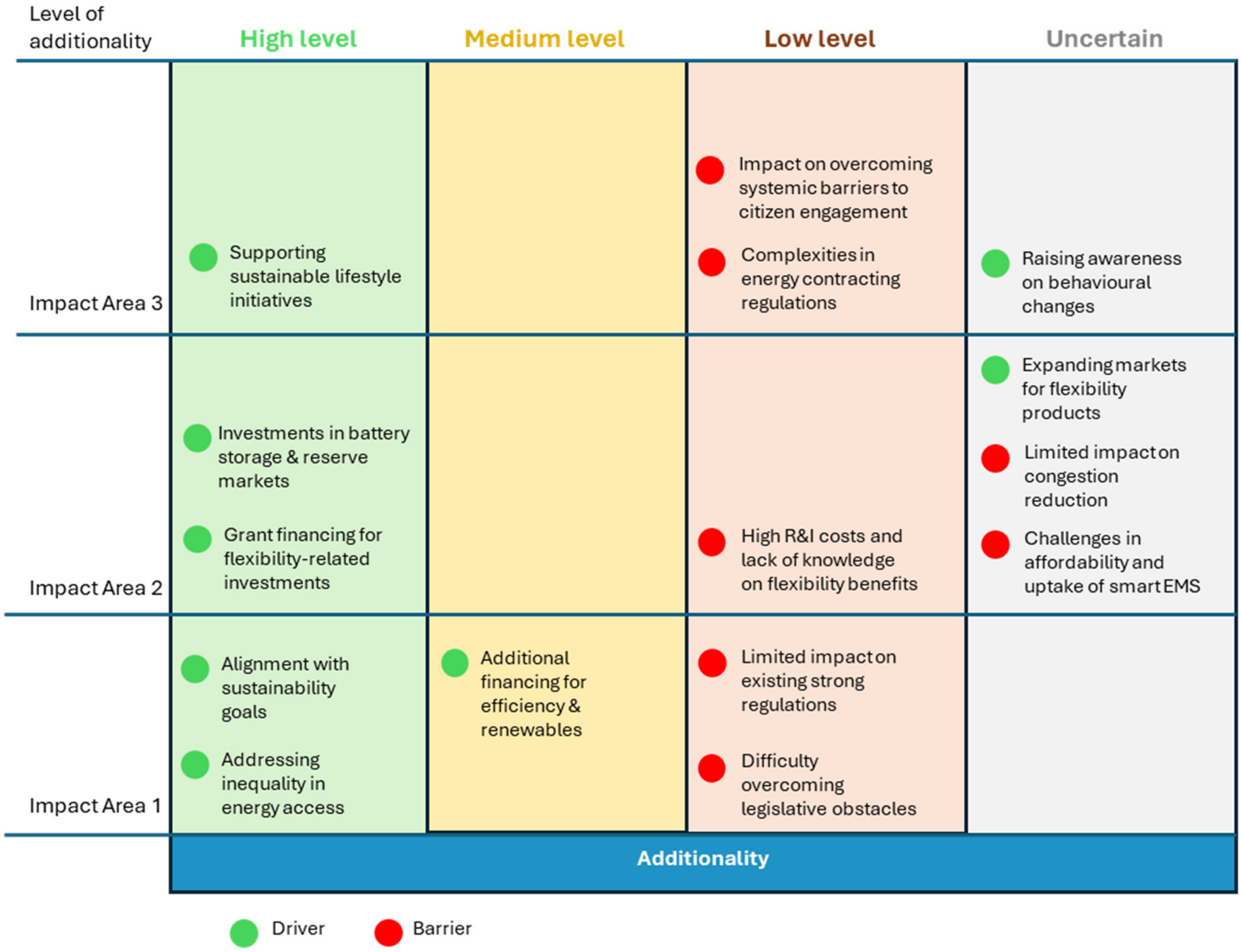


**Figure 5.** Levels of additionality in different impact areas.

## 6.1. Synthesis of Case Studies

*Impact area 1: High energy efficiency and local renewable energy production*

Assessing the drivers, it becomes evident that while PED initiatives align with sustainability targets and encourage increased use of local renewable energy sources, their direct impact on enhancing these aspects varies. PEDs demonstrate limited additionality in cases where existing regulations and quality standards are already in place, as their inclusion does not significantly enhance the regulatory framework or set higher standards.

