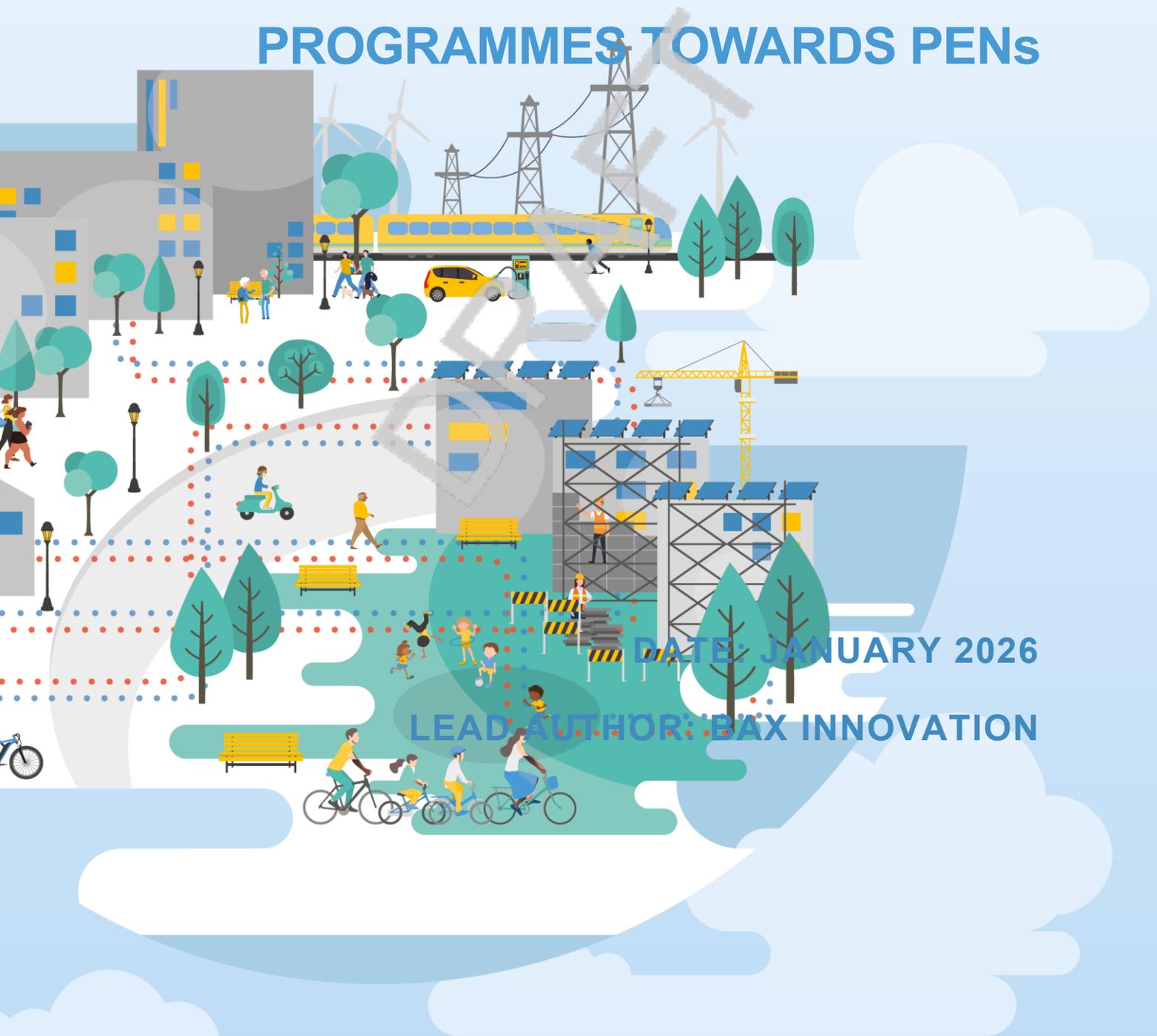


DELIVERABLE 7.5: IMPLEMENTATION PLANS FOR 12 SUSTAINABLE INVESTMENT PROGRAMMES TOWARDS PENs



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1. Introduction

Produced under the oPEN Lab Horizon 2020 project, this document has been developed by innovation consultancy Bax Innovation, with supporting input from project partners BPIE, Flux 50, ENoLL, IBS.

It is targeted primarily towards future positive energy neighbourhoods (PEN) project initiators such as local public authorities, social housing developers, and local energy services providers, as well as higher-level EU policymakers, funding bodies, and researchers, with several core objectives:

- **Describe** the relevance and value of PENs within the broader context of Europe's latest climate, strategic, and economic objectives
- **Highlight** the findings from the oPEN Lab Living Labs in Genk, Pamplona, and Tartu, and their learnings for supporting scalable PEN development in other cities
- **Demonstrate** the typical real-world political, economic, technical and societal challenges, and opportunities underlying potential PEN development in Europe, by using 12 city contexts as theoretical testbeds.
- **Support PEN project initiators to plan, prepare, and implement** scalable PEN projects in their own regions, based on an assessment of the political, economic, societal, and technical maturity and factors of their own localities.
- **Supplement** the oPEN Lab project learnings with relevant insights from other European projects and programmes

Finally, this document also makes a **case for the increasing role and responsibility of regional and metropolitan public authorities within Europe's climate and transition**. Regional authorities are uniquely positioned between local cases and European policymakers. As such, the boldest and "mission-oriented" cities are well-placed to design and facilitate the new investments, collaborations, and markets necessary for transforming first-of-a-kind PEN demonstrators into commercially viable opportunities for rapid and widespread replication and scaling.

A note on using cities as PEN project testbeds:

This document uses 12 European cities and metropolitan authorities to represent potential PEN project initiators. It thematically clusters these cities and provides implementation and strategic plans for each cluster. We bring this city-focus deliberately, to avoid falling into the "pilot trap" of isolated projects and instead assess and suggest the broader factors required for genuine PEN market viability and scalability. Assessing individual projects typically focusses on technical feasibility and bespoke subsidies. In contrast, analysing wider city ecosystems identifies the critical regulatory and economic levers needed to standardise PEN investment conditions. This transforms PENs from high-risk one-off experiments into bankable components of city energy and economic infrastructure.

2. Executive summary

Produced by Bax Innovation for the oPEN Lab Horizon 2020 project, this document attempts to provide a strategic roadmap for scaling Positive Energy Neighbourhoods (PENs) from niche pilots to mainstream urban infrastructure in Europe. It is targeted primarily at European city planners, policymakers, funding bodies, and energy service providers seeking to transition PENs from their current subsidised experiments to commercially viable market opportunities.

The document reframes PENs not merely as environmental or social projects, but critical engines or regional economic value aligned with Europe's latest strategic goals of industrial resilience and economic competitiveness. By combining energy-efficient buildings with local renewable generation and energy sharing through collective self-consumption market models, PENs may offer a solution to volatile grid energy prices and territorial energy security. PENs can transform cities into hubs of sustainable economic activity, reducing the energy bill of entire regions and retaining economic value locally through lower levelized costs of energy.

A central theme addressed is the difficulty of scaling PENs beyond initial demonstrations (the "Pilot Trap"). This document highlights that while PEN technologies are largely mature (Technology Readiness Level 8), they struggle with commercial viability and long-term societal buy-in, and current projects often prioritise bespoke community engagement over bankable business models. To achieve scale, PENs must be reframed as standardised investment products (e.g. social housing or industrial park "Typologies") that balance desirability, feasibility, and viability to attract private capital.

To bridge the gap between this policy ambition and on-the-ground reality, the document introduces the Mission-Driven Innovation (MDI) methodology developed by Bax Innovation. This supports public authorities in taking a more proactive role in market-making, utilising tools and perspectives like Multi-Level Governance (coordinating Micro, Meso, and Macro actors) and Innovation Readiness Levels (IRL) across Political, Economic, Societal, and Technological (PEST) domains, to translate separate PEN components into integrated and scalable systems.

The document assesses 12 city PEN "Followers", generating three distinct city clusters:

- **Advanced Followers:** Favourable regulations but hindered by administration.
- **Grid-Constrained Cities:** High capacity but prohibitive grid congestion.
- **Legacy Regulators:** Strong infrastructure, but outdated regulation.

Based on this, we conclude that to scale PENs across Europe, cities and housing providers must simplify the PEN offering for end-users, developing affordable and inclusive energy services through market-oriented and low-engagement models. This alongside lobbying for new regulatory frameworks that reward energy flexibility and electrification (e.g. gas boilers to heat pumps) as new revenue streams. Finally, regions must establish dedicated organisations of local PEN expertise, to leverage project learnings and develop standardised opportunities.

3. The Opportunity: PENs in a changing Europe

Cities and urban environments in Europe comprise over 100m buildings, and buildings account for around 40% of Europe's climate footprint. Of these, 75% have poor energy performance¹. Climate neutrality in Europe therefore depends on a successful transformation of its urban neighbourhoods and energy system.

Positive Energy Neighbourhoods (PENs) combine energy-efficient buildings, renewable energy generation, and local energy flexibility to create neighbourhoods that produce more energy than they consume. They represent a vital tool in advancing Europe's goals of climate neutrality and economic competitiveness, turning cities into engines of green growth, strategic resilience and local economic thriving.

PENs support a sustainable, resilient, and economically competitive Europe

In the context of rising energy costs, pressure on household budgets, and a growing concern for energy security within Europe, PENs offer a potential solution. By reducing energy demand, generating clean energy onsite, and enabling energy sharing within communities, PENs lower dependency on external sources and reduce long-term energy expenditure. As demonstrated by social housing projects like ASTER in Flanders, under the right regulatory and economic conditions, rooftop solar represents the most cost-effective option for meeting the basic energy needs of most households, with the latest neighbourhood energy systems shown to deliver electricity at significantly lower prices than the market average.

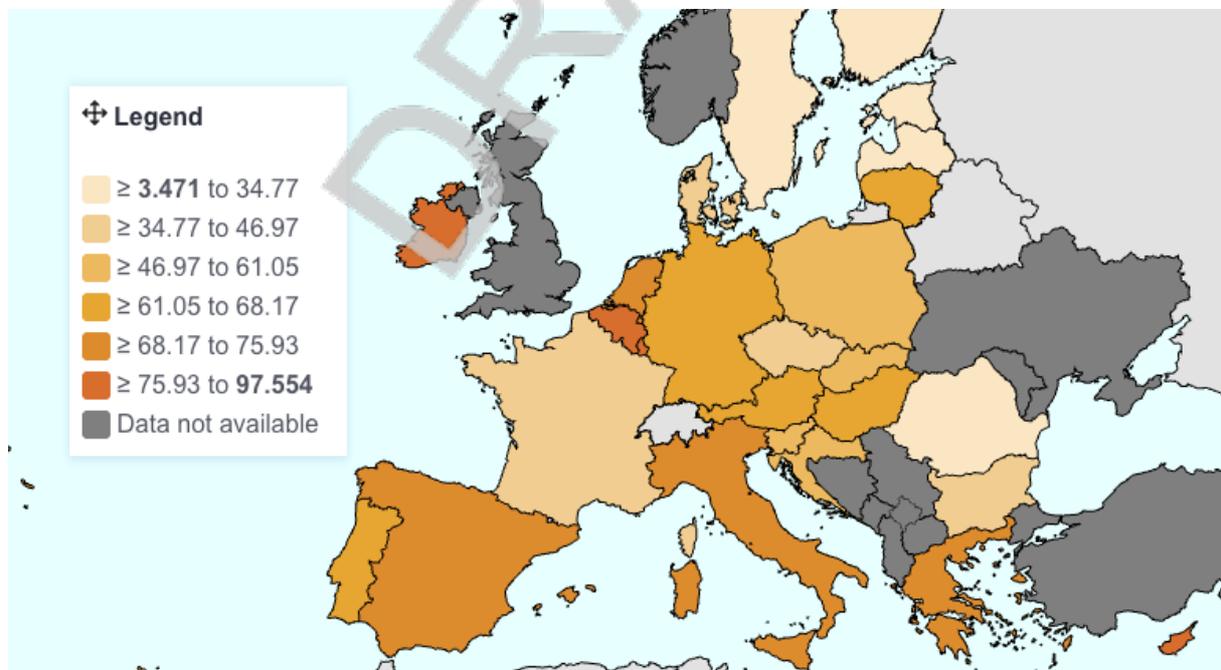


Figure 1: PENs offer energy resilience and strategic independence in Europe - in 2023 almost all countries were net energy importers (energy import percentage shown above).

Socially, PENs can also promote inclusive and just urban development. When coupled with regional policies that enable affordable renovation and tax-exempt energy sharing, they can reduce energy poverty — especially among low-income households who spend a high share

of their income on energy — and strengthen communities through shared ownership models and local investment. At the same time, they support urban regeneration and improve quality of life in endemically underserved areas.

Finally, PENs align with Europe’s renewed focus on strategic autonomy and industrial resilience, as outlined in the Draghi report on EU competitivenessⁱⁱ. Through encouraging an aggregated approach to sustainable urban and housing transformation, PENs can stimulate new demand for European clean technologies and innovation. In doing so, they can generate new markets, investment and business opportunities for services in energy system management, energy services and maintenance, retrofits and prefabricated building workflows, and infrastructure. This contributes to reindustrialisation, job creation, and the development of regionally rooted value chains.

PENs not as niche innovation, but as core urban infrastructure for Europe

Crucially, amidst a growing European priority around economic competitiveness, a commercially viable scaling strategy for PENs should reframe such developments not just as socially and environmental desirable features of an urban landscape, but integral infrastructural vehicles and sound investments supporting economically secure cities for the long-term.

Given this changing European response to geopolitical tension and economic uncertainty, as PENs evolve from first pilots and towards mainstream urban planning principles, it is primarily their *economic* contributions to urban livelihoods that will be embraced and scaled, with benefits for sustainability, circularity, and social inclusivity desired as secondary but not core features of the future PEN sector.



Figure 2: Putting PEDs in a strategic European context: Draghi’s 2025 report emphasises the need for local energy innovations to strengthen Europe’s territorial resilience and regional economic competitiveness.

PENs – the energy backbone for thriving local economies

As described in Chapter 1 of Draghi's report on the future of European competitiveness (described above), continued innovation in Europe depends on a secure supply of affordable and reliable energyⁱⁱⁱ. Equally at local level, low energy prices allow businesses to provide services at lower cost, creating a more stable commercial environment for local industry, investment, and engaged citizens.

For homes, energy represents one of the highest living cost items. By lobbying for, advocating, operationalising, and leveraging the steadily reducing costs of energy supplied by locally owned renewables, storage, and management technology, cities can reduce their proportion of imported fossil energy, reducing urban energy costs and retaining economic value locally¹.

A critical tool for unlocking this potential is making operational existing EU regulation like collective self-consumption (CSC) – or advocating for it where not yet available locally. CSC recognises small scale renewable energy systems as non-commercial activity and therefore exempted from the commercial taxes and grid fees of traditional energy markets. This means that clean energy generated by one installation can be shared with several buildings nearby at a price that is close to the cost of its production, and avoiding the transaction costs of selling and buying it back through the energy system operator. This offers locally produced energy a crucial structural advantage over grid energy often generated hundreds of kilometres away from consumption.

Local levelized energy costs (LLCOE) – the case for local energy vs the grid

Innovation within the local energy sector is increasingly showing that the primary value to homes, cities, policymakers, and investors, of locally generated and locally produced energy, is supplying affordable energy. Disaggregating the final cost of energy to consumers reveals the true opportunity of local energy such as that produced by PENs. Despite generation costs for new renewables as low as €0.05/kWh, final household electricity costs in Europe are much higher because they also include network charges, taxes, levies and other charges, together accounting for around 50% of the final price in many countries, with higher shares in some cases such as Germany^{iv}.

Once finally reaching the customer, the average price of grid energy in Europe in 2025 is around €0.28/kWh - with exceptional lows of €0.10/kWh in eastern Europe due to extensive coal production, and highs of €0.39/kWh in Germany. With around €600 billion in grid investments planned in Europe by 2030 alone, the price of grid energy is only expected to increase, as many of these new costs will inevitably be passed on to consumers.

¹ While city governments and local authorities do not always have direct control over their regional energy policies, they can actively lobby policymakers for change, and work closely with their local DSOs to make clean decentralised energy more available (see Girona case study in Chapter 5).

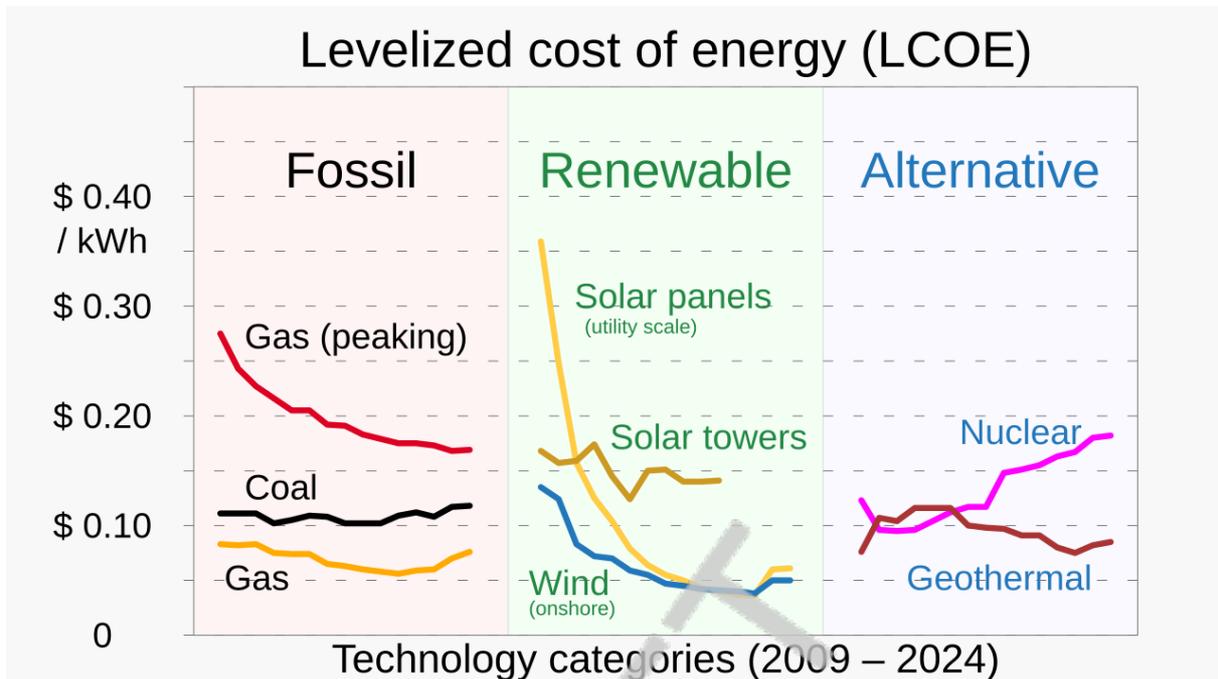


Figure 3: Local clean energy systems like solar PV avoid the additional system fees that define grid energy (Lazard, 2025 Levelized Cost of Energy+ Report).

In contrast, the price structure of locally generated clean energy is fundamentally different, bypassing the largest cost components of the centralised grid energy. Anchored to steadily reducing renewable and smart storage technology costs and exemptions from grid fees and taxes, the final price of energy from solar and storage for consumers is approaching half that of the grid. Latest research and recent pilots indicate that final consumer prices for solar-storage systems are now as low as €0.09/kWh, with continued economic and process efficiencies suggesting a downward trend. For countries in central and western Europe, there is already a clear competitive and economically grounded value proposition for decentralised clean power generation over grid energy.

For practical use within cities, this LCOE principle supports a clear case for long-term an urban clean energy investment programme - see the Appendix for Bax's *City Energy Bill (CEB)* concept, which reframes this investment from a short-term cost to an enormous long-term opportunity.

4. Challenge: The PEN “pilot trap”

Europe’s local energy sector, including positive energy neighbourhoods (PEN), remains stuck in the “pilot trap.” In their proposal for a *Pan-European Cities Climate Impact Investment Fund*, the Scalable and Smart Cities Working Group find that for over a decade, policymakers and local authorities have tested integrated local energy solutions, yet despite more than €1bn in EU funding, technical advice, community facilitation, and awareness efforts, scalability is limited (European Smart Cities, 2025). The sector accounts for a tiny share of Europe’s energy system, with fewer than 10,000 communities recorded (BUILD UP, 2024).

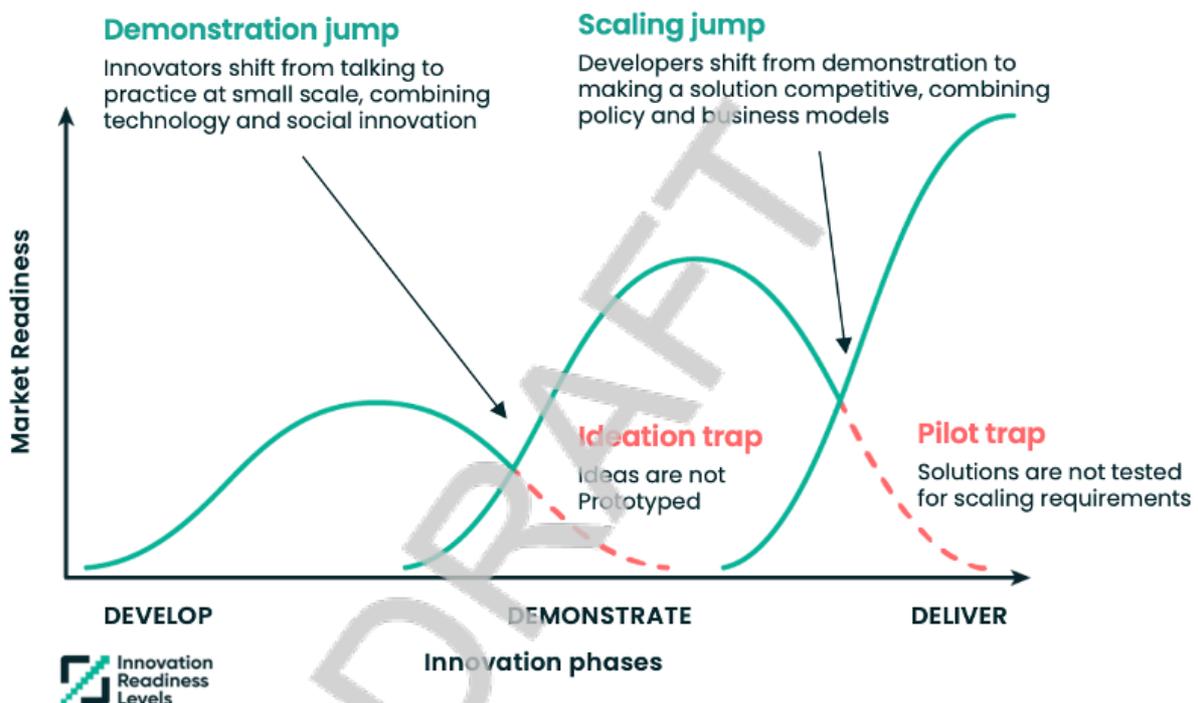


Figure 4: Positive energy neighbourhoods, like many local energy system innovations, often risk falling into the infamous “pilot trap”, unable to demonstrate a pathway towards long-term market viability.

Balancing desirability, viability, and feasibility

PEN innovation typically struggles to demonstrate long-term market uptake beyond initial public subsidisation. A core reason for this is that such projects have so far been designed explicitly as one-off pilot demonstrators of locally grounded technical and social innovations. Long-term commercial viability and engagement with uptake investors have not been a priority until now.

Viable market uptake for PENs can be considered to lie at the intersection between:

- **Desirability** (demanded and encouraged by both social end users and policymakers)
- **Feasibility** (technically possible and reliable)
- **Viability** (commercially sustainable)

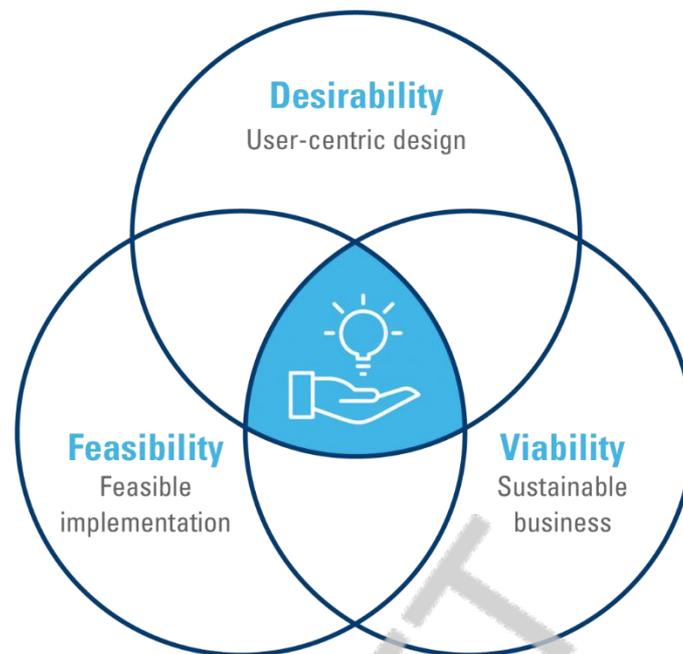


Figure 5: The market uptake Venn diagram - where are PENs in 2025?

Within this framing, we situate PENs firmly within high technical feasibility already, and many PEN components with commercial viability (inc. active energy generation, energy monitoring, but not yet deep renovation)². However, PENs lack full-scale desirability: despite political support and legislation for renovation and clean energy sharing in many European contexts, few sites show success in securing long-term buy-in from dwellings in a deep renovation process, even under heavily subsidised conditions.

Towards full-scale commercial viability and household desirability, PENs now need to be reframed as viable business propositions and not just subsidised R&D projects, offering clear incentives for residents to be involved, and attracting further investment from both public and private financiers, by demonstrating a combination of:

- Proven technologies (feasibility)
- Steady cashflow (viability)
- Market demand (viability and desirability)
- Policy alignment and support, and regulatory compliance (desirability)
- Supply chain (viability)
- Reliability of counter parties (viability)
- Insurance or warranty (viability)
- Abatement cost performance (viability)

The PEN investment challenge

² oPEN Lab partner VITO has done extensive work on the feasibility, desirability, viability perspective on PENs within their Deliverable 9.4 *Innovation Management Plan* (Oct 2025)

The primary challenge in scaling positive energy solutions stems from a fundamental mismatch between current PEN project pilot design, and the longer-term need for large-scale, bankable investment opportunities^v. In this sense, the PEN scale-up challenge is both “bottom up” as well as “top down”:

- **Project design (“bottom up”):** Despite over a decade of pilot projects, further scaling has failed because the prevailing PEN “project logic” favours isolated, small-scale, and highly context-specific projects prioritising maximal community engagement over realistic commercial viability. While useful for social sciences researchers, this piecemeal approach prevents the cost-effective aggregation of building opportunities in order to attract and bundle significant private capital.
- **Public authority capacity (“top down”):** Cities (i.e. public authorities) often lack both the incentives and specialised capacity and training to structure PEN projects in a way that is genuinely appealing to large investors and the private sector. In this sense, public PEN developers typically lack the “language” of bankability.

To unlock investment, the transition to PENs must be both simple and profitable. This requires a systemic shift away from bespoke pilots and towards leveraging existing reliable solutions with proven business models and established value chains, such as solar PV, heat pumps, building envelope and energy storage. It also necessitates ambitious training programmes for local delivery partners, city authority staff, and on structuring financeable and low-risk projects^{vi}.

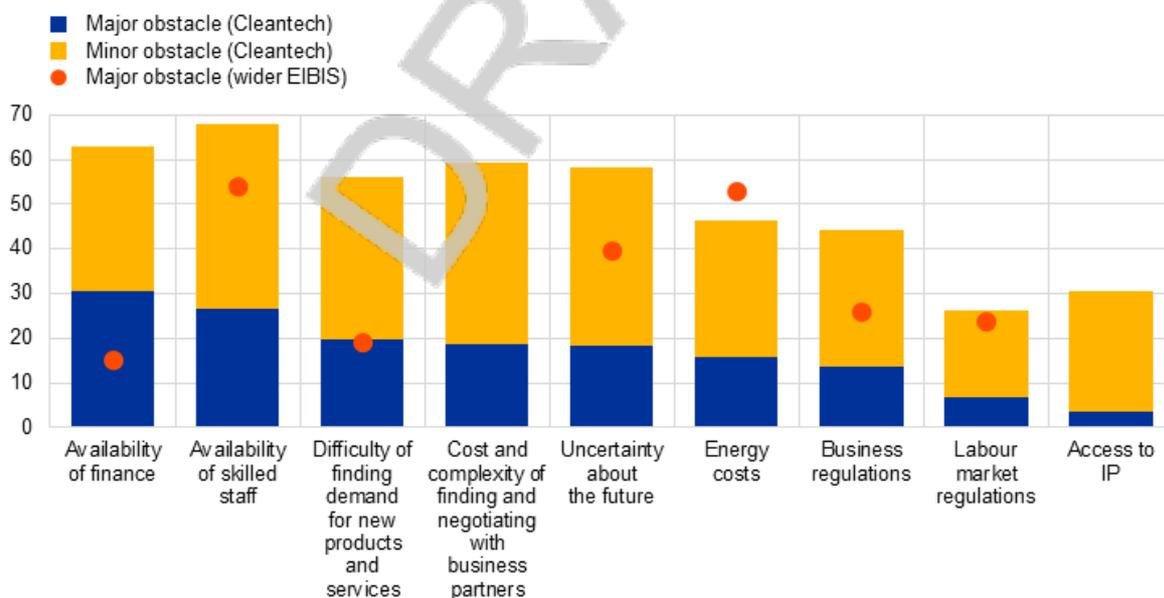


Figure 6: Beyond access to new sources of finance, scaling local clean energy systems such as PENs also depends on new skilled local labour, eligible project demand and design, more streamlined value chains, among many other factors (European Central Bank, 2025^{vii}).

5. Methodology: Mission-driven Innovation

Europe's sustainability transition is now described as a “*Systems transformation*”^{viii}, while the guiding policy framework proposed to governments is “*Mission-oriented policy*”^{ix}. Both policy documents share the underlying philosophy that Europe's future sustainability and innovation drive, including the deployment of PENS, require an emboldened public-sector taking a more proactive role within the innovation, governance, and market-making process. This will guide the translation of mature and separate sustainable energy “components” into fully integrated “systems” supporting end-goals in the public interest but delivered through an effective and well-incentivised private sector of entrepreneurs, technology, developers, and innovators.



Figure 7: Mazzucato's “mission-oriented” policy framework defines Europe's latest strategic approach to delivering regional transformation and innovation.

Connecting these strategic priorities of Europe mentioned above, with on-the-ground insights from sustainable R&D projects, *Mission-Driven Innovation* (MDI) is a public sector-facing innovation methodology, framework, and guidance tool developed by Bax throughout 2024. MDI provides a theoretical and actionable framework for delivering strategically aligned “missions” by public sector actors such as metropolitan and regional governments.

The MDI methodology consists of three key elements:

1. **Multi-Level Governance** describes the roles and measures relevant to be taken across the stakeholders at the Macro-, Meso-, and Micro- levels of governance
2. **PEST (Political, Economic, Social, Technological)** unpacks innovation support across their separate domains to guide understanding and coordinated and holistic action
3. The **Innovation Readiness Levels** metric is inspired by the industry standard Technology Readiness Levels approach but takes a more holistic approach to guiding innovation maturity from initial idea, through to pilot demonstration, and final scaling and market diffusion.



Figure 8: Bax's Mission Driven Innovation methodology is designed to help public authorities to take a more proactive role in guiding regional innovation.

Multi-level governance

For an organisation to support innovation, it is essential to understand where within the innovation landscape that organisation exists, and which tools (political, economic, societal, and technological) it has available to be able contribute to meaningful and realistic change. The MDI methodology enables this:

Scaling PENs across and beyond the initial pilot phase depends on coordinated innovation actions within and between several different levels of local, regional, national, and transnational governance at the same time. This is captured by Bax's Multi-Level Governance framework^x, with three key levels described for their role in the PENs development process:

Micro Level: communities, projects, and innovation providers

At the local level, legally codified Renewable Energy Communities (RECs) have been piloted widely but face challenges in economic competitiveness, organisational complexity, and long-term social desirability. High administrative costs and reliance on volunteer effort limit growth beyond the most motivated groups.

In parallel, EU provisions for collective self-consumption (CSC) (aka "energy sharing") are less commonly operationalised within cities and projects, but can create strong economic incentives for local energy sharing through VAT exemptions, reduced grid fees, and reduced legal regulations. Such frameworks have supported the emergence of professionalised service companies that develop and operate local energy sharing solutions and projects, attracting significant investment to grow in buildings and districts (see example of CleanWatts, below).



Figure 9: Venture-financed CleanWatts leverages Portugal's collective self-consumption energy market regulation to rapidly scale their energy community development services.

Meso Level: regional and metropolitan governments

At the regional and metropolitan level of governance, city and public authorities are increasingly central to transforming energy systems, many being committed to energy neutrality targets by 2050 or even 2040. Most provide funding, political, and technical support for energy communities, empowering citizens in managing local renewable energy, especially in the form of rooftop solar. Hundreds of such now communities exist.

These city-sponsored initiatives foster social engagement and new value creation among citizens. However, they still rely heavily on ongoing citizen participation and public financial support and therefore do not show signs of true scalability and subsidy independence.

A key challenge for the coming years will be for regional and metropolitan governments to identify and invest in the most scalable energy community solutions, such as helping to make available and operationalise collective self-consumption for local households and businesses, and in advocating for new, PEN-supportive energy market legislation towards the European Commission and policy makers.

Macro Level: European regulatory, funding, and energy market foundations

At the highest and most influential governance level of large-scale European policy and funding programmes, energy markets in Europe are heavily regulated, making energy market policy a key driver and condition for a successful transition towards PENs. European policies now support local energy systems by introducing legal frameworks for renewable energy communities (e.g. RECs, and CECs) as well as tax-privileged local energy sharing (CSC), among others.

These frameworks promote collective ownership and sharing of locally generated renewable energy, backed by public sector grants that have lowered costs for technologies like rooftop solar and established smart meters as standard. While renewable energy technology is now widely cost-competitive, commercialising energy storage remains a priority and challenge. National rules vary in how they apply these models, reflecting local conditions.



Figure 10: Bax’s Mission-Driven Innovation methodology provides a framework for guiding sustainability innovations at different levels of governance.

Side note: Meso-level actors – a crucial lever for scaling PENs

As “Meso” level actors within Bax’s above multi-level governance framework, city and municipal governments are uniquely positioned and opportune to lead Europe’s local energy transition. This is due to their dual ability to both lobby “upwards” towards EU policymakers and grid operators for long-term energy system change, whilst simultaneously providing direct financial, technical, and capacity support “downwards” to local projects and innovators^{xi}.

Indeed, for cities the topic of energy management and energy affordability can no longer be ignored, being responsible for 75% of all global energy consumption, and increasingly experiencing the effects of climate change and geopolitical shocks on energy bills.

To explore this stakeholder role for the local energy transition more thoroughly, Bax conducted 15 interviews with metropolitan authorities, EU-level policy makers, energy communities, and positive energy district developers^{xii}. Throughout April – June 2025, these interviews explored:

- The current forms of political, economic, technical, and legal **support** provided, and aware of, by metropolitan authorities towards local projects, communities, and policy makers

- The primary **challenges** with scaling ECs and PENs from initial pilots to market-viable opportunities
- Common **perceptions** and attitudes of local people towards energy communities and PENs, their value and local needs not sufficiently addressed

Bax's key findings were that the successful development and scaling of local energy systems represent an unprecedented opportunity to create long-term wealth and ownership among local homes, communities and businesses. However, despite this, many metropolitan governments typically overlook their unique position to support this goal by advocating more ambitiously for both policy change as well as providing typical short-term support to local energy projects such as energy communities and PENs.

From those interviews, the best examples of metropolitan support for local energy projects were those that sought to replace short-term demonstration with building long-term knowledge and capacity among local communities and relevant local energy market stakeholders.

- For example, Girona in Spain is actively negotiating with their local DSOs and energy utilities, making collective self-consumption available for energy communities in Girona^{xiii}, to support a commercially sustainable energy community framework such that further public subsidies are no longer required.

DRAFT

Innovation Readiness Levels

After having identified the organisation’s position and tools within the multi-level governance landscape of innovation, the MDI methodology then measures maturity of these tools.

MDI adapts the industry-standard Technology Readiness Levels scale to be made more holistic and applicable to a wider range of sustainability missions - “The Innovation Readiness Levels” (IRL). IRLs provide a structured framework for assessing the preparedness of a sustainability innovation for real-world deployment. IRLs take a broader view than TRLs, in that the former encompasses its societal, regulatory, and market integration as well as technical alone.

Applied to the development of PENs, IRLs can guide its target public sector and city stakeholders in evaluating PEN progress from early-stage concept validation, to piloting integrated energy systems, and securing final investment for large-scale replication and diffusion across Europe.

The Innovation Readiness Levels® scale in full

Phase	Innovation Readiness Level		Description
Design From problem to plan	1	Challenge Observed	A challenge is observed and agreed upon by industry practitioners and experts.
	2	Idea Described	A solution concept is described by technical experts in sufficient detail to set a clear plan to validate the solution’s viability.
	3	Concept Articulated	A solution articulated as a proof of concept that is validated by technical experts
Demonstrate From plan to live demonstration	4	Concept Validated	The proof of concept is validated with non-technical experts within the wider innovation ecosystem, including end users.
	5	Prototype Tested	A prototype is shown to be feasible (but not yet commercially or politically viable) when tested in highly controlled conditions that simulate the real-world application.
	6	Prototype Demonstrated	A first-of-a-kind project supported with public funds tests a small-scale version of a scalable solution in a controlled environment.
Deliver From demonstration to everyday use	7	Solution Demonstrated	Repeated pilot demonstrations show buy-in from key stakeholders and a track record of positive user engagement, technical efficiency and financial viability. Public subsidy may still be used at this stage.
	8	Solution Scaled	Widespread deployment across multiple geographies, replicated by partners and funding instruments beyond the project scope and without public support.
	9	Solution Standardised	A mature and bankable solution that is treated as part of standard operating practice.



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Figure 11: Bax’s Innovation readiness levels (IRLs) framework helps assess and guide sustainability innovations towards real-world deployment and scale-up.

PEN Readiness – is Europe ready to scale PENs?

Later in this document, 12 cities are assessed in terms of their “Readiness” to support, develop, and scale-up PEN. Some examples of this in terms of the IRLs are provided below, supported by experiences from the three Living Lab sites within oPEN Lab.

Political Readiness of PENs in Europe – frameworks in place, but local adoption slows delivery

Political readiness describes the availability of the policies and regulations needed to make particular innovations possible and to realise their value streams. In the case of PENs, such policies refer to: 1) requirements and political support for “deep” renovation, 2) policies supporting clean energy installation, generation, and storage, 3) and the legal recognition of energy community structures to enable energy sharing among local consumers and maximise energy savings and unlock new revenue.

At the European level, the key **regulatory PEN building blocks** are now in place (whilst not always transposed and available across every European country):

- The latest **Energy Building Performance Directive** (EPBD, 2024/1275) requires all new public buildings to be zero-emission from 2028 (and by 2030 for other buildings),
- The latest **Renewable Energy Directive** (2023/2413) provisions unmet energy needs to be covered by local renewable energy sources, through “solar-ready rooftops” and district heating.
- **Fit for 55 / Clean Energy Package** (revised in 2023/24) establishes a common EU framework for renewable and citizen energy communities and renewables self-consumers, recognising energy communities and collective self-consumption as instruments for citizens and local actors to generate, consume, store and sell renewable electricity.
- **Reformed Electricity Market Design (Directive (EU) 2024/1711 and Regulation (EU) 2024/1747)** clarifies and extends the right to energy sharing to all consumer groups and strengthens the role of energy communities, tasking Member States with creating enabling frameworks and protections for participants, while leaving concrete tax and network-tariff incentives to national implementation.

Examples from oPEN Lab’s Living Labs:

- In the **Genk Living Lab**, policy challenges include poor policy incentives for prefabricated renovation solutions, restrictions on low-cost energy sharing between dwellings, and the phasing out of solar panel subsidies in 2024
- In **Pamplona**, the political environment is more supportive, including a generous radius for the collective self-consumption energy market mechanism allowing for tax-exempt energy sharing
- In **Tartu**, double taxation on energy storage, restrictive energy sharing regulations, and poor mandates for renovation hinder PEN progress. Another major challenge is the lack of obligation for grid operators to purchase locally generated renewable energy, restricting a key source of revenue

At a European level, we propose Political Readiness Level 7 for the PEN sector – “Solution demonstrated”. This reflects the fact that many of the necessary policies already do exist and have been demonstrated in several regions and real-world contexts, but not yet widespread across all Member States to classify as “Solution scaled” in RL 8, yet.



Economic Readiness – positive energy, negative business case

Economic readiness describes the availability of business and financial models making new innovations commercially and market viable, and attractive for both the supply and demand side of relevant markets.

The business case for PENs is predominantly challenged by the prohibitive costs of renovation, which can be as high as building a new dwelling entirely. These costs cannot be repaid through energy savings within a timeframe considered reasonable by most households and businesses – a recent investigation by ASTER in Flanders, Belgium, found the breakeven time required for their own social housing renovation would take 180 years.

It is important to note that PEN economic readiness can be heavily conditioned by PEN political readiness - policy change can unlock new markets and revenue streams previously not available. Spain's progressive *collective self-consumption* regulation, for example, allows tax-exempt energy sharing between neighbours, with recent proposals for a new 5km (from 2km) radius around the generation site now being considered^{xiv}.

Building renovation can provide significant social, environmental, and energy benefits such as improved local air quality, comfort, and public health. However, we find that such benefits can be administratively costly to report: French social housing developer *Valloire Habitat* sought financing of €23m to renovate an urban housing block of 280 units in the French city of Orléan. One bank offered an “high ESG impact” loan, entailing a discounted interest rate for meeting inclusivity and energy efficiency criteria. However, it was found that this loan provided marginal cost savings of €5,000 per year and was furthermore more complex and time consuming to monitor and report on than a conventional commercial loan.



Figure 12: Despite initial interest, Valloire Habitat could not proceed with an ESG bank loan due to the burdensome reporting requirements involved compared to conventional finance options.

Examples from oPEN Lab's Living Labs:

- **Tartu resident's** existing energy costs are low due to district heating that a business case built on energy savings is not attractive, and they have struggled to secure approval for renovation from residents. Further, national regulations prevent cost-effective energy sharing among several neighbours and a lack of skilled workforce and knowledge in sustainable renovations presents further barriers to implementation.

- **In Genk**, electricity prices at 3-4x higher than gas in Belgium, making a transition to all-electric home energy economically unviable, added to the high upfront costs of renovation. Double-taxation grid tariffs further weaken the business case for energy sharing and storage, while regional finance opportunities do not incentive deep renovation.
- Finally, **in Pamplona**, while relatively more financial support and energy market tools are already in place in Spain, long-term investment planning into local energy systems such as PENs is harmed by a frequently changing regulatory framework - for example, with the radius covered by CSC.

At a European level, Economic Readiness for the PENs sector is Level 3 – “Concept articulated”. An economically viable business case for PENs has not yet been shown as sufficient for validation from important external stakeholders such as investors and policymakers. While energy efficiency mortgages do exist for individual buildings in many countries, the economic challenge of renovation at the particular neighbourhood scale is a crucial barrier.



▪ **Societal Readiness – navigating the transition to market-viability**

Societal readiness describes the engagement, buy-in, and relevant capacity of relevant end-users and stakeholders to participate in PENs.

Often reliant on strong and continued motivation of key volunteers, it represents a common barrier to designing scalable PEN projects. No PEN social engagement models have successfully demonstrated a way to balance values of inclusivity with needs for commercial viability and rapid uptake. While project partners typically place great importance on the integration of citizen and resident values through regular co-design, such participation requirements (i.e. “project push”) in fact increasingly represent a barrier rather than an enabler of successful urban energy solutions.