However, PEDs exhibit moderate-to-high additionality when they facilitate additional financing, enabling the implementation of additional energy efficiency and renewable energy measures that might not have been feasible otherwise. Furthermore, PEDs role in addressing inequality issues within urban environments showcases their ability to offer additional benefits beyond what might have been achieved through conventional approaches.

On the other hand, when evaluating barriers, PEDs effectiveness in addressing these challenges and providing additional solutions is limited. While they aim to overcome obstacles such as contractual difficulties and injection-point unavailability, their impact remains constrained, as observed in cases where barriers persist despite PED implementation. Similarly, legislative obstacles and unprofitable business cases present significant challenges that PEDs are yet to effectively address, indicating limited additionality in resolving such barriers.

*Impact area 2: Increasing flexibility of the local energy system*

While PEDs have effectively strengthened certain drivers, such as minimizing electricity costs through investments in battery storage and participation in reserve markets, their impact on other drivers is less certain. For instance, while PEDs aim to address congestion bottlenecks in cities by increasing flexibility, their effectiveness in strengthening these drivers is uncertain without specific outcomes. Additionally, while PEDs contribute to expanding markets for energy flexibility products and services, their role in this regard is limited by the absence of a comprehensive PED approach.

However, PEDs have demonstrated clear additionality in providing grant financing for investments and system development. This funding has enabled crucial investments in equipment and human resources development.

When considering the barriers, PED initiatives have shown mixed levels of effectiveness.

While efforts have been made to address challenges such as high R&I costs and a lack of quantitative knowledge on the benefits of flexibility measures, the effectiveness of PEDs in fully overcoming these barriers is limited. For example, while PEDs aim to improve the affordability and uptake of smart energy management systems, evidence of their impact in this regard remains unclear. Nonetheless, PEDs have demonstrated clear additionality in addressing certain barriers. For instance, they have successfully overcome connection restrictions due to congestion by implementing flexible assets like EMS and batteries, which have facilitated grid connections.

*Impact area 3: Citizen engagement in the governance of PEDs*

PED initiatives have shown varying levels of impact, exemplified by their contribution to city's goal of pioneering sustainable lifestyles. By introducing new resources and tools for sustainable mobility development, PEDs have clearly supported initiatives within the district. However, the impact of engaging the community in the energy transition, although a medium-relevance driver of PEDs, remains uncertain. While PED initiatives may have increased awareness of behavioral changes, their translation into significant community engagement is not well documented.

Turning to barriers, PED initiatives have addressed certain challenges, but their effectiveness varies. For instance, while PED has bolstered residents' knowledge and motivation by providing additional support and resources, systemic barriers may persist. Additionally, while PEDs may have explored solutions for complex energy contracting regulations, systemic barriers endure. Furthermore, while citizen engagement serves as both a driver and a barrier, PED initiatives have not substantially strengthened this aspect, indicating ongoing challenges independent of the PED approach.

### *6.2. Cross-Cutting and Generic Drivers and Barriers in PEDs*

*Generic driver 1: Sustainability*

The three cities involved have embraced climate mitigation goals and are intensifying their climate policies, driven by strong political and societal momentum for citizen participation in energy supply and demand. This driver underscores the importance of closely aligning projects with established climate goals and sustainability targets, emphasizing the need to reduce greenhouse gas emissions, mitigate climate change impacts and promote environmentally sustainable practices. The project aims to contribute to broader efforts in combating climate change and fostering sustainable development by prioritizing alignment with these goals.