Supported by insights from oPEN Lab, other European PEN projects, and industry insights, Bax proposes to reconsider the value of social participation as an outcome (i.e. “market pull”) of effective PEN design, rather than a required input (i.e. “project push”). After a decade of European innovation on this topic, PENs should by now be able to offer solutions that are self-evidently valuable to their end-users such that the local community wants to be involved voluntarily, rather than being subsidised to do so by projects.

PEN engagement should follow the latest social science and industry research, which suggests that the vast majority of homes and businesses prioritise energy convenience and cost first and foremost (Marcia Poletti, Octopus Energy, February 2025). Meanwhile, local engagement can and should educate citizens around energy literacy, bills, and affordability, and engagement methods should strive to be responsive to local sensitives, aligning with existing cultural events to improve local reception and support (Directorate General for Energy and Geology in Portugal, interview held by Bax in May 2025).



Figure 13: Tartu Living Lab’s social engagement process demonstrated the challenges of collective decision making to deliver efficient renovation solutions.

Examples from oPEN Lab’s Living Labs:

All Living Labs have experienced challenges with social participation methods that balance inclusivity with speed.

- **In Genk**, PEN development has been temporarily hindered by tensions between residents and construction teams, as residents felt their concerns were overlooked during installation. The broader impact of the project on residents was underestimated, highlighting the need for better communication and community involvement.
- **Pamplona** has struggled with communicating the benefits of collective energy, particularly in social housing contexts where motivation is limited by economic and social vulnerabilities.
- **In Tartu**, societal readiness is challenged by the complexity of coordinating a collective renovation across hundreds of private owners. Additionally, the benefits of renovation beyond minimal cost savings have been challenging to communicate effectively to residents.

The societal readiness of PENs is at Level 5 – “Prototype demonstrated”: hundreds of approaches to long-term community engagement around PEN development have been tested across Europe. However, none have been able to demonstrate an approach to social participation that can scale without significant and ongoing public funding.



▪ **Technology Readiness – from components to integrated systems**

In general, the individual energy technologies required to generate PEN outcome are now available, and no longer represent a significant innovation barrier to PEN viability:

- **Innovative renovation materials** and construction techniques now enable zero-emission buildings, integrating high-performance building components, off-site prefabrication, and single-day retrofitting for small dwellings. These architectural preconditions are essential for PEDs, paving the way for cities and communities to achieve energy autonomy.
- **Small-scale renewables** are becoming the cheapest and most reliable source of energy for many homes and businesses over the long-term – especially as the costs of grid energy increase due to a growing need for energy system investment and maintenance.

At the component level, the technical readiness of PENs in Europe is Level 8 – demonstrated and scaled across several different contexts and real-world conditions. Some key challenges remain around the affordability of PEN technologies compared to more typical options which achieve lower quality technical outcomes (i.e. prefabricated vs on-site renovation processes). The availability of supply chains and labour markets for system delivery and installation is also a challenge. Finally, the technical complexity around energy monitoring and integration at the neighbourhood level is still in development stage (VITO working on it through the “Open Thor Living Lab” site)).



6. Approach: Business and finance models

In the following chapter we highlight several examples of how deep renovation, large-scale local clean energy generation, and affordable housing can each separately be achieved through commercially viable business models, organisational structures, and financial vehicles. The described examples are grounded in real-life cases across Europe, delivered by a wide range of public, private, social housing, and citizen organisations.

It is important to clarify at the outset that there is no such thing as a “PEN business model” by itself. Comprised of so many separate revenue streams and business cases across energy, mobility, heating, and housing, attempting to cluster all PEN value propositions together into a single investment product is highly complex and cumbersome. Rather, there exist several separate business cases for PEN components which, when combined, may produce energy, economic and social outcomes supportive of the PEN mission.

PEN business models

Renovation and energy efficiency

The business case for building renovation is notoriously challenging. Given the associated high capital costs and slow payback timelines, deep renovation can often be just as expensive as constructing a new dwelling entirely - as observed within the project’s Living Labs in both Pamplona and Genk. Meanwhile, Tartu’s Living Lab has shown that despite the potential efficiencies of renovating an entire apartment building as a single development, it is also slow due a collective decision-making process.

Innovative business models for renovation must therefore find a way to reduce, spread, or shift the high capital costs to reduce financial barriers of entry, as well as offering a hassle-free installation process for residents.

Energy services companies

Energy Service Companies (ESCOs) can support the commercially viable delivery of renovation by shifting the financial and technical burden away from households and towards expert teams of local service providers. ESCOs cover the initial capital investment (CAPEX), with costs recovered through long-term service agreements with the building, and regular payments linked to guaranteed energy savings after renovation. This model makes home upgrades more accessible for homes and reduces financial risk for end users.

It should be noted that due to the perceived risk of the projects and their delivery partners, the cost of capital for ESCOs can be high (up to 7%). To address this, and make renovation more financially viable, ESCOs can aggregate multiple small renovation projects together through a “portfolio approach”. This can raise capital more effectively, secure lower interest rates than offered for individual energy projects, lower investor risk, and reduced transaction costs. Novel financial institutions like Solas Capital currently offer such a service, providing small energy efficiency loans to ESCOs^{xv}.

The EU-funded RenESCO pilot project demonstrated a highly successful delivery model of ESCO-driven renovation across 15 soviet era apartments in Latvia^{xvi}. The project’s works were

cofinanced by a local bank, requiring zero up front cost from the low-income dwellers. Investments were repaid through future guaranteed energy savings across 20 years, whilst the apartments' values increased by up to 40% in some cases.

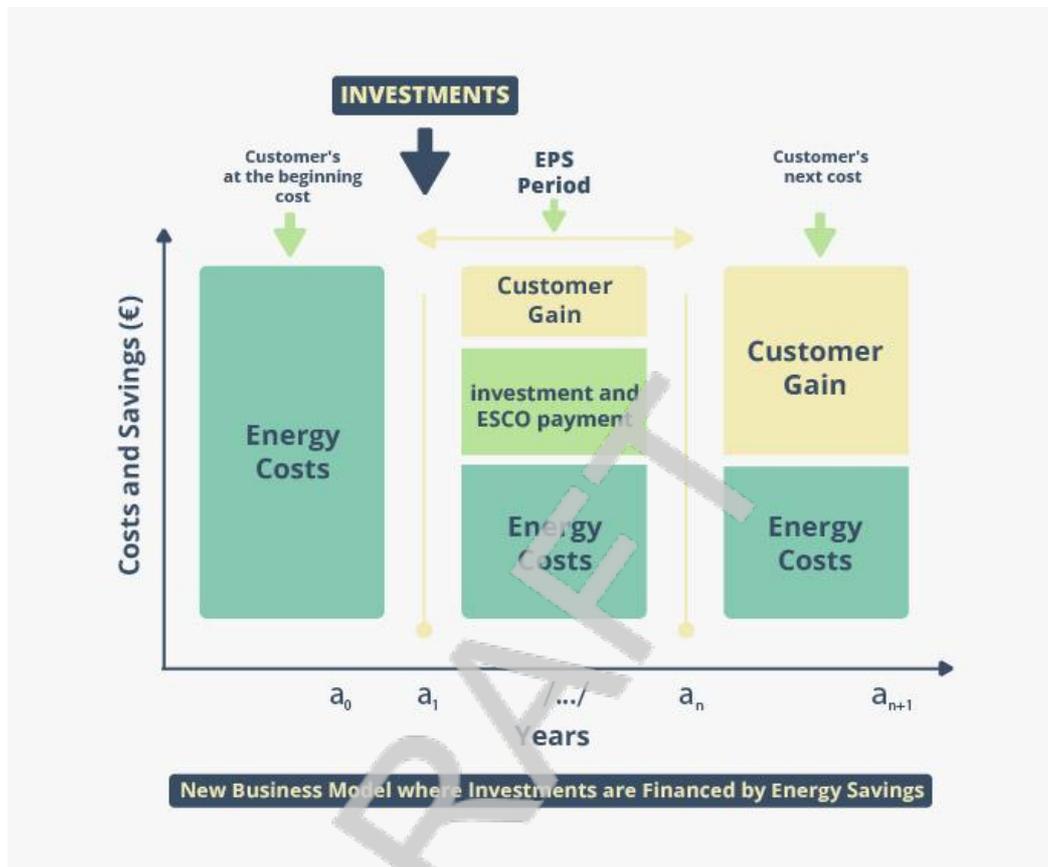


Figure 14: The ESCO business model can make building renovation more financially viable by shifting the financial and technical burden to technical experts through service contracts.

Energy efficiency, or “green”, mortgages

An energy efficient mortgage (EEM) is a specific type of loan product used by buyers to finance the purchase of an energy-efficient home, or to fund renovations that improve a property's energy performance. These mortgages work by providing a clear incentive for homeowners in the form of a reduced interest rate on the loan.

For example, *Triodos Bank* offers mortgages that have received the EEM Label^{xvii}. Their model directly links sustainability to savings: the more energy-efficient the home is, the lower the interest rate the borrower pays on the mortgage. This structure encourages homeowners to invest in energy-saving measures. The EEM Label is not used at scale across Europe yet, however.



Figure 15: An energy efficient mortgage label reduces the interest rate on a mortgage, providing buyers with a clear financial incentive to buy renovated and energy efficient buildings, and helping to attract private finance towards renovation.

Neighbourhood-scale clean energy generation and sharing

The viability of functional PENs is critically dependent on successful neighbourhood-scale generation and sharing to include as many beneficiaries as possible within the radius of clean energy self-consumption. However, the physical integration of sufficient renewable capacity in dense urban areas is notoriously complex, often limited by space constraints and regulatory barriers.

Collective Self-Consumption (CSC) is increasingly effective for overcoming these barriers. Legislated at the European level since 2019, and most advanced within Spain and Portugal, CSC can enable a group of buildings — such as households, public facilities, and businesses within a steadily growing radius^{xviii} — to act as an effective virtual energy community without legally having to become one. Within this neighbourhood, electricity produced by local renewable sources (typically solar) is shared virtually among participants. This shared energy is distributed using the local grid but often incurs low or no additional DSO (distribution system operator) tariffs, since not considered a commercial activity. CSC systems match local generation with nearby demand, significantly reducing pressure on wider energy networks. Instead of transporting energy over long distances from centralised facilities, energy remains local, improving efficiency and grid resilience.

Example 1: CleanWatts, scalable energy communities in Portugal

Portugal and Spain have been pioneers in implementing the CSC model, aided by generous solar generation potential and supportive local policies. A prominent example is CleanWatts, a Portuguese venture capital-backed company that designs, finances, builds, and operates RECs for towns and communities.

CleanWatts uses the CSC model to enable tax-exempt energy sharing, creating significant local impact. As of its latest reports, CleanWatts has over 30 RECs operational and more than 200 in various stages of building and licensing. This network already includes over 10 MWp of installed solar capacity, with an additional 60 MWp still contracted for delivery.



Figure 16: By leveraging Europe's collective self-consumption energy sharing policy, CleanWatts offers a scalable and commercial path to developing energy communities in Portugal.

The benefits for the community and environment are significant:

- **Energy bill savings:** Energy shared within the community is approx. 20% cheaper than average grid tariffs (€0,23/kWh), providing a strong financial incentive for local participation and no upfront investment cost requested.
- **Membership:** CleanWatts' operational RECs currently serve over 350 members. A total of +3,000 members is expected once all contracted RECs are functional.
- **Environment:** The project pipeline will offset over 100,000 tons of CO₂ emissions annually, demonstrating the model's significant contribution to decarbonisation.

As of 2025, CleanWatts has raised around €30m to scale-up its commercially viable energy community across Portugal and Spain.

Example 2: ASTER, €100m finance unlocked to provide affordable energy to social housing

In Flanders, CSC is recognised and available - but only possible within a single apartment building due to policies around collective metering, tariffs, and administrative costs (e.g. users are charged a fee both when exporting and importing energy to/from the distribution network).

Despite this current limitation, ASTER^{xix} has instead built a viable business case by leveraging its large base of social housing developers and tenants to negotiate favourable energy tariffs and competitive rates within its procurement for services.

ASTER is a non-profit association of social housing companies in Flanders. Its mission is to make social housing more sustainable through the development of clean and affordable energy solutions for tenants. ASTER secures financing to deliver and maintain the energy services on the site on behalf of the social housing providers. ASTER owns the PV assets and charges an initial fee plus annual fee for maintenance. A local ESCO company operates and maintains the energy assets themselves.

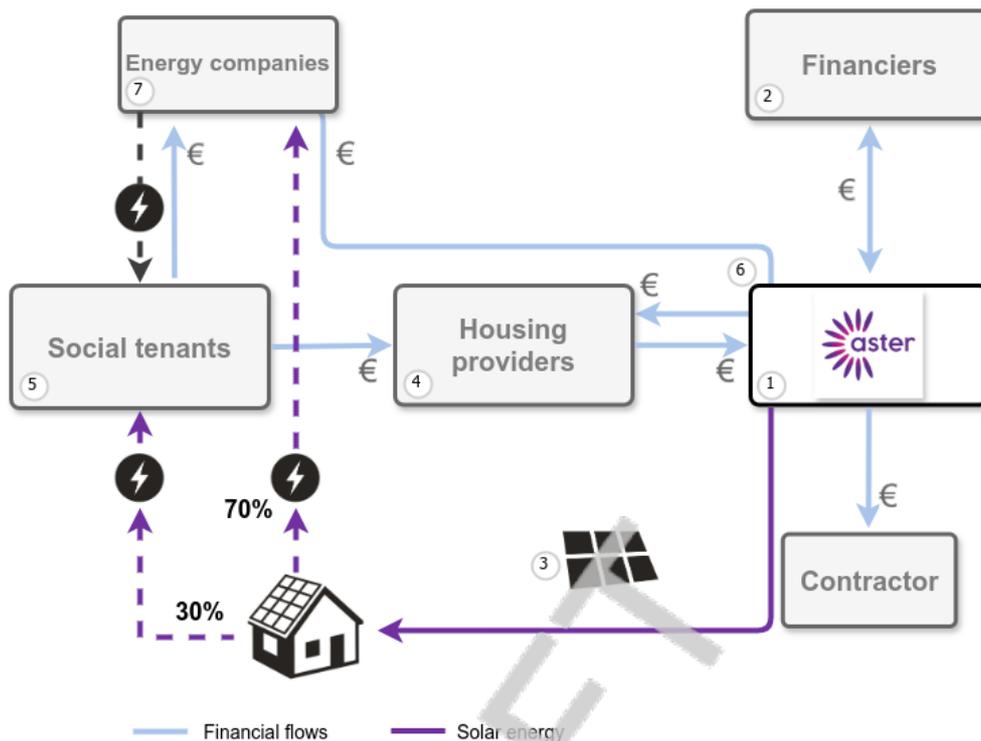


Figure 17: ASTER's business model offers clear incentives for households, energy service providers, and regional banks, unlocking over €100m of financing to roll-out solar, storage, and EMS for social, environmental, and economic benefit.

The social housing tenants benefit from up to 40% reductions in energy bills through direct self-consumption of their rooftop solar – paying €0,19/kWh compared to grid average of €0,35/kWh).

As the sole developer of 45MWp solar capacity across the social housing sites, ASTER can aggregate a large volume of energy consumption and production across several buildings to negotiate favourable energy tariffs with the DSO, further reducing tenant bills and increasing revenues to repay investors.

In 2022 ASTER secured a €105m loan from a private bank and now has plans to expand its energy services to storage and electric heating, as well as energy sharing. By the end of 2025, ASTER hopes to establish itself as an independent energy supplier, ASTER Energie.

Affordable housing

The integration of affordable and inclusive housing is also a fundamental yet often overlooked component of PENs. While typically defined by their more technical goals of achieving a clean energy surplus, PENs should also account for the changing social needs of urban communities. Given the ongoing cost of living crisis across Europe^{xx}, and the increasing proportion of energy within a total household budget, considering housing is a central ingredient within a broader PEN strategy.

Without considering affordability and wider market dynamics, PEN investments could in fact further increase property values, and risk displacing residents from new "eco-enclaves". Instead, coupling energy efficiency, local energy generation, and housing affordability can

ensure that all residents regardless of income can benefit from local energy bills, a healthier living environment, and resilient communities.

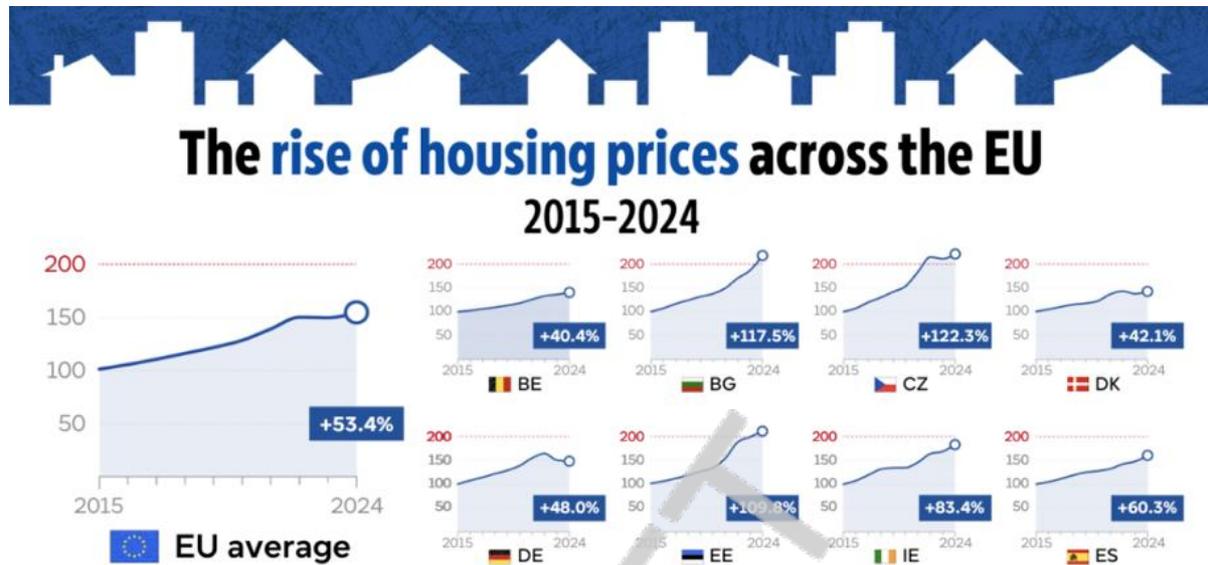


Figure 18: By offering novel models of home financing and ownership, PENS could help protect residents from Europe's housing affordability crisis (European Parliament, 2024)^{xxi}.

Example 1: Cooperative housing – ensuring affordability by cooperative ownership and insulation from the market

Cooperative housing is a form of collective ownership whereby residents collectively manage and control their housing, rather than owning individual units.

One specific variation gaining traction, especially in Barcelona, is the “grant of use” (Spanish: *cesión de uso*) model. Here, residents form or join a cooperative, which develops or acquires a building, often through long-term leases on public or community-owned land (e.g., 75 years). Each household pays an initial entry contribution (capital share) and a monthly fee covering building maintenance, common services, and repayment of loans. Members collectively manage the cooperative, including decision-making on governance, maintenance, and community life.

The cooperative entity legally owns the building, while members hold long-term, non-transferable rights to use their individual homes. Residents do not own the property, nor can they sell or rent their units at market value – this removes the property from the conventional housing markets, helps to prevent speculation, and ensures long-term affordability for cooperative members.

In terms of project financing, the total cost of the La Borda project was €3,246,557, secured from three primary sources^{xxii}:

- **Coop57:** The largest portion, 52%, was provided by Coop57, an ethical financial services company, through equity loans and bonds.
- **Residents:** The co-operative residents themselves provided 18% of the total funds.

- **Other contributions:** The remaining 30% was raised through loans and grants from various public and social entities, including the Barcelona City Council, the Government of Catalonia, the Spanish national government, social economy organizations, and individuals.

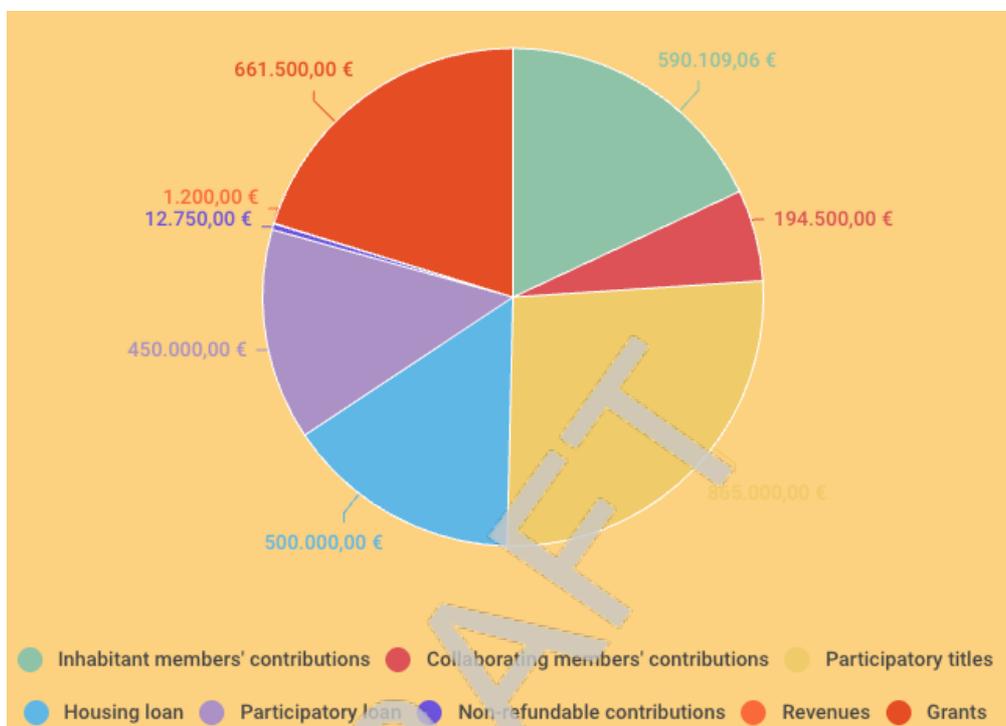


Figure 19: La Borda's total €3,2m construction cost was financed through a combination of ethical bank loans, private member contributions, and low-cost loans and grants from supportive regional public organisations.

Crucial to the affordability and overall viability of La Borda is their access to cheap land on which to build, owned by a supportive municipality and available for subsidised social projects^{xxiii}. The example of Community Land Trusts (CLTs) below explains this factor in further detail.

Example 2: Community land trusts – addressing core land factor of housing affordability

CLTs are non-profit, community-led organisations that acquire and hold land in a legal trust to ensure it is used for the public good and made permanently affordable. The core principle of CLTs is in recognising that the value of land represents an increasing share of total property prices. By separating ownership of the building (privately owned) from ownership of the land below (collectively owned), CLTs remove land from the speculative real estate market and thereby help to stabilise housing costs over time.

A CLT owns land in perpetuity and leases it to individuals, housing cooperatives, or non-profit developers through long-term (e.g., 99-year), renewable ground leases. Residents can buy or rent homes on the land, but resale prices are capped by an equity-sharing formula that preserves affordability for future occupants. Governance is typically shared among residents, community members, and public-interest stakeholders, ensuring local accountability.



Figure 20: Land value represents an increasing share of the rising costs of housing^{xxiv}. CLTs address this by holding land ownership within non-speculative community trusts.

An example is the Community Land Trust Brussels, who work closely with local governments and civil society to secure land and to develop affordable housing. Across the CLTB's 11 plots of land and almost 200 homes, affordability has been kept far below comparable local market rates, in some cases almost 50% cheaper^{xxv}.

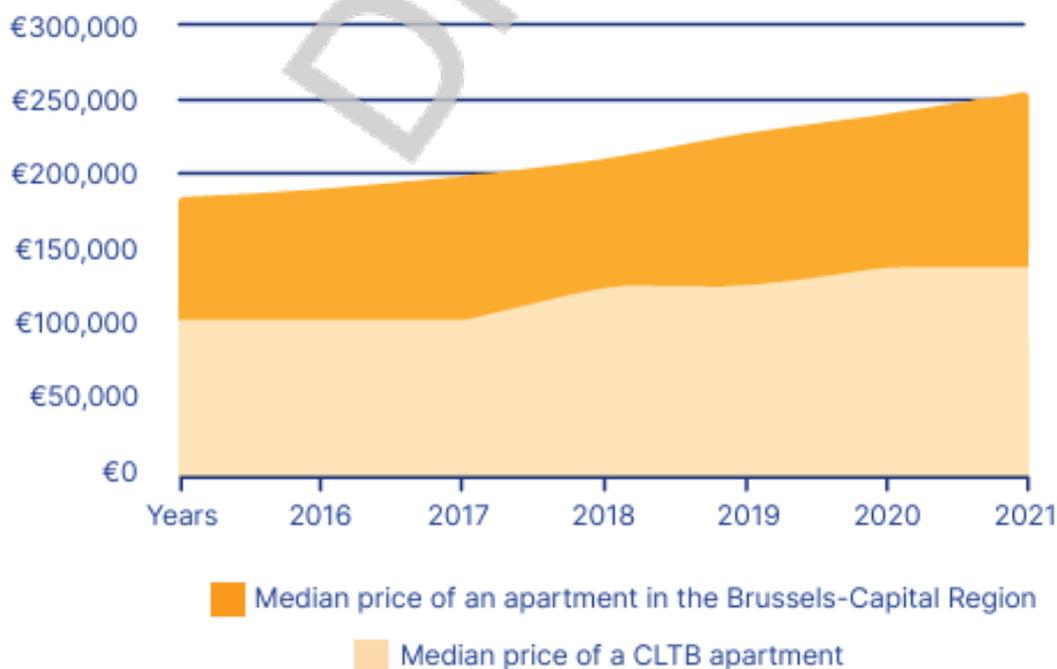


Figure 21: By retaining land ownership in a community-owned trust, private residences are kept permanently affordable through the Community Land Trust model (e.g. CLT Brussels).

PEN finance and funding models

Delivering Europe’s urban clean energy transition demands a financial commitment far exceeding the capacity of public budgets alone. While metropolitan governments and regional municipality authorities can set bold policy commitments and help to de-risk initial investments, they are unlikely to be the primary funders - due both to the scale of investment as well as European fiscal laws limiting levels of public debt taken on for new investments.

Innovative financial models will therefore be required to bridge the scale-up gap, effectively using public money (through grants, loan, guarantees, off-take contracts etc.) to attract and catalyse available private capital.

Indeed, existing earmarked public investment in Europe is estimated to cover only 15-20% of the total capital needed for the energy transition. Despite ambitious catalysts like REPowerEU and the Recovery and Resilience Facility (RRF), a further €400-450bn annually until 2030 is still unaccounted for.



Figure 22: Despite strong existing public commitments, up to €2,25tn in additional climate investment is still needed to deliver on Europe's targets by 2030 (European Central Bank, 2025) ^{xxvi}.

It is expected that remaining must be sourced from the private sector, with successful cities attracting institutional investors, pension funds, commercial banks, as well as alternative finance such as large-scale crowdfunding platforms.

Besides supporting the design and creation of bankable project opportunities, public authorities can also facilitate capital flows through such tools as: first loss guarantees; novel public-private partnerships that distribute financial risks and rewards; offering long-term offtake agreements to local energy projects, providing guaranteed revenue and therefore supporting investor confidence.

Public SPV – unlocking private capital through long-term guarantees

A Special Purpose Vehicle (SPV) is a separate legal entity created to carry out a specific project or function, often with the aim of isolating financial risk and attracting private investment. In the context of local energy transitions, an SPV allows municipalities to act as enablers of infrastructure investment without burdening their core budgets. The City of Aarhus provides a strong example through the establishment of the Aarhus Climate Company—a publicly owned, independently operated SPV tasked with rolling out solar PV on 70,000m² of municipal rooftops.

The SPV coordinates the installation, financing, and operation of the systems. It partners with local suppliers and signs power purchase agreements (PPAs) with public buildings to buy the electricity generated at a predictable, long-term rate. This guarantees stable cashflow, reducing investment risk.

Examples of public-driven SPVs in Europe include: the Aarhus Climate Company, MES Barcelona, and SEM Energies Dijon.

City Climate Fund – mobilising private investment through a city-led funding portfolio

City Climate Funds are local investment vehicles created by municipal governments and designed to aggregate separate sustainability projects into a single, bankable portfolio. Instead of financing individual assets, which are typically too small or risky for investors, city funds bundle together reliable revenue-generating projects (like renewable energy installations) with socially important but lower-returning initiatives (like deep retrofits and social housing).

City funds typically use public capital to mitigate risk, often via first-loss guarantees, helping to "de-risk" the broader portfolio and successfully attract large-scale private investors from pension funds, and banks that would otherwise be uninterested.

The *Leuven 2030 Climate Fund* exemplifies this approach by consolidating the city's "Breakthrough projects" into a unified investment strategy. For PENs, this model is particularly relevant as they require the simultaneous integration of diverse assets, including district heating, solar PV, and building efficiency, also across fragmented ownership structures. A City Climate Fund could finance a PEN as a holistic ecosystem of investable assets, ensuring that the high-ROI energy assets would cross-subsidise the costly but necessary infrastructures, and help enable the transition of entire neighbourhoods at scale.

D7.5: Implementation plans for 12 sustainable investment programmes towards PENs

Visualised – PEN business and financial models

Business model #1 - Shared energy savings within single apartment “neighbourhood”

This business model leverages energy cost savings across multiple-dwellings to repay renovation costs.

Benefits: Passive building renovation is contractually simple to deliver, has zero operational costs, and delivers instant energy savings.

Limitations: A viable business case depends on high baseline energy costs, and simple decision-making processes among fragmented apartments.

Example: Tartu Living Lab – not successful

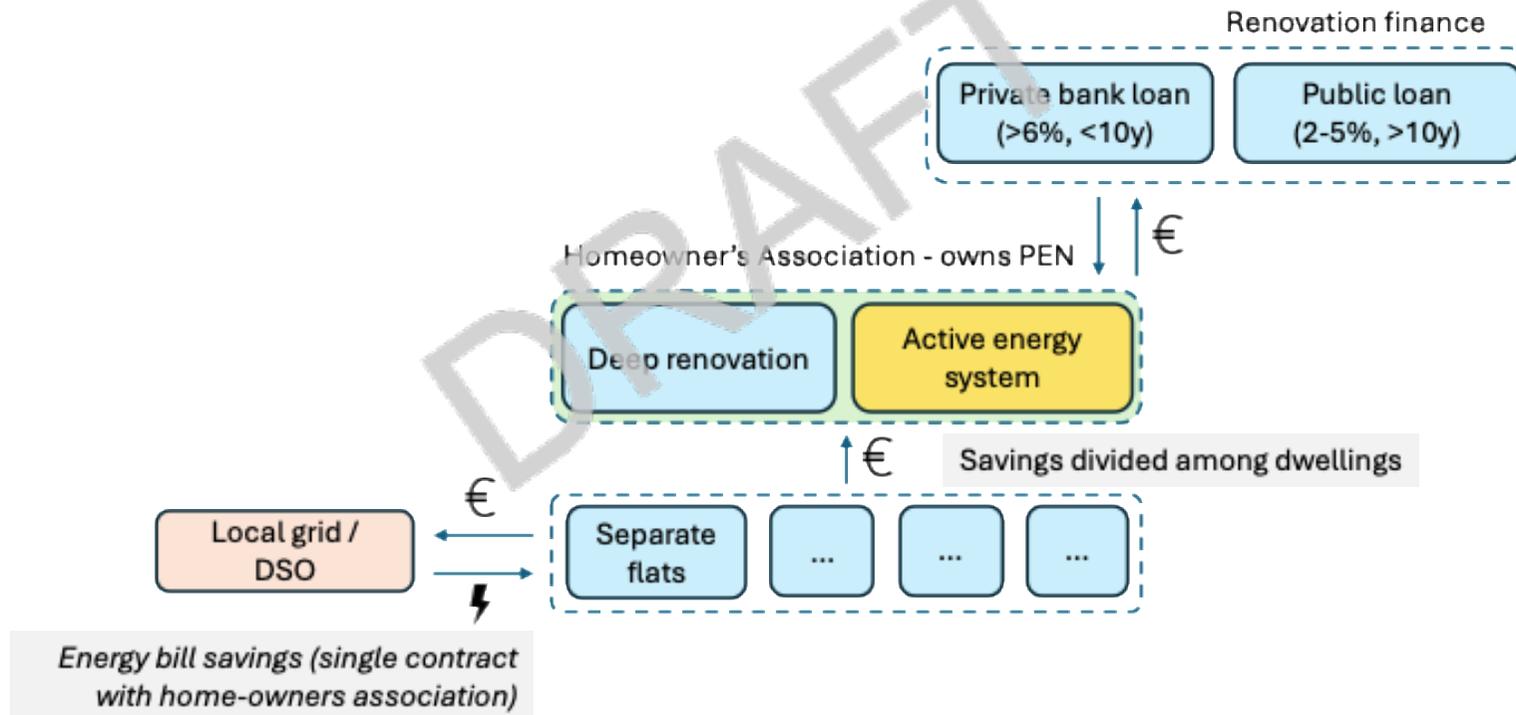


Figure 23: PEN business model based on shared energy savings in an apartment block.

Business model #2 – Energy services contracting

This business model outsources the energy system capital costs and technical maintenance to a service provider (ESCO).

Benefits: Reduced capital costs for PEN community or building owner, and energy savings assured through energy savings contract with ESCO.

Limitations: Higher long-term costs for the building potentially with no final ownership. The ESCO typically secures financing at commercial rates which are passed onto the customer (unless reduced via a public guarantee).

Successful example: RenESCO (Latvia), Super-I project (Italy), BASE energy savings insurance model

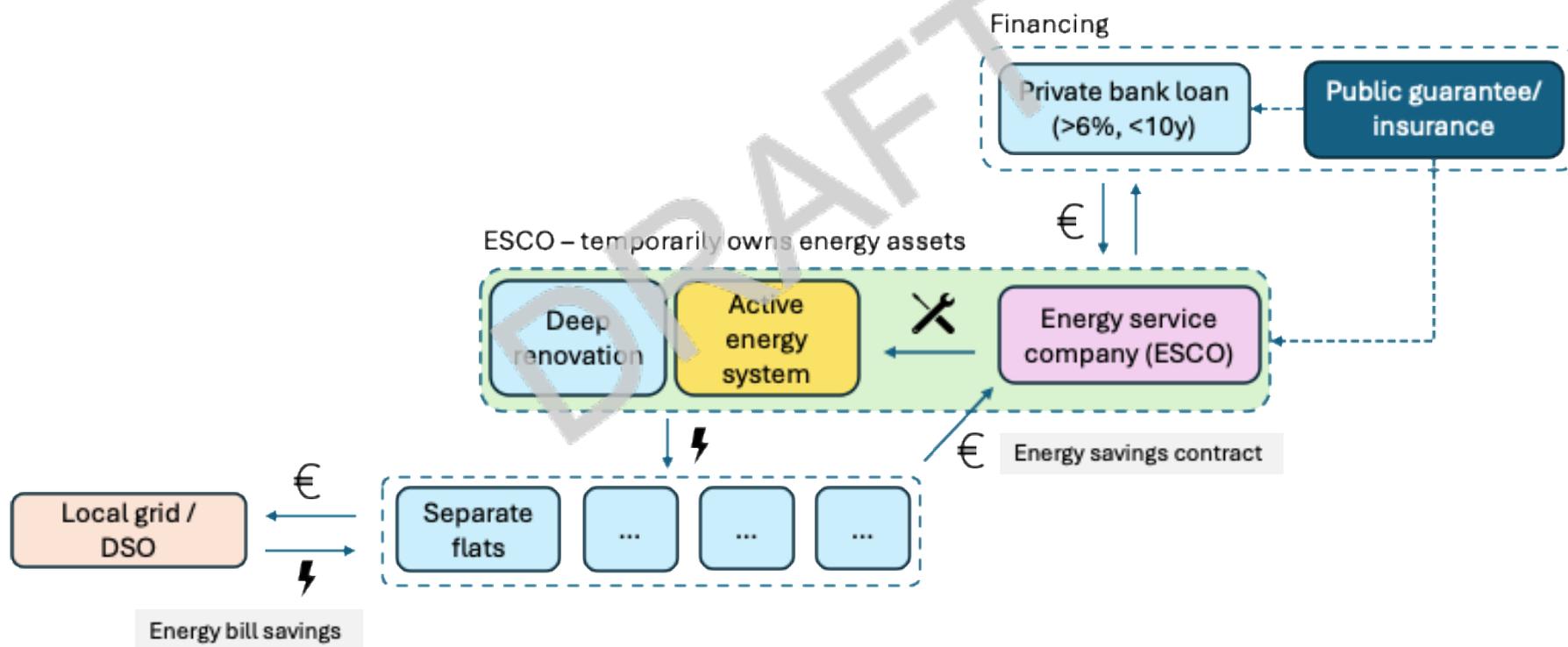


Figure 24: PEN business model involving ESCO and public guarantee

Business model #3 – Energy sharing through collective self-consumption

This business model uses digital metering technologies to measure, leverage, and pass on the reduced costs of local energy distribution, allowing local buildings to virtually share energy cost savings from the renewable generation of a single site.

Benefits: CSC leverages new local energy system regulation and market forces to support a commercially scalable energy community approach.

Limitations: Many countries in Europe do not currently allow for the locally-adjusted energy bills that a CSC business model relies upon.

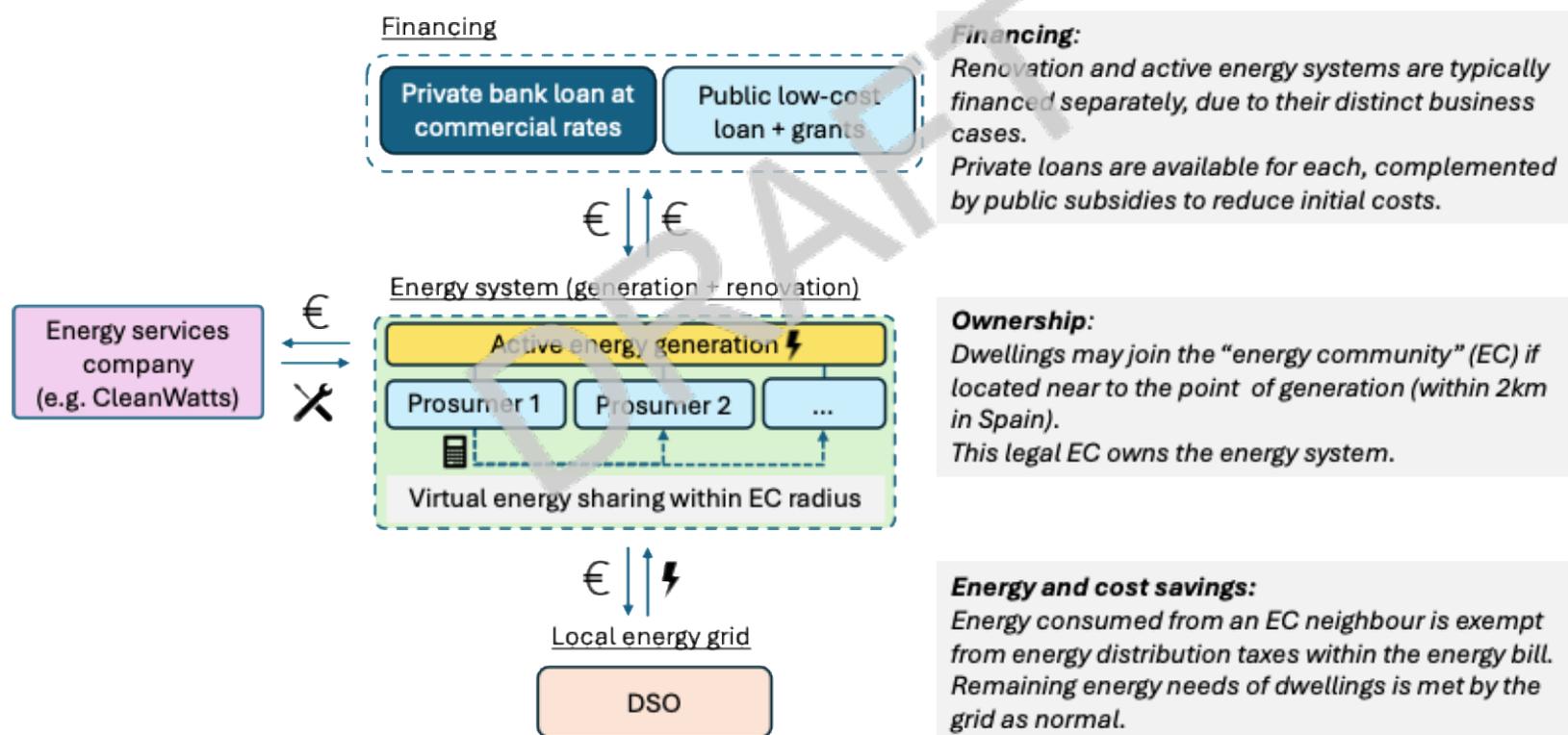


Figure 25: PEN business model based on energy sharing, leveraging collective self-consumption regulation.

Business model #4 – Energy sharing through collective self-consumption

The legally separate “special purpose vehicle” (SPV) owns the energy system and sells the energy to off-takers through a PPA contract.

Benefits: The SPV simplifies financing and isolates financial risk for banks; a complementary public guarantee reduces cost of finance; the PPA ensures consistent long-term revenue and investor payback; buildings receive reduced energy bills.

Limitations: Public guarantees are not yet widely used throughout Europe, and PPAs with separate building owners can be complicated.

Successful example: Aarhus Climate Company (Denmark)

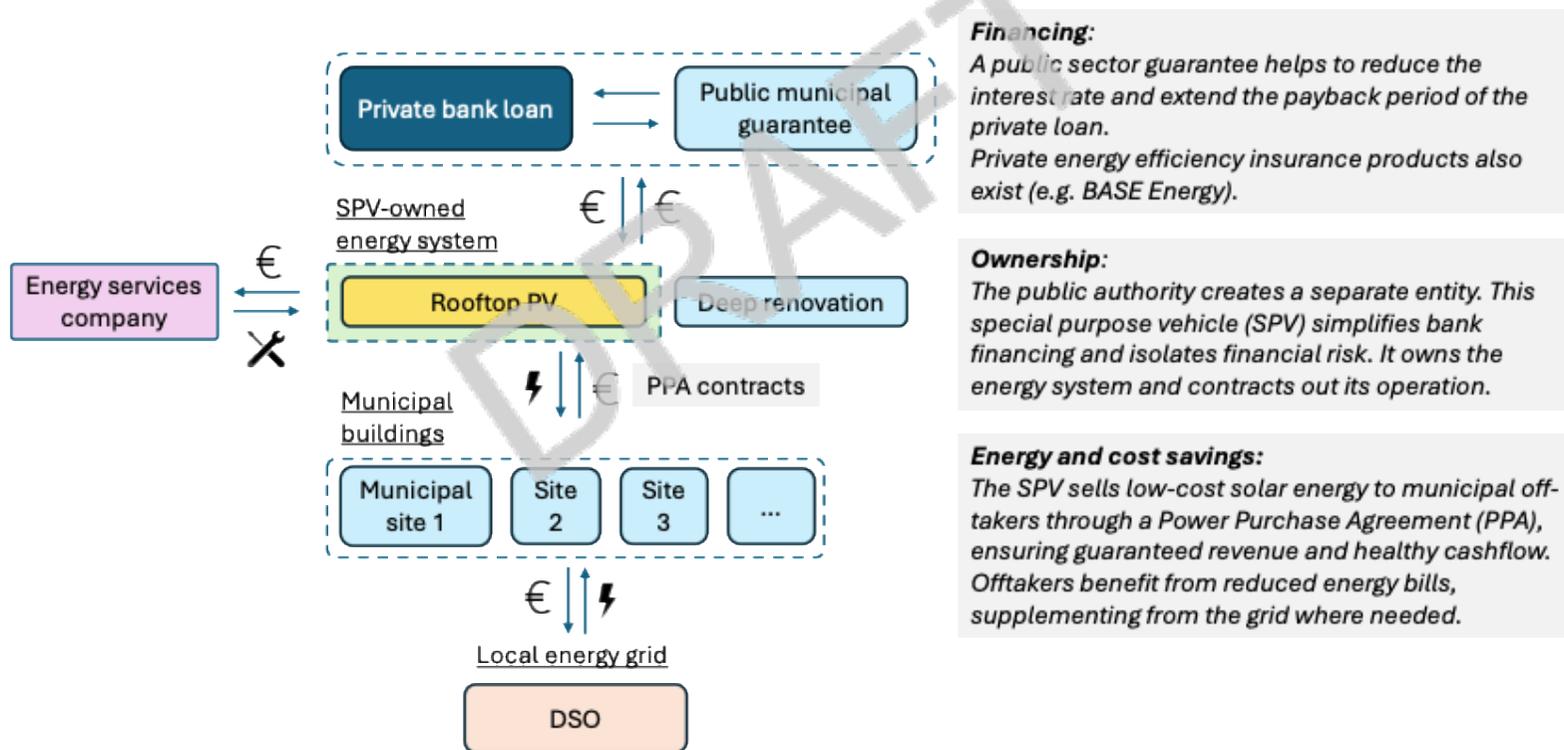


Figure 26: PEN business model for delivering city-wide energy systems through a municipal-sponsored SPV.