Furthermore, this driver emphasizes the significance of raising awareness among stakeholders and the general public about projects aimed at transforming historical cities into smart cities. Educating stakeholders about the potential benefits, including improved quality of life, enhanced infrastructure and economic growth, is essential. By fostering understanding and appreciation for these initiatives, the projects aim to garner support and engagement from various stakeholders, facilitating smoother implementation and long-term success.

All three PED projects have developed long-term strategies towards sustainability, aiming to make their cities climate-neutral by 2050. Espoo and Amsterdam are EU Cities Mission cities, aiming to make their cities climate-neutral by 2030 [40].

The additionality of PEDs lies in their potential to create a positive energy balance, in which the energy produced exceeds the energy consumed, leading to a reduction in overall energy demand and greenhouse gas emissions.

*Generic driver 2: Breaking silos between policy and R&I domains*

Breaking silos between policy and R&I domains is crucial for the successful implementation of PED projects. This driver highlights the importance of fostering collaboration and communication between different stakeholders, including policymakers, researchers and industry experts, to ensure that PED projects are aligned with the latest research and technological advancements. It also emphasizes the need for continuous learning and adaptation to ensure that PED projects remain relevant and effective in achieving their goals.

PEDs have the potential to create a holistic approach to urban development, in which energy, infrastructure and environmental considerations are integrated into policy and research efforts.

*Generic barrier 1: Planning and timing of the development of the PED and its components*

The planning and timing of the development of a PED and its components are crucial for the success of the project. PED development is a cluster of different developments that are partly mutually related and subject to external factors. In Amsterdam, the main development was the construction of the buildings and related infrastructure, which encountered delays. The second main development was the design, development and installation of the smart grid infrastructure, including storage and related energy management, followed by the energy trading system. The third was the (legal) design of the energy community for governance, with its own timeline.

Developing a PED, the first of its kind in one city, is conceptually and organizationally challenging. Planning is of crucial importance, but developments rarely occur as planned, and many details are not foreseen. Amsterdam's example has shown that although innovative technology is available, to organize and implement it still poses a challenge.

The initial intention of having two different greenfield developments included in the PED was to increase the insights gained on the impact of building characteristics on the costs and benefits of PEDs, thus strengthening the empirical basis for the conclusions. Furthermore, it would be possible to investigate the use of storage within a virtual PED energy network. However, it has become clear that the implementations of these two developments have substantially diverged, which has made coordination more difficult.

PED development is complex and subject to external factors, which can lead to delays and challenges in coordinating various components, such as building construction, smart grid infrastructure and energy management systems. The additionality of PEDs lies in their potential to create a more efficient and integrated approach to urban development, where planning and coordination efforts are streamlined to minimize delays and maximize the benefits of PEDs. PEDs also allow greater flexibility in being able to deal with emerging challenges in energy transition, as with the case of grid congestion in Amsterdam.

*Generic barrier 2: Limited uptake of PED concepts by municipality*

The limited uptake of PED concepts by municipalities is a significant barrier to the successful implementation of these projects. The embedding of PEDs into cities' municipal energy and climate policies, and into the planning of energy infrastructure, is proceeding very slowly. After five years of project implementation, the question of how the knowledge gained on PEDs is effectively embedded into the municipal organization is still under evaluation. This is caused by (1) PEDs as holistic measures in energy and climate policies being too broad a concept to fit into current municipal policy and planning methods and processes, (2) a lack of capacity among policy makers and urban planners to actively engage in PED projects, as they are overburdened by their core business, and (3) a lack of political interest. This creates a contradiction between political ambition (see above) on the one hand and a lack of capacity to benefit from R&I projects on the other.

PEDs could create a more comprehensive approach to urban development, where PED concepts are integrated into municipal policies and planning efforts, leading to more sustainable and energy-efficient cities.