Business model #5 – Zero energy bill affordable housing

A legal cooperative or community group accesses affordable land through either a municipal grant or community land trust (CLT). The building is kept within cooperative ownership and taken off the housing market. Local engineering companies support renovation, construction, and energy system design through energy service contracts. Tenants pay membership fees in exchange for lifetime “grant of use” of housing, priced according to a non-profit business model.

Benefits: Community land trusts and cooperative housing models are shown to generate housing at below-market rates, whilst supporting social cohesion and stability through co-living arrangements.

Limitations: Collective housing requires high levels of motivation, thereby excluding most homes. It is also so far only demonstrated for new-build housing on urban land given by the municipality at nominal cost.

Examples: European Community Land Trust Network (ECLTN), Sostre Civic cooperative housing network in Barcelona

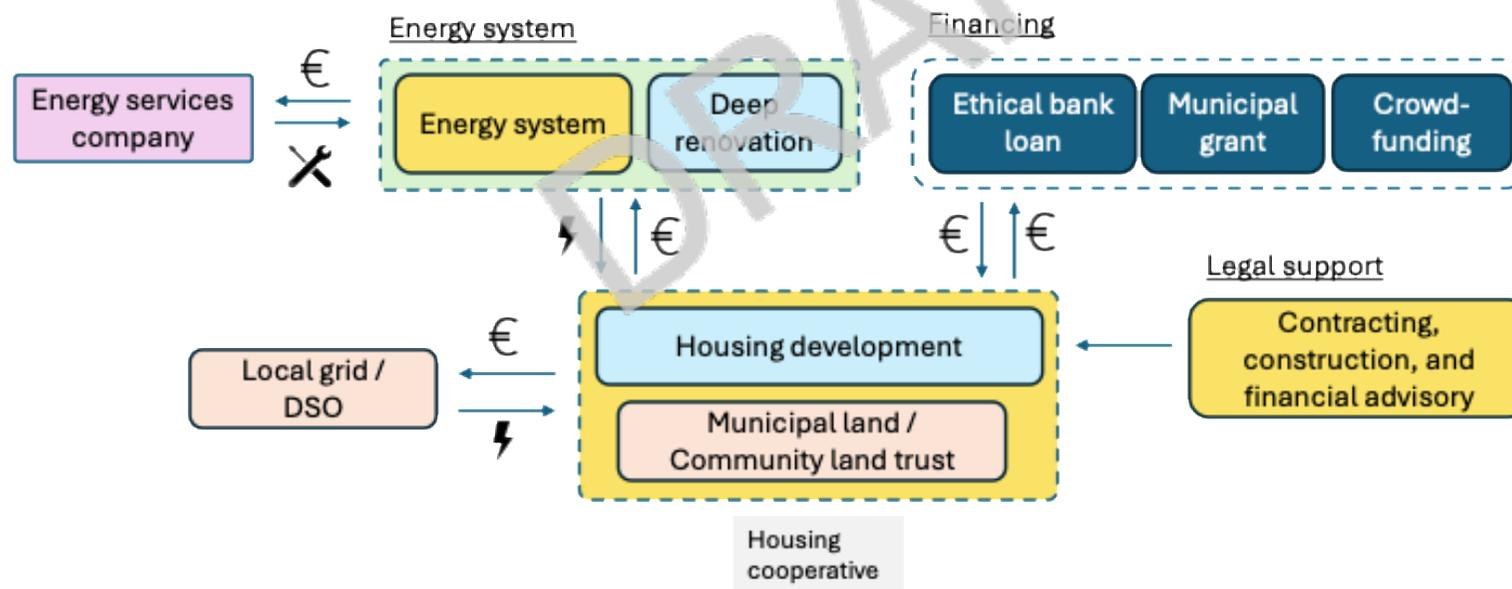


Figure 27: PEN business model for affordable and efficient urban housing.

7. PEN Typologies – exploring the case for PEN development standards

Under what urban contexts are PENs most viable - and why?

Drawing inspiration from industry practice – enhanced with on-the-ground results from the oPEN Lab’s three Living Labs - Bax proposes several “PEN Typologies” to explore and compare the most effective ways to deliver PENs in urban environments³.

This Archetype approach reflects an evolution in EU research and development from positive energy “buildings” to “neighbourhoods”, given that a per-building approach was found insufficient to deliver the energy transition at the speed and scale required. Given that the smallest functional unit for a cost-effective, rapid, and system-level urban energy transition is therefore now considered the “neighbourhood”, the question now then becomes what “type” of neighbourhood is best suited?

PEN Typologies addresses this question, simplifying the range of neighbourhoods down to more manageable numbers of customer segments, each with a typical range of physical, technical, ownership, and commercial characteristics that can be used to inform a development and investment case. The idea also draws on similar industry practice by social housing developers, energy suppliers, and regional innovation clusters in Europe, who evolve from a per-building approach to a clustering or typology approach:

- Social housing association ASTER defines a set number of “building typologies”, sent to their technical delivery partners to describe the technical specifications of their solar installations depending on building type
- TNO in Netherlands takes a “bundling” approach, producing standardised renovation solutions for similar building types^{xxvii}



Design file: Charles de l'Épéeplein 1 0101 9000 Ghent
ASTER identification number: 306-00015.001

Name WM: Thuispunt Ghent
Contact WM: Sien Vervoort, 0471 80 26 60, sien.vervoort@thuispuntgent.be
Unique ID of WM: CNKTK
Contact EnergyVision: Dean De Sutter, dean.desutter@energyvision.be

Contact ASTER: Wim Van Puyvelde, 03 369 83 55 / 0467 33 56 47, wim.van.puyvelde@aster.vlaanderen, techniek@aster.vlaanderen
Contact inspection/damage: aster@energyvision.be
Date of technical visit: 18/02/2025

Information

Type and number of solar panels	RSM108-9-435BNDG (435 Wp)	4 solar panels	1.740 kWp
Type of inverter	ASTER X1-MINI-1.5K-G4	1.65 kVA	

Figure 28: ASTER’s building typologies provide standardised technical instructions to local delivery partners, distinct and replicable for each particular social housing building type.

³ Similar work has been explored by project partners IBS, in their Deliverable 2.5 *Benchmark and categorisation of PEN organisational models* (December 2025)

A summary of the PEN Archetype analysis is presented below, with more detail on each Archetype included in the Annex at the end of the document.

Key comparisons between PEN Typologies

The PEN archetype approach reveals that the implementation pathway for PENs is not one-size-fits-all but must be adapted to leverage the unique physical and social opportunities presented by different building environments.

Further, in most cases, we find that the critical bottleneck is not access to and roll-out of mature PEN technologies, but in finding an appropriate governance and ownership model that can a) effectively secure financing, b) inclusively account for dwelling priorities, c) be delivered at the speed required, and d) at large scale. Using the Archetype approach, we find that the specific factor of building ownership can have the most significant implication on final PEN implementation pathways.

Adding to this, physical similarities and opportunities between different PEN types can be undermined by different governance characteristics – both high-rise and social housing represent homogenous building types ripe for cost-efficient renovation, but each have different ownership models which affect overall PEN viability.

- For single-owner PEN Typologies** (social housing, industrial sites):
 The primary challenge is in developing an attractive business case that can both attract external financing whilst also being viable for the residents. This strategy should deploy capital for scaling proven technical models (industrialised renovation, waste-heat capture).
- For fragmented-owner PEN Typologies** (high-rise apartment, and distributed private dwellings):
 The challenge is in governance and engagement across a large number of fragmented dwelling and owners. The strategy should explore how intermediaries (One-Stop-Shops) and platforms (EaaS) can overcome the collective action problem to rapidly deliver PEN solutions.

Taken together, we can summarise the pros and cons of each PEN Archetype below.

Archetype	Key takeaways
High rise	Presents the hardest governance challenge - the "condominium problem" of many fragmented owners within the same building makes renovation slow, expensive, and legally complex. Effective technology is ready (e.g. BIPV to leverage large horizontal façade space), but governance - and therefore bankable financial models - require further development.

Distributed	Has the highest citizen potential but is challenged by extreme fragmentation and technical challenge of heterogenous building types. Digital tools and legal frameworks (RECs) may overcome this by aggregating dwelling preferences into a single platform.
Social housing	Represents the highest potential for PEN development, in terms of both speed, scale, and social impact. The single-owner model removes the primary governance barrier, simplifies contracting, and large building size exploits economies of scale to reduce renovation costs.
Industrial	Offers best potential business case by leveraging strong private-sector economic incentives (cost-savings, efficiency) and large technical potential (waste heat, roof space). Also well-suited for delivery and management by proven business models like EaaS.

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8. PEN Followers: Assessing PEN readiness across 12 European sites

Through a combination of interviews (Q1-Q3 2025), supplementary desk research, and close collaboration with oPEN Lab project partners - namely EnoLL, Flux50, and TREA – a group of 12 European cities was chosen to explore potential PEN replication, and the core factors supporting PEN replication in typical urban contexts.

Further detail around the rationale of the 12 cities is included in the Annex.

The assessment process comprises 4 key parts:

1. **The existing policy and strategic ambitions of the city is assessed**, including its capacity and commitments to supporting neighbourhood-scale clean energy renovation, generation, and sharing projects.
2. **The existence of relevant projects and pilots is then reviewed**, indicating the foundations of political, economic, and societal buy-in as well as technical familiarity with such ambitious urban development initiatives.
3. **A PEN Readiness assessment is conducted for each city**, covering the domains of political, economic, societal, and technical expertise and maturity.
4. **Finally, suggested actions are provided** for each city, highlighting topics and collaborations that need greater investment to successfully evolve PENs from initial pilots to scalable and commercially viable urban development opportunities.

Phase	Innovation Readiness Level		Description
Design From problem to plan	1	Challenge Observed	A challenge is observed and agreed upon by industry practitioners and experts.
	2	Idea Described	A solution concept is described by technical experts in sufficient detail to set a clear plan to validate the solution's viability.
	3	Concept Articulated	A solution articulated as a proof of concept that is validated by technical experts
Demonstrate From plan to live demonstration	4	Concept Validated	The proof of concept is validated with non-technical experts within the wider innovation ecosystem, including end users.
	5	Prototype Tested	A prototype is shown to be feasible (but not yet commercially or politically viable) when tested in highly controlled conditions that simulate the real-world application.
	6	Prototype Demonstrated	A first-of-a-kind project supported with public funds tests a small-scale version of a scalable solution in a controlled environment.
Deliver From demonstration to everyday use	7	Solution Demonstrated	Repeated pilot demonstrations show buy-in from key stakeholders and a track record of positive user engagement, technical efficiency and financial viability. Public subsidy may still be used at this stage.
	8	Solution Scaled	Widespread deployment across multiple geographies, replicated by partners and funding instruments beyond the project scope and without public support.
	9	Solution Standardised	A mature and bankable solution that is treated as part of standard operating practice.

Figure 29: The Readiness Level scale (1-9), used to rank each of the 12 "follower" cities.

Following the individual city assessments, broader key trends and patterns are then extracted to highlight common factors between cities within "high" versus "low" PEN readiness.

An overview of the 12 city Followers is provided in the table below, including brief justifications for the inclusion. Further information can also be found in the Appendix at the end of the document.

Locality	Country	Justification for inclusion
1. Pamplona	Spain	Replication of Rochapea’s renewable energy community (REC) model is already happening beyond the initial oPEN Lab demonstration.
2. Barcelona	Spain	Demonstrates a rapidly scaling cooperative housing sector and ambitious city-led approach to energy financing.
3. Madrid	Spain	Has expressed interested in replicating Pamplona’s REC model.
4. Mechelen	Belgium	Recommend by Genk Living Lab partners VITO as a promising Flanders replication site.
5. Oostend	Belgium	Recommend by Genk Living Lab partners VITO as a promising Flanders replication site.
6. Antwerp	Belgium	The primary location for ASTER’s rapidly scaling social housing energy business model and so representing good potential for PEN design and replication
7. Tartu	Estonia	Provides useful lessons for PEN development and renovation across multi-story apartment blocks.
8. Amsterdam	Netherlands	Shows a mature cooperative housing sector and was highly recommended from ENoLL Living Lab events.
9. Aarhus	Denmark	Their novel public “Climate Company” financing model demonstrates high political buy-in and ambitious, and the region is actively working on PEN projects.
10. Lisbon	Portugal	Portugal has a rapidly growing market-oriented approach to energy communities (e.g. led by CleanWatts).
11. Munich	Germany	One of the EU’s 100 Climate Neutral and Smart Cities initiative.
12. Stockholm	Sweden	One of the EU’s 100 Climate Neutral and Smart Cities initiative.

Table 1: An overview of the 12 follower cities assessed by Bax for their PEN Readiness and insights.

PEN Follower Site 1: Pamplona, Spain

Snapshot - Pamplona is a major city in Spain with a population of over 300,000 residents in the wider metropolitan area. Pamplona is a member of the Covenant of Mayors and has a 2030 Energy Transition and Climate Change Strategy^{xxviii}, aligned with EU climate goals. Pamplona aims for climate neutrality by 2050.

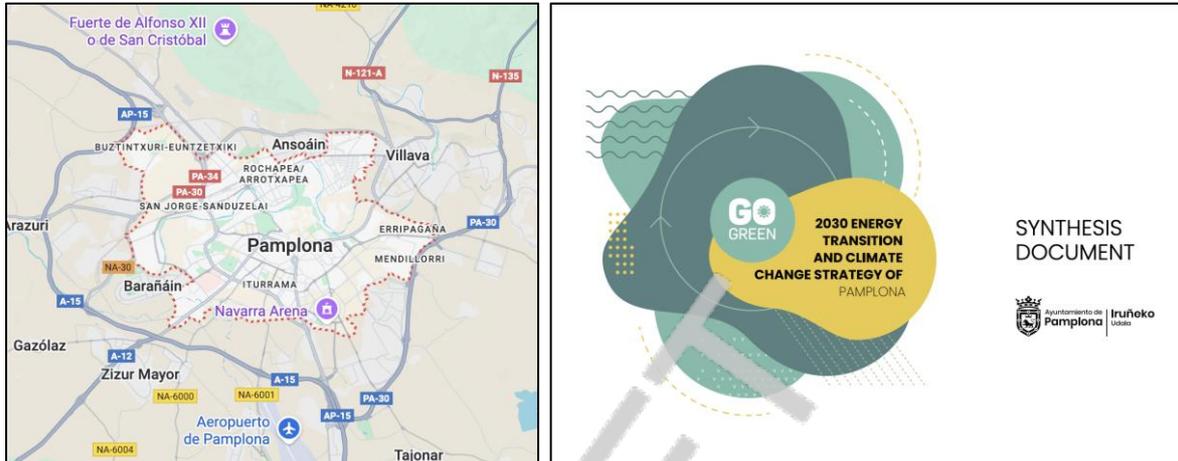


Figure 30: Pamplona, Spain

Pamplona’s PEN Readiness

Overall, Pamplona scores a 7 in terms of PEN Readiness, based on the PEST breakdown as described below.

PEN Readiness		1	2	3	4	5	6	7	8	9
P	Political buy-in and local energy markets							<input checked="" type="checkbox"/>		
E	Available funding and finance							<input checked="" type="checkbox"/>		
S	Community capacity and demand							<input checked="" type="checkbox"/>		
T	Technical maturity and local suppliers							<input checked="" type="checkbox"/>		

Figure 31: PEN Readiness Pamplona

P - Political (IRL 7)

Pamplona works under a clear local strategy that aligns with the Covenant of Mayors and the Navarra regional roadmap. The city’s plan specifies governance and actions for local energy, buildings, and renewable energy assets. Regional and EU programmes support municipal action. Permitting follows national frameworks and regional guidance that enable rooftop PV and community initiatives. Legislation like *Royal Decree 244/2019*^{xxix} and *Royal Decree-Law 7/2025*^{xxx} allow energy sharing within a range of 5km.

The city developed an *EU City Facility* (EUCF) strategy concept explicitly aimed at Positive Energy Districts, embedding PEN development in local governance^{xxxi}.

E - Economic (IRL 7)

National and regional funding (EU-backed) is available for local projects and energy communities. Examples from funded projects are Efidistrict Fwd^{xxxii} (ERDF funding), STARDUST^{xxxiii} (Horizon 2020) and oPEN Lab^{xxxiv} (Horizon 2020). Additionally, the *EUCF* strategy helps attract private finance beyond grants. Power purchase structures and public portfolios can be combined with self-consumption to further de-risk investment.

Spain's collective self-consumption energy market legislation allows tax-exempt energy sharing between consumers, improving PEN business cases. The Spanish government implemented a wide range of incentives to stimulate energy sharing, such as the abolishment of the "sun tax"^{xxxv}, subsidies, or tax reductions for the installation of solar PV^{xxxvi} (amongst which also local incentives)^{xxxvii}. The distance limit for energy sharing has recently been expanded to 5km, further balancing local clean energy supply and demand within communities^{xxxviii}.

While energy sharing in Pamplona has the potential to deliver renewable energy at affordable prices, the high upfront investment costs for residents and small businesses, complex bureaucracy and the instability of available subsidies remain the biggest economic obstacles to scale energy sharing initiatives^{xxxix}. Additionally, the balance between fixed and variable costs on the energy bill limit the saving potential for households and reduce the attractiveness of installing solar PV^{xl}. Grid congestion creates uncertainty for implementation of new projects and their ROI, Plan Energético de Navarra 2030 aims to mitigate.^{xli}

S - Social (IRL 7)

Pamplona has extensive experience with neighbourhood-level renovation and citizen benefit pilot projects.^{xlii} Local communication and participation are embedded in the city's strategic process. Energy sharing can lower bills but also requires simple solutions and support to ensure accessibility by vulnerable groups. Especially administrative and permitting complexity negatively impacts participation at scale.^{xliii}

The organization OTC Navarra, an initiative launched by the government of Navarra and the public company *Nasuvinsa*, provides legal and technical support for the development of energy communities^{xliiv}. This initiative has the potential to accelerate the adoption of energy communities, which represents a core organisational pillar of PEN development.

oPEN Lab partners CENER and AHU highlight that Pamplona is successfully replicating existing PEN initiatives (amongst which, their One Stop Shop) to other neighbourhoods.

T - Technology (IRL 7)

Spain has full smart-meter rollout, enabling more effective collective self-consumption and demand-side flexibility innovations. For example, the Txantrea district heating project provides a live, low-carbon thermal backbone that can be paired with solar PV, storage and EMS at neighbourhood scale^{xliv}.

During Pamplona's participation in EU project STARDUST^{xlvi}, the city developed smart city capabilities through several innovative pilots, strengthening their positioning for PEN development further.

Like in many places in Spain, the uptake of renewable energy is causing grid congestion, leading to delays in grid connections, and curtailing. The Plan Energético de Navarra 2030 mentioned prior aims to strengthen the grid in the region, aiming to resolve grid issues that create uncertainty for the local energy transition.

Advancing Pamplona's PEN readiness

Pamplona has a lot of essential elements in place to implement PENs, including a PED strategy, legislation enabling energy sharing, and relevant learnings through innovation projects like STARDUST. To fully exploit their PEN potential, we recommend:

- Reduce administrative complexity for residents to encourage participation in energy sharing initiatives.
- Provide sufficient and stable subsidies to encourage the installation of solar PV, allowing residents to reap the benefits of more affordable energy.
- Leverage existing initiatives like OTC Navarra to scale local energy communities.

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PEN Follower Site 2: Barcelona, Spain

Snapshot – Barcelona is the second biggest city in Spain with a population of 1.7 million residents in the city itself, and 5.7 million residents in the metropolitan area. Barcelona is a member of the Covenant of Mayors and has written a local Sustainable Energy and Climate Action Plan (SECAP) - the *Barcelona Climate Plan 2018-2030*. The city's goal is to achieve climate neutrality and operate 100% on renewable energy by 2050.

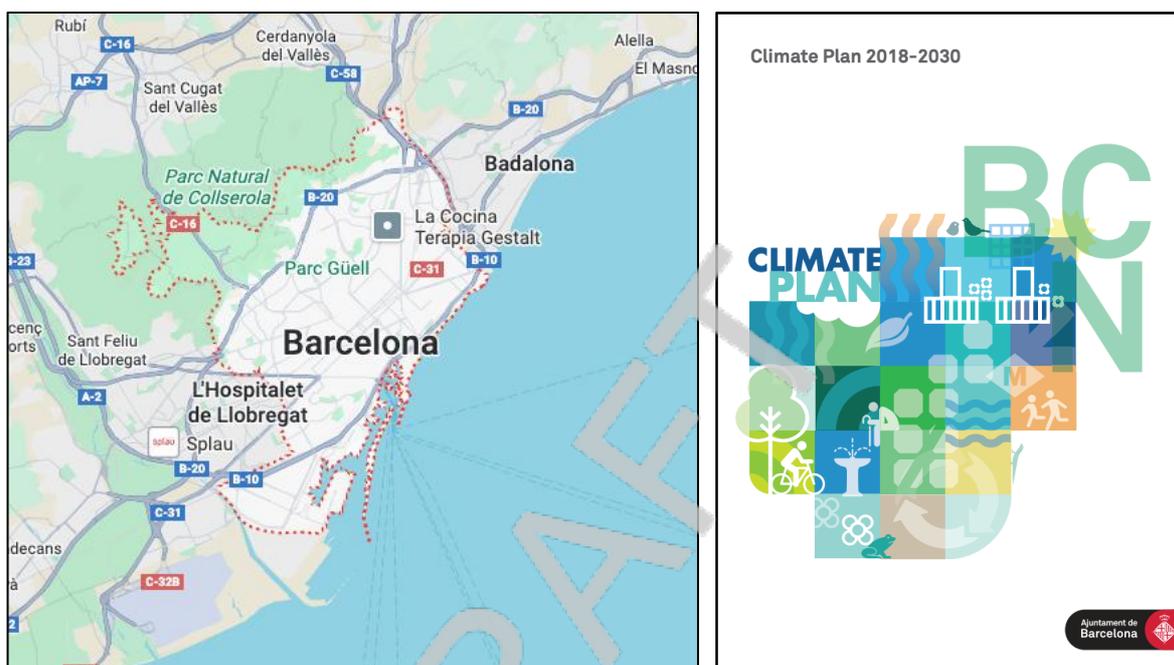


Figure 32: Barcelona, Spain

Barcelona's PEN Readiness

Overall, Barcelona scores a 7 in terms of PEN Readiness, broken down below:



Figure 33: PEN Readiness Barcelona

P - Political (IRL 7)

The autonomous community of Catalunya encourages local authorities such as Barcelona to develop local energy systems and decentralised energy governance. To advance the local energy transition, Barcelona declared a “climate emergency” in 2020.^{xlvii} Additionally, the Barcelona Energy Agency and Barcelona Energia (a city-owned energy distributor that promotes 100% renewable energy) were founded to achieve the city's ambitions^{xlviii}.

Community engagement is central to the policy development in Barcelona, with the goal to create resilient and autonomous energy systems.

E - Economic (IRL 7)

Just like Pamplona, Barcelona benefits from existing national regulation that allows for economic benefits for local energy systems via collective self-consumption. This enables the formation and commercial viability of decentralised energy communities with reduced dependency on the central grid. While energy sharing has the potential to deliver renewable energy at affordable prices, limited availability of rooftop solar installations, population density^{xix} and complex administrative processes make that the concept is not yet adopted at a larger scale.

Financial resources are readily available to reduce obstacles for energy investments. To incentivise the installation of rooftop solar, Barcelona introduced *MES Barcelona*ⁱ, an organisational public entity coordinating a €50m endowment for clean urban energy initiatives. Additionally, local tax reductions for the installation of solar PV are availableⁱⁱ, as well as grants for retrofittingⁱⁱⁱ.

S - Social (IRL 6)

Creating awareness and engagement amongst communities is central to Barcelona's energy transition. While energy sharing could support reduced energy poverty, the administrative burden required for its delivery can be a major obstacle for most residents, and limits participation. Simplification of administrative processes and more explicit communication on the associated incentives could contribute to more widespread participation.

To reduce energy consumption and energy poverty, the city of Barcelona set-up several Energy Advice Pointsⁱⁱⁱⁱ. In addition to their efforts to help vulnerable households reduce their energy usage, these EAPs could potentially be used to educate citizens on subsidies for solar PV or to assist with the administrative process of setting up energy communities.

The cooperative housing sector in Barcelona also provides a strong foundation for socially inclusive energy initiatives like PENs. Barcelona's cooperative housing sector is now well beyond initial pilots and rapidly scaling with over 25 housing sites across the city, supported by key local legal and financial organisations such as Sostre Civic and Dinamo^{lv}.

T - Technology (IRL 8)

The technology for rooftop solar photovoltaic systems, which acts as the primary source of renewable energy in Barcelona, is widely available in the city and benefits from ample sunshine. Integration between systems is facilitated by smart meters, which have a high degree of adoption and are managed by the DSO.

Grid constraints are becoming a bigger risk, just like in other places in Spain (as highlighted by the nation-wide blackout in April 2025). Multiple initiatives are set-up to future-proof the grid, such as grid renovation that is being executed by Red Electronica^{lv}. The city also sees a significant uptake of battery storage, in line with the general trend in Spain^{lvi}, which increases demand side flexibility and self-consumption, reducing grid congestion.

Additionally, Barcelona gained significant experience with EMS, smart homes and energy efficiency through Horizon 2020 project GrowSmarter^{lvii}, and smart charging through Endolla^{lviii}, highlighting the roll-out of new technologies in the city.

Advancing Barcelona's PEN readiness

With a combination of easily accessible technology (T), available funding and important legislation in place, Barcelona scores high in PEN Readiness. However, while energy sharing is legally supported (P) and commercially viable (E), adoption rates (S) are still low. To fully exploit the potential for PENs, we recommend the following steps:

- Reduce administrative complexity for residents to encourage participation in energy sharing initiatives.
- Scale solar PV adoption by engaging with stakeholders such as social housing cooperations (e.g. Sostre Civic and Dinamo).
- Leverage Energy Advice Points to advice on subsidies, grants and administrative processes to reduce barriers to energy sharing.

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PEN Follower Site 3: Madrid, Spain

Snapshot - Madrid is the largest city in Spain with a population of over 6m residents in the wider metropolitan area. Madrid is a member of the Covenant of Mayors and has a climate roadmap - Roadmap to Climate Neutrality by 2050, towards their achieve of climate neutrality by 2050.

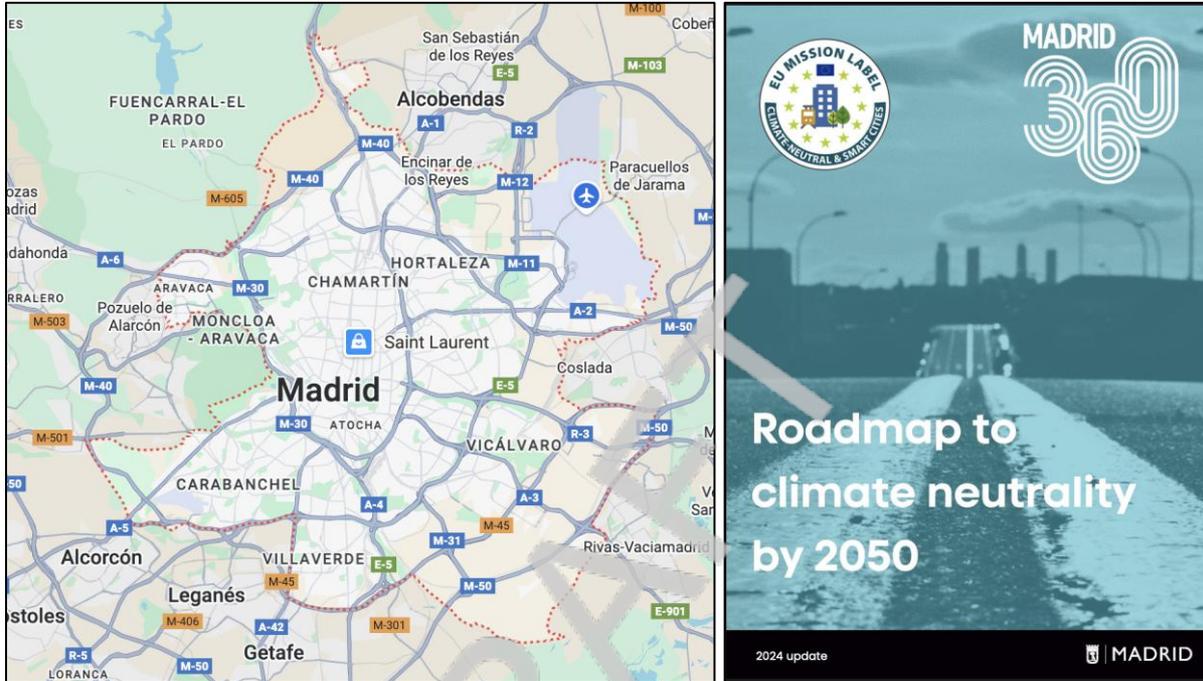


Figure 34: Madrid, Spain

Madrid's PEN Readiness

Overall, Madrid scores a 7 in terms of PEN Readiness, based on the PEST breakdown as described below.

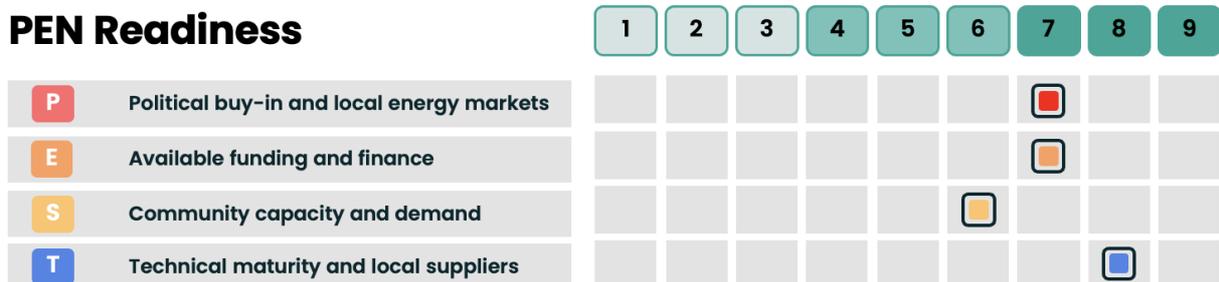


Figure 35: PEN Readiness Madrid

P - Political (IRL 7)

Madrid has a formal roadmap that aligns city action with EU goals and commits to climate neutrality by 2050^{lix}. Additionally, the city uses the *Madrid 360 Environmental Strategy*^x to drive low-emission zones and permitting rules that affect local energy and retrofit works. Madrid is part of the *EU Cities Mission* and has signed a Climate City Contract^{lix}, which strengthens

multi-level governance for neighbourhood projects. The roadmap acknowledges Covenant of Mayors membership and frames actions across buildings, mobility and local energy.

Like Pamplona and Barcelona, Madrid benefits from EU and National legislation supporting cost-effective energy sharing within a range of 5km - an important enabler of PENs.

E - Economic (IRL 7)

As energy sharing is allowed in Spain, Madrid has an operational and active framework for collective self-consumption that underpins their renewable energy communities and neighbourhood energy sharing sector. However, just like in other Spanish cities, administrative complexity and bureaucracy prevent large scale adoption.

The *Getafe* local energy pilot case in Madrid tested collective self-consumption of solar PV within energy communities. It was implemented for two neighbourhoods and proved the financial viability of energy communities in Madrid as a replicable model^{lxii}. Madrid also introduced its first eco-solar neighbourhood in *Orcasitas*, transforming an area that was struggling with energy poverty into one of the most energy efficient neighbourhoods by implementing solar PV and energy sharing, reducing energy bills by up to 33%.^{lxiii} These initiatives successfully demonstrated that maximizing self-consumption by sharing the energy between local households and public buildings can lead to significantly reduced energy costs.

S - Social (IRL 6)

Plans like the *2050 Climate Neutrality Roadmap* and the *Madrid 360 Environment Strategy* create strong strategic and political support helping to mobilise local stakeholders and communities. While Madrid is already piloting energy sharing, large-scale community-energy activity requires simple administration process and clear energy bill benefits.

Vulnerable households can benefit from energy sharing legislation and new technologies to increase energy efficiency, but outreach and administrative support are essential. The *Getafe* pilot indicates existing neighbourhood appetite and social value. An initiative similar to *OTC Navarra* in the Basque region (see Pamplona assessment) could help Madrid to replicate the *Getafe* initiative to other neighbourhoods.

T - Technology (IRL 8)

Spain's full smart-meter rollout enables effective collective self-consumption across neighbourhoods and creates opportunities for demand side flexibility, both key enablers of PENs. While Spain was the first country to reach a 100% penetration of smart meters in 2018, a second generation of improved hardware is currently being installed^{lxiv}.

Madrid is making significant progress in electrifying its public transport by implementing smart charging infrastructure. In 2024, the city developed a large-scale smart charging station for busses in the *Carabanchel* district^{lxv}, which contributes to the cities ambition to create more charging points. A tender for a new charging centre in *La Elipa* has recently be launched by municipal transport company *EMT*^{lxvi}. Additionally, *EMT* is experimenting with repurposing e-bus batteries for energy storage at their bus stations to prolong battery lifespan^{lxvii}.

Through PV / energy sharing pilots like in Getafe and Orcasitas, Madrid gained valuable experience in neighbourhood retrofitting that supports PENs. With solar PV being available at scale, Madrid can replicate these pilots to other neighborhoods.

Advancing Madrid's PEN readiness

With a combination of easily accessible technology, available funding and relevant legislation in place, Madrid scores high in PEN Readiness. However, while energy sharing is permitted, adoption is relatively slow due to administrative and economic barriers. To fully exploit the potential for PENs, we recommend the following steps:

- Reduce administrative complexity for residents to encourage participation in energy sharing initiatives.
- Scale solar PV adoption by engaging with stakeholders such as social housing cooperations.
- Establish an organisation to support the development of energy communities, replicating the pilots of Getafe and Orcasitas to other neighbourhoods.

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PEN Follower Site 4: Mechelen, Belgium

Snapshot – Mechelen is a mid-sized city in Belgium with a population of 130,000 residents in the wider urban area. Mechelen is a member of the *Covenant of Mayors* and has written a energy and climate strategy, adopted in 2020 towards climate neutrality by 2050.

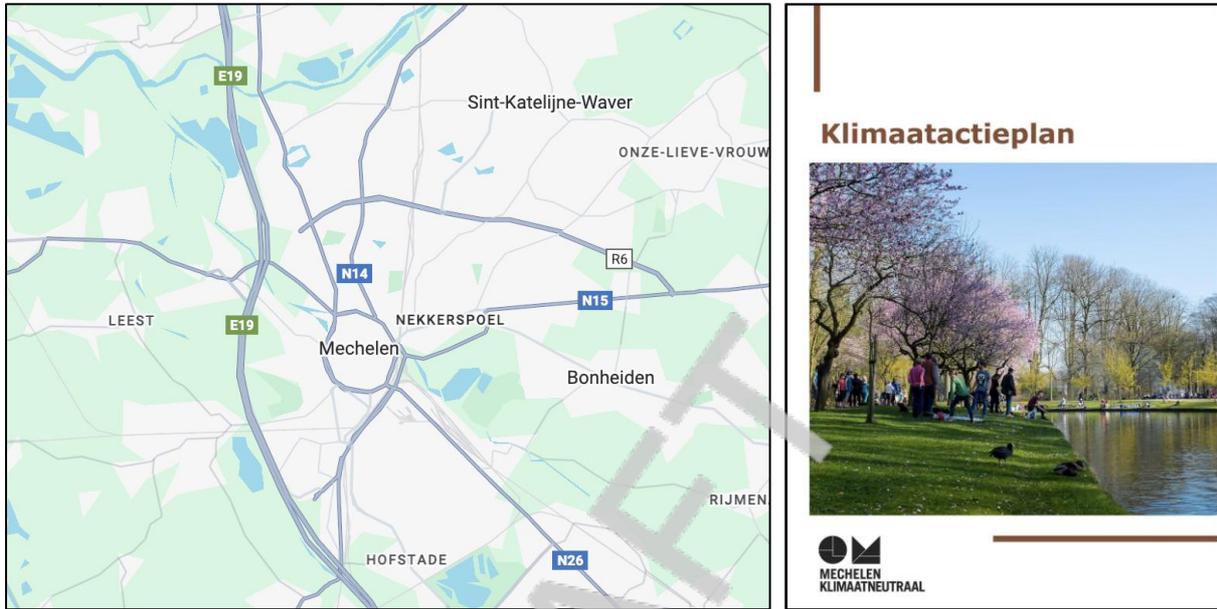


Figure 36: Mechelen, Belgium

Mechelen’s PEN Readiness

Overall, Mechelen scores a 7 in terms of PEN Readiness, based on the PEST breakdown as described below.



Figure 37: PEN Readiness Mechelen

P - Political (IRL 7)

The Belgian region of Flanders allows energy-sharing through renewable energy communities, supported by an approved DSO framework for the administrative process.^{lxviii} In addition to their *Klimaatactieplan*^{lxix}, the city adopted a *Municipal Heat Plan* in 2024^{lxx} that sets clear governance strategy for heat zones and heat projects. A dedicated Heat Coalition convenes public, private and civic actors to coordinate delivery. Mechelen won the *2025 Covenant of Mayors Award* for heat decarbonisation, strengthening their mandate and ambition.

E - Economic (IRL 7)

Belgian energy market design allows collective self-consumption and energy sharing beyond single buildings via energy communities since 2023. However, as grid operators charge high administrative costs (sometimes up to 150 euros per year), and under current legislation energy sharing only affects the energy component of the bill (not taxes, operator costs, etc.) there is currently no financial incentive for energy sharing.^{lxxi lxxii}

Flemish grid operator Fluvius is deploying congestion solutions^{lxxiii} and flexible energy markets^{lxxiv}; this can create new financial opportunities for demand side flexibility but adds operational duties. Funding for retrofitting and investments into renewable energy sources are available for residents (e.g. Mijn VerbouwPremie^{lxxv}) and for city-led initiatives (e.g. through EU funding, or their *Local Energy and Climate Pact*, LEKP).

Mechelen has a replicable PEN blueprint in place with their *Keerdonk Energy Hub* (produced by the ACCESS project), combining solar PV, V2G and energy sharing to create a positive business case^{lxxvi}.

S - Social (IRL 7)

Mechelen considers the heat transition alongside affordability and plans to replace older social owned homes with energy-efficient buildings.^{lxxvii} This offers clear neighbourhood-scale entry points for PEN. Where it fits, the city aims to place borehole thermal energy storage on social-housing land, and where space is limited, use public domain sites offering streets a shared low-carbon heating option instead of relying on individual heating systems.

VITO, an oPEN Lab project partner, identifies Mechelen as a priority PEN site due to its strong social housing sector, and planned large scale renovations. In Nekkerspoel, collective renovations are planned, giving a ready-made cluster for shared solar, shared heat, and simple resident sign-ups. In Otterbeek, the city teamed up with citizen's energy cooperative Klimaan and social housing cooperation Woonland to create the first social housing energy community in Belgium, installing solar panels on 200 social housing units.^{lxxviii}

Beyond social housing, Mechelen already supports private renovations, including collective building permits, so owners can join forces rather than each navigating rules alone. Through several EU projects, the city installed a one-stop-shop for home renovations to support citizens.^{lxxix} This supports the many residents and SMEs that need administrative help and financial support for home renovations.

T - Technology (IRL 7)

Mechelen has significant solar PV potential on public roofs, widespread adoption of smart meters, and successful EMS/EV smart charging pilots - technological know-how on PEN implementation is available. The Keerdok plan shows load-shifting and local matching are already operational^{lxxx}.

Regional grid congestion exists in some substations and new flexible connection contracts provide priority grid access to demand-flexible parties. Data access via smart meter rollout simplifies verification of self-consumption and sharing ratios. Further development of demand-side flexibility would improve PEN readiness for Mechelen.

Advancing Mechelen's PEN Readiness

Mechelen is identified as a priority PEN site due to its strong social housing sector and PEN opportunity within planned renovations. Additionally, the city has solid technical knowledge and the legislation in place to fully leverage the economics benefits of energy sharing. We recommend the following steps:

- Reduce administrative complexity for residents to encourage participation in energy sharing initiatives.
- Further develop demand side flexibility services to establish more flexible capacity.
- Establish an organisation to support the development of energy communities, replicating the pilot of *Keerdonk* to other neighbourhoods.

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PEN Follower Site 5: Ostend, Belgium

Snapshot – Ostend is a coastal city in Belgium with a population of over 90,000 residents in the wider metropolitan area. Ostende is a member of the *Covenant of Mayors* and has a climate mitigation plan and a climate adaptation plan, targeting climate neutrality by 2050, in line with Flemish and EU goals

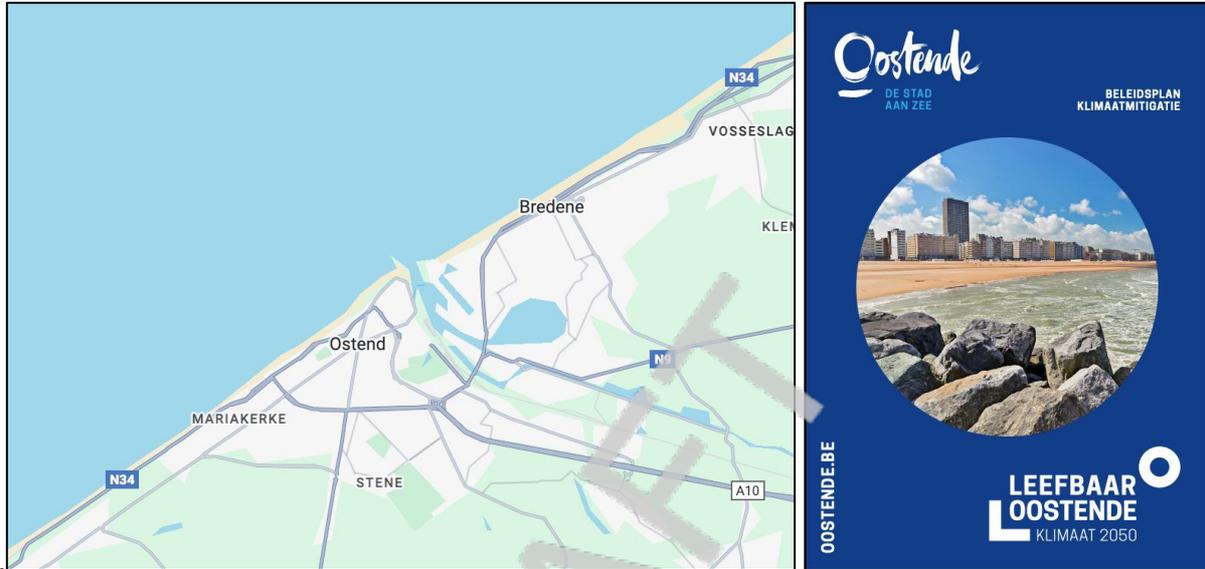


Figure 38: Ostend, Belgium

Ostend’s PEN Readiness

Overall, Ostend scores a 6 in terms of PEN Readiness, based on the PEST breakdown as described below.