*Generic Barrier 3: Complex administrative procedures, legal obstructions, and bureaucracy*

This barrier refers to the bureaucratic hurdles and administrative complexities that often accompany large-scale urban development projects. It involves navigating multiple layers of government regulations, securing permits, and coordinating with various stakeholders, which can lead to delays and increased costs. This includes energy market regulation. Addressing this barrier requires streamlining administrative procedures, fostering inter-agency collaboration, and leveraging digital technologies to simplify processes and improve efficiency.

The additionality of PEDs lies in their potential to create a more streamlined and efficient approach to urban development, where administrative procedures are simplified and bureaucratic hurdles are identified and reduced, leading to the more cost-effective and timely implementation of PEDs.

*Generic Barrier 4: Preservation Requirements in Heritage Listed Cities*

This barrier highlights the challenges posed by stringent preservation requirements and regulations in cities with rich historical heritage. It involves navigating complex processes and ensuring that any smart city interventions are compatible with the architectural and cultural heritage of the city. Overcoming this barrier requires careful planning, stakeholder engagement, and innovative solutions that balance the preservation of heritage with the implementation of modern technologies and infrastructure.

PEDs have the potential to create innovative solutions that balance the preservation of heritage with the implementation of modern technologies and infrastructure, leading to a more sustainable and culturally sensitive approach to urban development.

## 7. Conclusions

This paper introduced the concept of additionality as a method to assess and understand the benefits of PEDs, examining the extent to which PEDs offer tangible additional benefits beyond what would have occurred without their implementation. To test whether this perspective could provide new insights into PED impacts, we applied this approach to three ongoing PED developments in Amsterdam, Évora, and Espoo. As final monitoring results are not yet available for these ongoing projects, the assessment was based on interim results in qualitative terms, which were mainly provided by the opinions of experts involved in these projects.

The main findings include the following: Understanding the additionality of PEDs is crucial for evaluating their effectiveness and justifying investments. Our findings suggest that PEDs have the potential to create a positive energy balance, in which the energy produced exceeds the energy consumed, leading to a reduction in overall energy demand and GHG emissions. This is achieved through a combination of high energy efficiency, local renewable energy production, and external renewable energy production integrated into the PED energy system. Furthermore, PEDs can increase the flexibility of local energy systems by maximizing self-consumption and minimizing peak power demand through the installation of smart (micro) grids, energy management and battery storage. This flexibility is crucial in locations where the existing grid infrastructure is becoming a constraint on new connections and the growth of renewable energy production.

In addition, PEDs aim to involve citizens and other local stakeholders in governance and provide opportunities for residents to influence and interact with energy systems, particularly through energy communities. This citizen engagement is essential for enhancing benefits for citizens and increasing the impact of PEDs societal goals.

However, our analysis also highlights several generic drivers and barriers that can affect PED implementation and impact different areas. These include alignment with climate goals, breaking silos between policy and R&I domains, the planning and timing of PED development, the limited uptake of PED concepts by municipalities, complex administrative procedures, and preservation requirements in heritage-listed cities. Our observations reveal a lack of differentiation between the drivers and barriers related to individual solutions, such as the energy efficiency of buildings, and those directly related to and influenced by the PED approach itself.

Furthermore, our analysis uncovers the absence of a detailed framework describing the essential components, desirable features, and the drivers of and barriers to PED development. A PED should not be merely an umbrella for policies and measures that could be implemented without a PED approach anyway, but it should bring added value and accelerate progress towards the societal goal of a sustainable energy transition. As PEDs evolve and address remaining challenges, their additionality in driving a more sustainable and resilient urban energy future is likely to increase.

Although our three case studies were based on preliminary and qualitative data and the results of the assessment are, therefore, indicative only, we can conclude that the additionality perspective could provide new insights and understanding on PED-impacts, beyond those resulting from the current practice of evaluation. We recommend that pro-jects include this approach in their final evaluation practices, based on the actual monitoring data.

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