Figure 39: PEN Readiness Ostend

P - Political (IRL 6)

While Flanders sets the legal frame for energy sharing and energy communities, the city of Ostende operates within those powers. Ostend has adopted a *Climate Mitigation Plan (2021)*^{lxxxix} and a *Climate Adaptation Plan (2024)*^{lxxxix}, which provide city-level direction and political support. Ostende is part of Interreg project DECA, with the goal to further strengthen governance in climate adaptation plans.^{lxxxix}

The city hosts the citizen heat cooperative Beaumont^{lxxxiv}, that is mobilizing citizens to co-invest in sustainable energy and can act as an institutional lever to accelerate implementation of heat networks and other renewable energy sources.

E - Economic (IRL 6)

As Ostende is bound by the same legislation as Mechelen, the city faces a similar lack of financial investment for energy sharing, which means that maximizing self-consumption of produced energy is the primary driver of return on investment for solar PV. Municipal funding can align with broader Flemish instruments and EU calls, but dedicated city and public capital funding for PENs is limited. The capacity grid tariff rewards demand peak reduction, which strengthens the business case for EMS, batteries, and flexibility.^{lxxxv}

S - Social (IRL 6)

Ostend works through regional “Energy Houses^{lxxxvi}” and local partners to support citizen renovation and advisory, which could be used to mobilise widespread PEN participation. These help desks provide support with grants and loans (e.g. *Mijn VerbouwPremie*, *Mijn VerbouwLening*^{lxxxvii}) to lower barriers for residents. Citizen energy system ownership is exemplified by the *Beauvent* energy cooperative, which develops and operates renewable energy systems and heat networks and is owned by thousands of member-investors^{lxxxviii}. However, to mobilise large numbers of residents for PEN-like initiatives, easier administration processes and clear financial benefits are needed.

T - Technology (IRL 7)

PV potential on Belgium’s coastal public roofs is good, and Belgium’s smart-meter rollout supports effective metering to leverage sharing and flexibility business models.^{lxxxix} The Ostend district heating network provides a tangible district-scale anchor to build a PEN around. EMS and neighbourhood batteries are now technically feasible and align with the capacity tariff incentive, curbing demand peaks. Grid capacity constraints can appear at local substations in tourist seasons, so PEN designs should consider peak-shaving and flexibility.

The city is piloting new technologies like EMS and EV smart charging through initiatives like “the smartest charge point in Flanders” at Ostend Science Park^{xc}, however, such technologies are not yet implemented at scale.

Advancing Ostend’s PEN readiness

Many important factors enabling PEN development are already available in Ostend - like energy sharing legislation, large scale smart meter roll-out and financial incentives for demand-side flexibility. However, the city lacks scalable political and organisational frameworks to reach large scale adoption. To fully exploit the potential for PENs, we recommend the following steps:

- Reduce administrative complexity for residents to encourage participation in energy sharing initiatives.
- Leverage local initiatives, like Beauvent and Energy Houses to increase uptake of renewable energy systems and to mobilise stakeholders to engage in energy sharing initiatives.

- Move beyond the pilot phase for new technologies like EV charging and batteries to increase flexible capacity.

PEN Follower Site 6: Antwerp, Belgium

Snapshot – Antwerp is the second biggest city in Belgium with a population of 1.2m residents in the greater metropolitan area. Antwerp is a member of the *Covenant of Mayors* and has a SECAP strategy via its Climate Plan 2030. The city aims to reach climate neutrality by 2050.

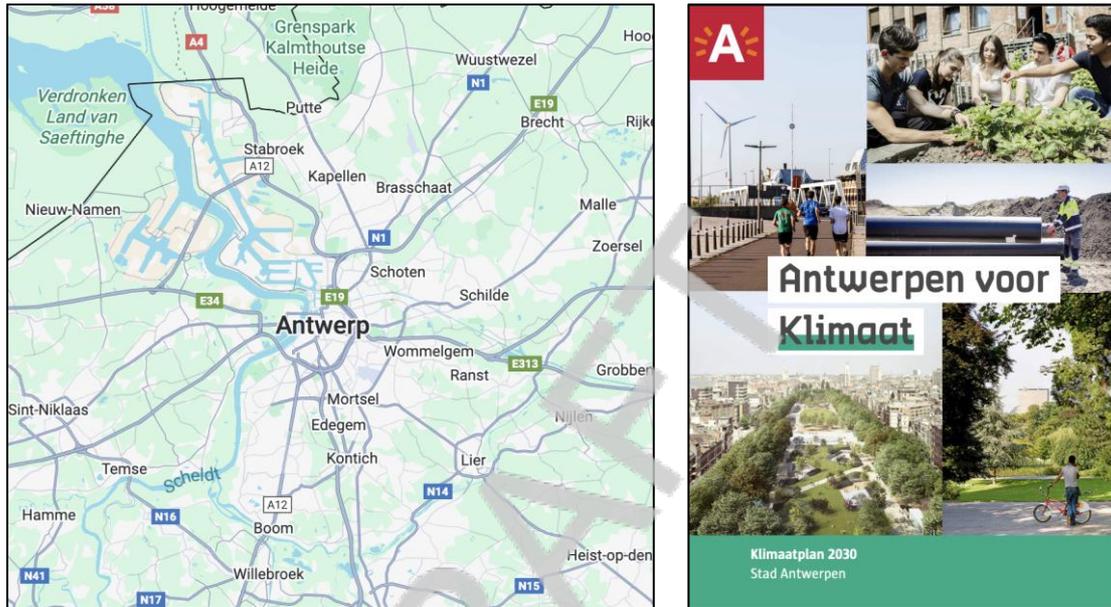


Figure 40: Antwerp, Belgium

Antwerp’s PEN Readiness

Overall, Antwerp scores a 6.5 in terms of PEN Readiness, based on the PEST breakdown as described below.

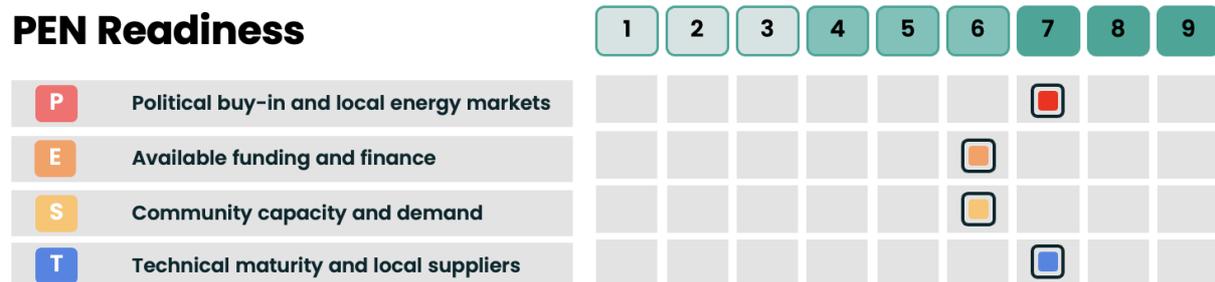


Figure 41: PEN Readiness Antwerp

P - Political (IRL 7)

Just like in Mechelen and Ostend, energy sharing is allowed in Antwerp by law. The city has embedded district heat planning within policy and backs a city-wide district heating program linked to its 2030/2050 goals. A new open-access heat network in the port highlights city–DSO–industry cooperation in practice^{xc1}. The city works with its network operator Fluvius on extending the network into social housing districts.

Antwerp is in the process of creating a Local Energy Action Plan (LEAP)^{xcii}, defining a more active role for the city's energy planning while working in closer collaboration with Fluvius and other key stakeholders.

E - Economic (IRL 6)

As Antwerp is bound by the same legislation as Mechelen and Ostend, the city faces a similar lack of financial investment for energy sharing, which means that maximizing self-consumption of produced energy is the primary driver of return on investment for solar PV. Legislation is currently being refined to improve financial incentives.

As with other Flemish cities, Antwerp has access to both regional Flemish as well as EU funding (e.g. Interreg project COPPER^{xciii}, and Net Zero Cities^{xciv}). The city does not yet have replicable financing frameworks for energy communities or PENs that can be scaled on a city level.

S - Social (IRL 6)

Antwerp runs *EcoHuis*, a city service that advises residents and vulnerable groups on energy saving and behaviour change^{xcv}. This initiative could be leveraged to mobilise residents to engage in energy communities and PENs beyond. Social housing areas are targeted for their potential district heat connections, which could help deliver low and stable energy bills.

Through the Net Zero Cities pilot, Antwerp strives to learn how to improve the rate of retrofitting by offering additional support and financing options to vulnerable households, which is important for PEN adoption.

Like many other cities assessed, Antwerp could develop easier administrative processes and highlight the clear financial benefits for energy sharing to help adoption at larger scale.

T - Technology (IRL 7)

Smart meter rollout by DSO Fluvius enables reliable allocation for energy sharing initiatives and future demand-side flexibility services. The Antwerp North Heat Network^{xcvi} provides large-scale thermal infrastructure that could be used to anchor PEN projects.

Pilots in the Port of Antwerp demonstrate engagement from industry^{xcvii}^{xcviii}. The city is already piloting new technologies, combining solar PV with new heating systems, EV-charging and batteries. With grid congestion a growing concern threatening to constrain further roll-out of renewable energy systems, peak-shaving capabilities are a critical element of PEN design.

Advancing Antwerp's PEN Readiness

While Antwerp has a strong political and technological foundation for PEN development, there is not yet a standardised (financial) framework for the development of energy communities or PENs at a larger scale. We recommend:

- Leverage trusted social initiatives like *EcoHuis* to mobilise residents and highlight benefits of energy communities.

- Ensure clear financial benefits for energy sharing.
- Create a standardised (financial) framework that allows for scaling energy communities and PENS.

PEN Follower Site 7: Tartu, Estonia

Snapshot – Tartu is the second biggest city in Estonia with a population of over 160,000 residents in the wider metropolitan area. Tartu is a member of the *Covenant of Mayors* and has a *Tartu Energy 2030* climate strategy towards climate neutrality by 2050.

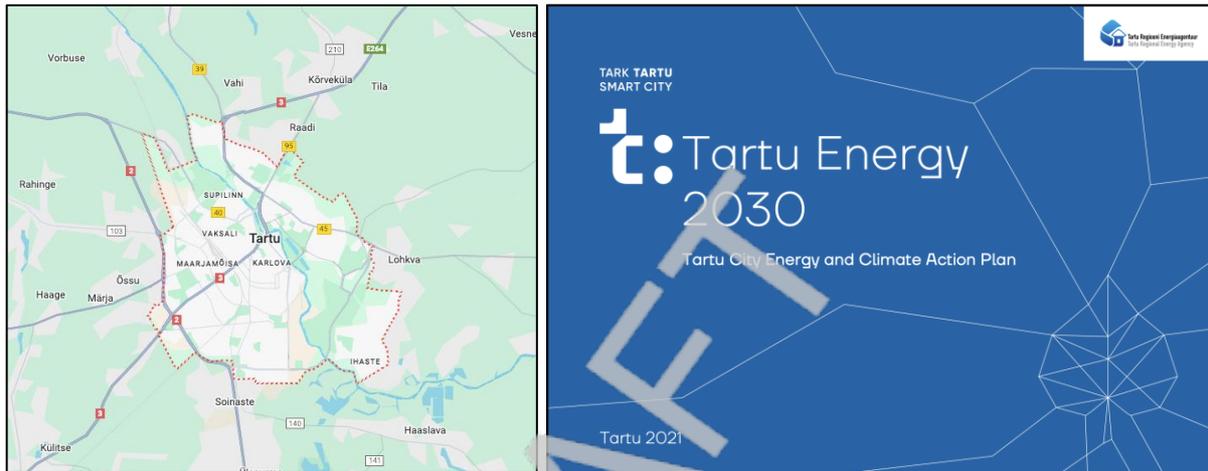


Figure 42: Tartu, Estonia

Tartu’s PEN Readiness

Overall, Tartu scores a 6 in terms of PEN Readiness, based on the PEST breakdown as described below.



Figure 43: PEN Readiness Tartu

P - Political (IRL 6)

Tartu has an approved strategic climate and energy action plan^{xcix} adopted by the City Government and with the Tartu Regional Energy Agency (TREA^c) as strategic partner^{ci}. The plan follows *Covenant of Mayors* methodology and sets a 2050 climate neutrality objective with clear governance and implementation roles. Local policy prioritises district-heating decarbonisation and local renewables which aligns with neighbourhood-scale energy.

While Estonia has regulation in place to enable energy-communities^{cii}, it is limited in scope and needs further refinement^{ciiiciv}, specifically to enable energy sharing outside of formal energy communities, which would further accommodate the viability of PENs.

E - Economic (IRL 6)

Tartu's role in local energy projects is limited by financial constraints, as the city is dependent on EU funding.^{cv} The business case for building-level PV and self-consumption is workable and supported by national funding. Their National Energy and Climate policy signals support for renewables and efficiency, with the ambition to establish a stronger market for demand-side flexibility^{cvi}.

Subsidies and loans for solar PV are widely available for local housing associations through the public financial institution KredEx – now the *Estonian Business and Innovation Agency*^{cvi}.

S - Social (IRL 6)

Tartu has experience mobilising residents through co-creation of regional climate strategy^{cviicix}. Additionally, national strategic partner TREA plays a big role in supporting community mobilization^{cx}. Apartment and Housing Associations (HoAs) provide an organisational backbone for steering collective action at building level.

While first energy communities have been formed, overall lack of trust towards cooperatives (informed from Estonia's political historical) hinders wide-scale adoption in Tartu.^{cx}

T - Technology (IRL 6)

Estonia has near-universal smart meters which supports EMS and energy asset control, with Ellerings Estfeed Data Hub facilitating the data sharing to eligible parties^{cxii}. The city plan emphasises PV growth, electrification, and improvements to district heating that fit neighbourhood solutions. Flexibility pilots exist, but neighbourhood-scale energy sharing beyond one building is not yet standard practice^{cxiii}.

While Tartu is experimenting with e.g. the installation of other energy assets or the use of real-time data, these initiatives are still in the initial pilot phase. Increased adoption of such technologies is needed to establish the case for demand-side flexibility supporting PENs.

Advancing Tartu's PEN Readiness

Tartu is laying the foundations for PENs with new instalment policies and energy markets enabling energy sharing and energy communities. To fully exploit the potential for PENs, we recommend:

- Further encourage neighbourhood-level energy sharing with simple and transparent processes, metering/billing rules, and data-sharing frameworks
- Further incentivise and encourage solar PV roll-out to capture the potential of this readily available technology
- Implement new technologies beyond pilot phases, demonstrating the technical and business case for demand-side flexibility that is required for PENs

PEN Follower Site 8: Amsterdam, Netherlands

Snapshot – Amsterdam is the largest city in the Netherlands with a population of over 900,000 residents in the city, and almost 2,5m in the broader metropolitan area. Amsterdam is a member of the Covenant of Mayors. The city works from its “Roadmap Amsterdam Climate Neutral 2050”, and the city’s goal is to achieve climate neutrality by 2050.



Figure 44: Amsterdam, The Netherlands

Amsterdam’s PEN Readiness

Overall, Amsterdam scores a 7 in terms of PEN Readiness, based on the PEST breakdown as described below.

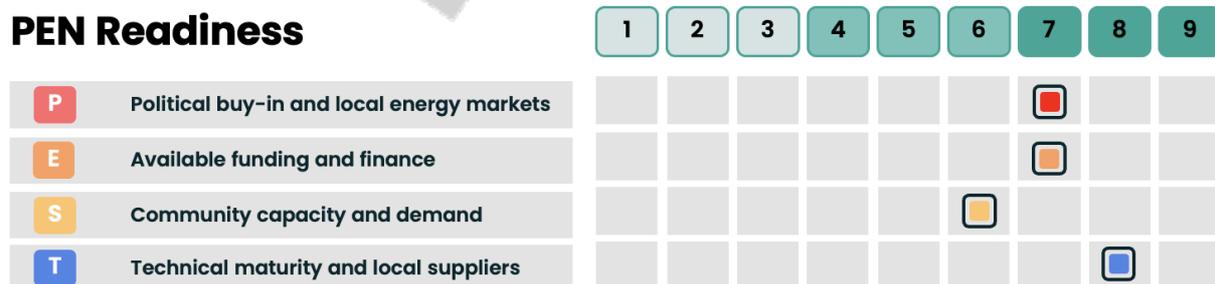


Figure 45: PEN Readiness Amsterdam

P - Political (IRL 7)

The Netherlands is implementing the new Energiewet^{cxiv}, which will enable energy sharing and strengthen local energy systems from 2026 onwards. Amsterdam has a clear long-term plan through its Climate Neutral 2050 Roadmap^{cxv} with defined transition paths. Regional Energy Strategies align municipalities, provinces, water boards and DSOs on siting and grid planning.

^{cxvi}Grid congestion is significant in most of the country and affects permitting pace and DSO arrangements. ^{cxvii}

E - Economic (IRL 7)

The national SDE++ subsidy supports businesses in larger renewable energy generation and decarbonisation projects, improving return on investment for renewable energy assets^{cxviii}. ISDE subsidies supports household and small households with the financing of home improvements like insulation, heat pumps and small thermal measures for buildings.^{cxix} Amsterdam complements this with local finance vehicles and loans that target CO₂ reduction. Amsterdam's Amsterdam Climate & Energy Fund ^{cxx}(AKEF) and the city Sustainability/Investment funds provide debt and catalytic capital for local projects.

Market models for collective self-consumption are expected improve with the introduction of the new Energiewet, but uncertainty remains until full implementation. Increasing back-delivery costs and the termination of the 'salderen' ^{cxxi}subsidy drives owners of solar PV to maximise self-consumption. Grid congestion creates strong fluctuation of energy prices, causing uncertainty for businesses and residents, but creating interesting opportunities for demand side flexibility services.

S - Social (IRL 6)

Amsterdam runs city-wide engagement under its Roadmap and supports neighbourhood initiatives. The Netherlands has an organised cooperative movement through Energie Samen ^{cxii}that helps communities develop projects. Social-housing retrofits and energy-poverty programmes exist but require continued scaling.

While there is broad support within the city for local energy initiatives, severe grid congestion constraints electrification efforts and delays new grid connections. Energiedelen at this moment lacks public awareness and clarity about administrative processes. Increasing back-delivery costs and the end of the 'salderen' subsidy creates worries amongst solar PV owners regarding the financial viability, even causing some solar PV owners to utilise curtailment strategies.

T - Technology (IRL 8)

Wide-spread availability of PEN enabling technology like solar PV, EMS and high smart-meter penetration enabling demand flexibility services and dynamic tariffs. Amsterdam is running pilots^{cxiii}^{cxiv} for demand side flexibility and storage while using tools like the Energy Atlas for spatial energy insight. Grid congestion across Liander's area is a binding constraint and requires peak-shaving and other solutions. National analyses and DSO updates confirm capacity limits and long waiting lists in several provinces. PEN operation should design for curtailment, batteries, and flexible load to fit within available capacity.

How to improve PEN readiness in Amsterdam?

The new Energiewet that is currently being implemented has the potential to facilitate wide-scale energy sharing, however, still lacks the financial incentives to really improve the viability of PENs. While availability and adoption of renewable energy assets is high in Amsterdam,

severe grid congestion increases risk and constraints the local energy transition. To fully exploit the potential for PENs, we recommend the following steps:

- Adapt the newly introduced Energiewet to improve financial incentives for energy sharing to increase adoption.
- Improve the business case for new and existing solar PV by subsidizing storage and flexibility assets, like batteries.
- Explore alternative solutions to grid congestion to reduce risk.

PEN Follower Site 9: Aarhus, Denmark

Snapshot – Aarhus is the second biggest city in Denmark with a population of around 1,000,000 residents in the broader metropolitan area. Aarhus is a member of the Covenant of Mayors, and the city works under its “Climate-neutral Aarhus 2030” plan. The city’s goal is to achieve climate neutrality by 2030 and reach a fully renewable energy system nationally by 2050.

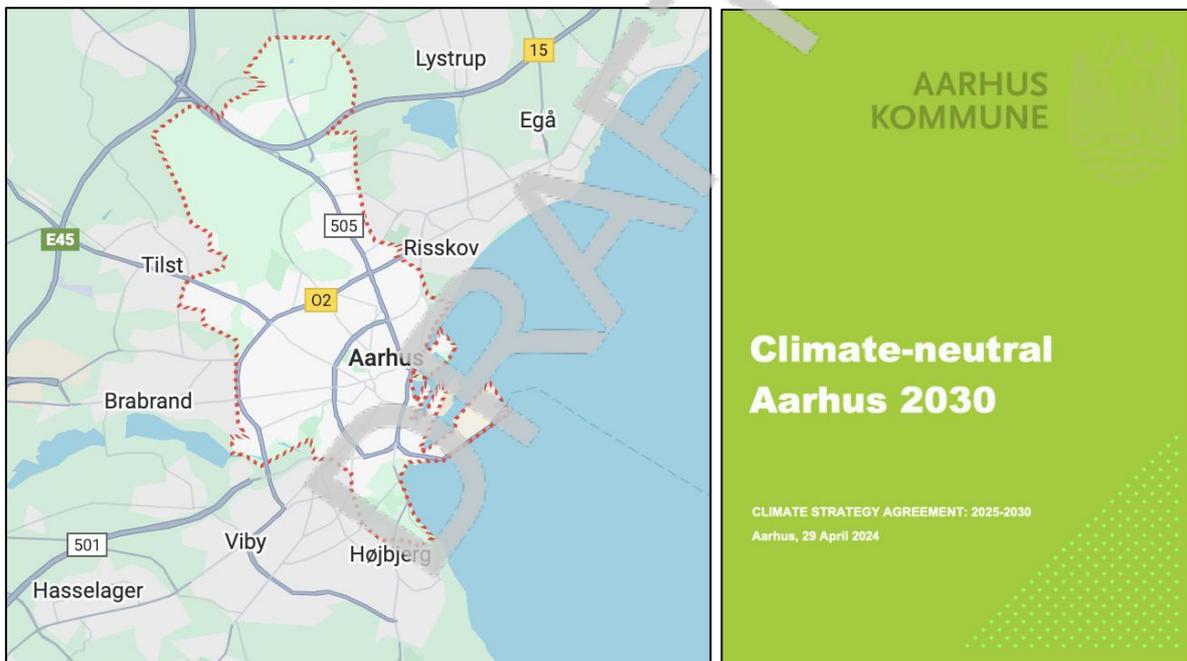


Figure 46: Aarhus, Denmark

Aarhus' PEN Readiness

Overall, Aarhus scores a 6.5 in terms of PEN Readiness, based on the PEST breakdown as described below.



Figure 47: PEN Readiness Aarhus

P - Political (IRL 7)

Aarhus has a formal city plan to reach climate neutrality by 2030, which gives clear local authority to act. Denmark provides a mature governance setting with defined roles^{cxxv} for the TSO (Energinet), DSOs, and a national DataHub (operated by Energinet) that supports market participation. Energy communities are recognised in Danish law, but the enabling rules are still developing and not fully optimised for energy sharing at neighbourhood scale.^{cxxvi} Regional policy in Central Denmark supports climate goals and aligns with city ambitions.

E - Economic (IRL 6)

Denmark’s market design enables hourly settlement and access to balancing and ancillary services via Energinet^{cxxvii}, which helps the development of future PEN business models. Tariff and retail structures are evolving toward more cost-reflective signals.^{cxxviii}

Funding routes exist through EU and national lines, which the European project CO-SHAPE as an example for the funding of energy related projects^{cxxix}. The project, amongst other things, focusses on the development of co-creation models for increased renewable energies. Another example is the Horizon2020 project AURORA^{cxix}, through which the city of Aarhus established an energy community, which led to many lessons learned^{cxixi} for scaling the concept. A concrete local lever is Aarhus’ municipal climate programme that steers investments under the 2030 plan, with projects expected to require private financing over time.^{cxixii}

S - Social (IRL 6)

Aarhus has strong civic capacity and university partnerships that support local climate action.^{cxixiii} Aarhus University and city programmes provide visible anchors for engagement and learning. Public engagement is active, which co-creation and co-ownership approaches demonstrated by the CO-SHAPE and AURORA projects, but mass participation in electricity-sharing schemes remains limited. Through the READY^{cxixiv} project, Aarhus gained initial experience with retrofitting neighbourhoods and with the currently ongoing RE-VALUE^{cxixv} project, Aarhus University aims to gather new learnings on retrofitting neighbourhoods in cooperation with Brabrand Housing Association and DEAS.

T - Technology (IRL 7)

Full smart meter roll out was completed nationally in 2020^{cxxxvi}, which enables amongst others hourly settlement, EMS, flexibility and data-driven operation of neighbourhood assets. The Energinet DataHub aggregates meter data and supports third-party access under clear rules. The READY project piloted a wide-range of relevant technologies, like waste-water heat recovery, EV charging, PV, second-life batteries, and more. Grid capacity can constrain local hosting in some areas, so PENs must design for peak-shaving and demand side flexibility. The regional district-heating strength complements electrification but does not replace the need for local PV and storage.

Aarhus is building a strong geo-thermic network that will eventually deliver 110 MW of thermal heat to the city’s residents^{cxxxvii}, and the city has a growing network of EV charging stations^{cxxxviii}.

How to improve PEN readiness in Aarhus?

With regulation in place for energy sharing and a market design that facilitates hourly settlement and access to balancing services, Aarhus has solid foundations for PED development. To fully exploit the potential for PENs, we recommend the following steps:

- Improve energy sharing legislation to improve financial incentives for residents and accommodate less complex administrative processes.
- Create replicable models for PENs, RECs and retrofitting.
- Design PENs for peak-shaving and demand side flexibility to reduce risk of grid congestion.

PEN Follower Site 10: Lisbon, Portugal

Snapshot – Lisbon is the biggest city in Portugal with a population of around 2,800,000 residents in the broader metropolitan area. Lisbon is a member of the Covenant of Mayors and has a SECAP (Lisbon 2030 Climate Action Plan / PAESC), and the city’s goal is to achieve climate neutrality by 2030.

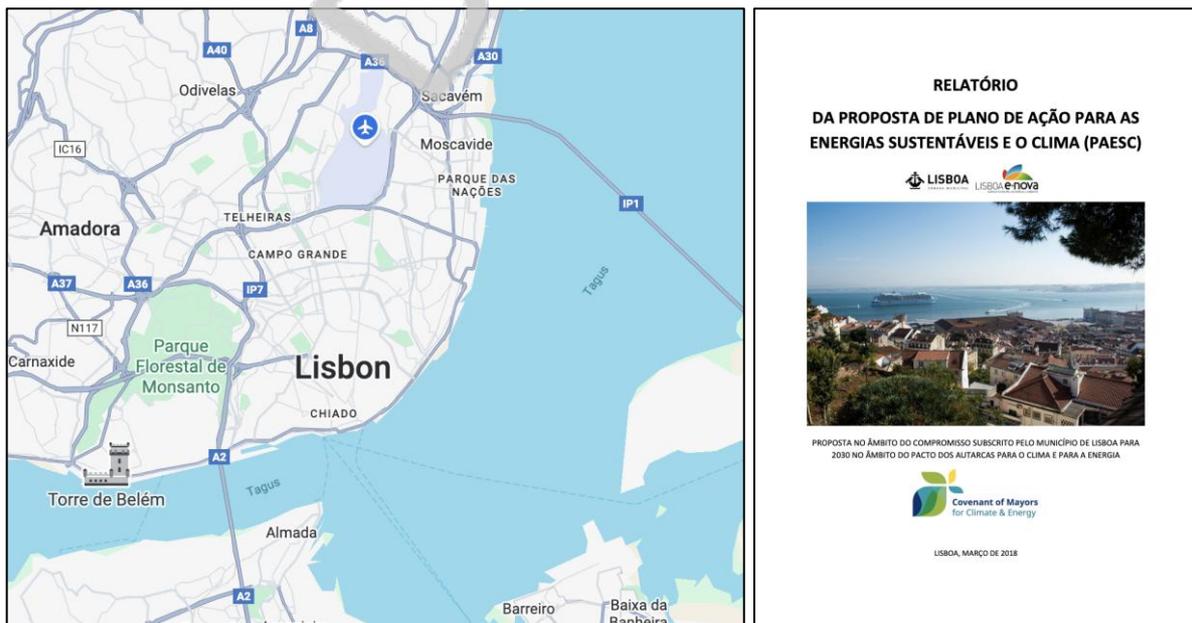


Figure 48: Lisbon, Portugal

Lisbon’s PEN Readiness

Overall, Lisbon scores a 7 in terms of PEN Readiness, based on the PEST breakdown as described below.

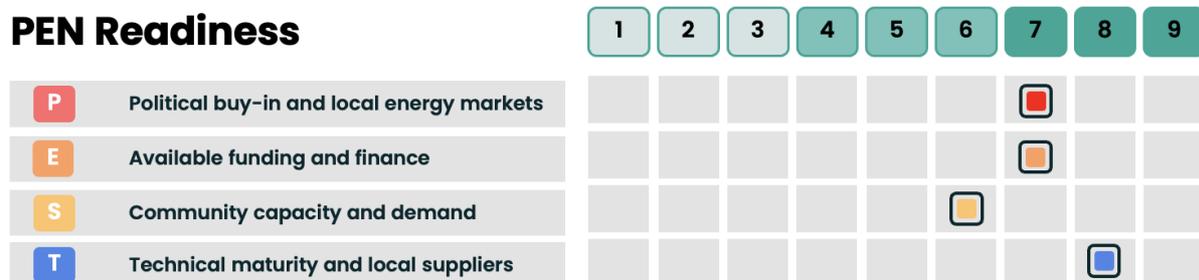


Figure 49: PEN Readiness Lisbon

P - Political (IRL 7)

Lisbon has a formal Climate Action Plan to 2030^{cxix} and is a Mission City (for which they signed a city climate contract^{cxl}), which strengthens governance and delivery of energy related projects. The city declares climate-neutrality 2030 as a core objective and aligns actions with the Covenant of Mayors framework.

National law enables collective self-consumption and the formation of renewable energy communities under Decree-Law 162/2019^{cxli}, with Decree-Law 15/2022^{cxlii} further improving financial incentives and simplifying administrative processes. The DSO (E-REDES) and national regulator provide a clear market role split. Regional coordination exists through the Lisbon Metropolitan Area. As Lisbon has a lot of potential for solar PV, the city created a specific solar strategy called Lisboa Cidade Solar, with the goal to have 103MW of installed solar capacity by 2030^{cxliii}.

E - Economic (IRL 7)

Decree-Law 15/2022 improved financial incentives for energy sharing and RECs by simplifying procedures, allowing access to energy markets for RECs, and reducing or even exempting grid tariffs. Recovery and resilience funding^{cxliv} is made available for (amongst other things) the installation of solar PV until the end of 2026. EU funding is accessible for energy related projects as well, of which the ELENA “Lisbon Alliance”^{cxlv} is a good example.

While Lisbon has experience with the development of Renewable Energy Communities which led to cost-decreases for participants, like in Telheiras and Lumiar, replicability might be challenging without EU funding as national alternatives are difficult to find^{cxlvi}.

E-REDES is currently experimenting with flexibility auctions, which might potentially lead to a formal flexibility market and could create new financial opportunities and encourage the up-take of flexibility assets^{cxlvii}.

S - Social (IRL 6)

Lisbon has active community mobilisation and NGOs that can help residents join projects, a good example of this is city's energy & environment agency Lisboa E-Nova^{cxlviii}. Participation at neighbourhood scale is growing but still in an early stage, as demonstrated by the CER pilots in Telheiras and Lumiar^{cxlix}. Administrative steps and awareness remain barriers for tenants and SMEs to engage in energy sharing^{cl}. Clear, transparent and standardised processes would most likely increase participation. Social-purpose pilots are showing potential to cut costs for vulnerable households. A concrete example of this is the Telheiras Renewable Energy Community in Lisbon.

T - Technology (IRL 8)

Smart meters are essentially universal in Portugal, enabling EMS, dynamic tariffs and flexibility^{cli}. PV and storage solutions are available, and smart meters allow data exchange for allocation^{clii}. DSO data platforms support third-party access under clear rules^{cliii}. Urban feeders can still face local constraints, so PENS should include peak-shaving and storage.

The city of Lisbon is technologically advanced and has vast experience with RESs. Through EU project COMPILE^{cliv} the city gained hands-on experience with energy sharing, combining microgrid, PV and EV technology. Additionally, the city is investing heavily in the electrification of its public transport by expanding the fleet of electric busses^{clv}, highlighting their knowledge on EV technology. Another example of Lisbon's technological capabilities is EU project SUBDOE^{clvi}, which provided the city with knowledge on renewable heat / cold generation and battery storage,

How to improve PEN readiness in Lisbon?

Lisbon has a solid foundation for PEDs, with favourable policies in place, technological availability and funding available for energy projects. While pilots are being started, the main challenge for Lisbon is scaling current initiatives and increasing participation of residents.

- Extend funding for installation of solar PV, make funding available nationally for the initial costs of setting up a REC.
- Reduce administrative obstacles to participate in energy sharing.
- Design PENS for peak-shaving and demand side flexibility to reduce risk of grid congestion and establish a formal flexibility market to enhance financial incentives.

PEN Follower Site 11: Munich, Germany

Snapshot – Munich is the third biggest city in Germany with a population of about 6,000,000 residents in the wider metropolitan region. Munich is a member of the Covenant of Mayors and has SECAP, the Integrated Action Program for Climate Protection (IHKM) On top of that the city has a Climate Neutrality 2035 plan as an overarching goal.

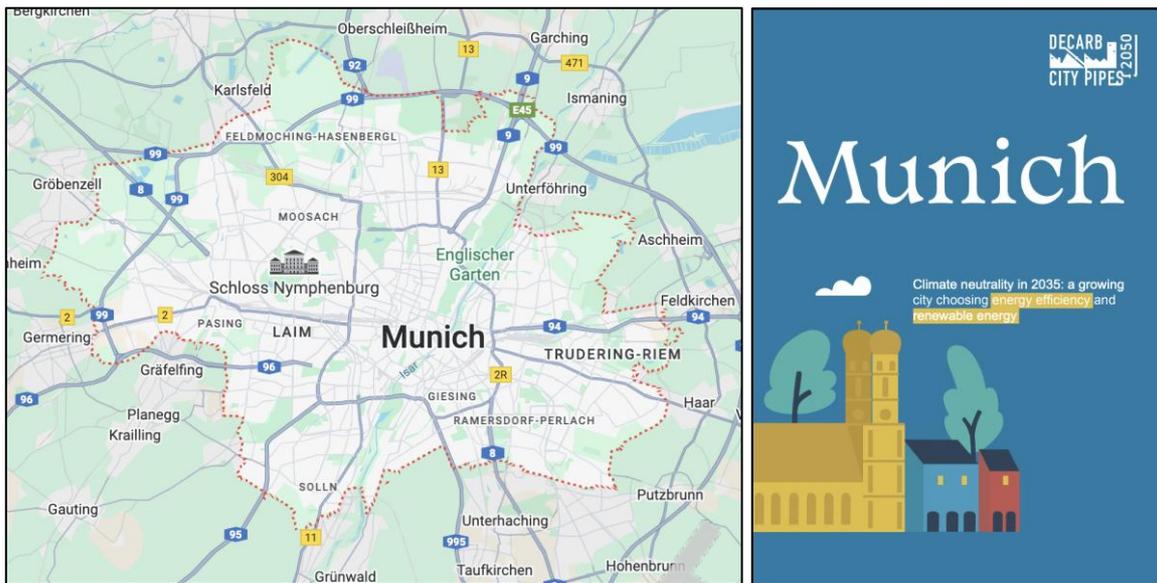


Figure 50: Munich, Germany

Munich's PEN Readiness

Overall, Munich scores a 7 in terms of PEN Readiness, based on the PEST breakdown as described below.

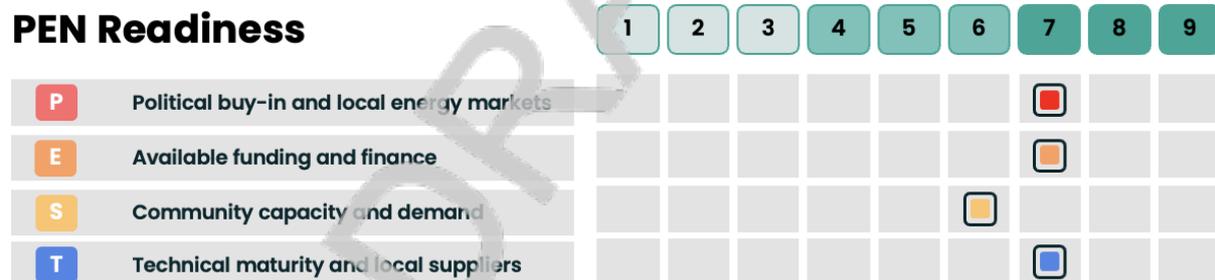


Figure 51: PEN Readiness Munich

P - Political (IRL 7)

Munich has a clear political mandate for climate neutrality by 2035^{clvii} and is part of the EU 100 climate neutral and smart cities initiative^{clviii}. National rules are being updated to align the electricity market and grid connections with EU requirements, which supports local energy systems. However, at the time energy sharing is only permitted within the same building or neighbourhood, without using the public grid. This will change as of January 1st, 2026 through the German Energy Industry Act^{clix}. Until energy sharing is allowed through the public grid, Munich cannot reach its full PEN potential.

The 100% city owned utility, Stadtwerke München (SWM), provides an institutional anchor for renewable energy, heat, and distribution-system functions^{clx}.

E - Economic (IRL 7)

Germany is currently updating legislation to enable energy sharing over the public grid. While this could create new opportunities, it is still uncertain whether this legislation will contain financial incentives or support^{clxi}, like in other countries, so neighbourhood sharing revenues remain less certain than self-consumption. On a national level, fixed feed-in tariffs are used to incentivise the installation of RECs^{clxii}.

The city of Munich uses municipal instruments and EU/national programmes to finance increased production of renewable energy, district heating, and energy efficiency initiatives. Examples of EU funded energy projects are ASCEND (closely related to PEN development) and Smarter Together (retrofitting, PV, EV, heating & cooling systems, and more) National and local subsidies are available as well. As an example, the city of Munich has funding available to subsidise retrofitting and energy efficiency measures through the FKG fund^{clxiii}

S - Social (IRL 6)

Munich has strong public institutions and is gaining experience with citizen engagement through related projects. In EU project ASCEND, citizen engagement is considered a core part of the project^{clxiv}. Additionally, SWM is offering free advice to lower income households on energy efficiency^{clxv}. Participation in new electricity market models is currently complex and needs to be simplified for tenants and small business owners, something that will hopefully be improved with the introduction of the German Energy Industry Act.

Social housing and public buildings provide lots of surface area for the installation of rooftop PV. In Harthof, SWM is collaborating with housing cooperative Isarwatt, with the aim to create a scalable framework that can be replicated to retrofit other areas or even turn them into Positive Energy Districts.

T - Technology (IRL 7)

PV, EMS, and energy data management capabilities are available city-wide, and EU funded projects like ASCEND and Smarter Together are allowing Munich to gain more experience with emerging technologies. SWM is increasing the production of renewable energy significantly, is expanding the cities EV charging systems, and is testing battery storage^{clxvi}.

National smart-meter rollout is being accelerated, providing the required data for flexibility and smart steering of assets. However, despite acceleration efforts, full roll-out is not expected to finish before 2032^{clxvii}. As smart meters are essential for PEN development, this is a major obstacle for PEN readiness in Munich. Large district-heating and emerging geothermal assets support integrated PEN operation alongside electricity. Grid constraints can appear at feeders, so PENs must include peak-shaving and flexibility products. Utility-led platforms and smart metering pilots improve operational readiness for multi-site control.

How to improve PEN readiness in Munich?

The city of Munich has a strong political mandate for energy related initiatives and has a high degree of technological readiness, which creates a strong foundation for PEN development. However, it is still lacking key components for complete PEN readiness, such as legislation for energy sharing in on a wider scale and intuitive, user-friendly administrative processes. To fully exploit the potential for PENs, we recommend the following steps:

- Prioritise financial incentives and support in the new energy sharing regulation implemented through the German Energy Industry Act.
- Reduce administrative complexity for new energy market models, making participation more accessible for residents.
- Accelerate smart meter roll-out further to fully capture demand side flexibility opportunities, a critical factor in PEN development.

PEN Follower Site 12: Stockholm, Sweden

Snapshot – Stockholm is the biggest city in Sweden with a population of almost 2,5m in the broader metropolitan area. Stockholm is a member of the Covenant of Mayors. The city’s main plan is the Climate Action Plan 2020–2030, and the city’s goal is to be fossil-fuel-free and climate-positive by 2040.



Figure 52: Stockholm, Sweden

Stockholm’s PEN Readiness

Overall, Stockholm scores a 7 in terms of PEN Readiness, based on the PEST breakdown as described below.

PEN Readiness		1	2	3	4	5	6	7	8	9
P	Political buy-in and local energy markets							■		
E	Available funding and finance							■		
S	Community capacity and demand						■			
T	Technical maturity and local suppliers								■	

Figure 53: PEN Readiness Stockholm

P - Political (IRL 7)

The city has clear mandate and goals to deliver local renewable energy, anchored in a strategy for a fossil-free Stockholm 2040^{clxviii}. National law supports city action through binding climate goals and long-standing market regulation for electricity and metering. The local distribution grid is operated by the DSOs Ellevio and Vattenfall Eldistribution (which is 100% state owned).

While the Swedish government initially resisted policies allowing energy sharing^{clxix}, recent regulation allows residents to share energy on the same plot of land or with neighbours.^{clxx} The legislation still has its limitations, both in terms of sharing range and financial viability (e.g. taxation reduces financial benefits)^{clxxi}.

The local government is applying progressive regulations to incentivise the adoption of Electric Vehicles. As of 2025, the city banned petrol and diesel cars within certain parts of the city center, expanding the area gradually until 2030^{clxxii}. Additionally, EV drivers enjoy reduced parking fees and the privilege to use the bus lane^{clxxiii}.

E - Economic (IRL 7)

Sweden's market design allows energy sharing, but financial incentives steer energy producers towards maximizing self-consumption and feeding excess energy into the grid^{clxxiv}. Household-scale rooftop PV and storage benefit from green-tech tax reductions, though recent adjustments have reduced some incentives^{clxxv}. Large National and EU funds are available for grid upgrades and climate action, with EU projects like GrowSmarter, RESCHOOL and ASCEND as examples.

To achieve its ambitions, the city has a clear financing plan^{clxxvi}. However, as Stockholm lacks the finances to foot the entire bill for the local energy transition and is looking to build a coalition through an initiative called "Scale Stockholm" Still, gathering sufficient funding remains a challenge and requires new forms of partnerships with public and private organizations^{clxxvii}.

Furthermore, newly introduced flexibility market creates financial incentives for flexibility capacity, and through Open District Heating, large companies and data centres are paid to share residue heat to the district heating network^{clxxviii}.

S - Social (IRL 6)

Stockholm is building strong civic capacity and trusted city institutions that can mobilise building owners and associations through the Net Zero Cities pilot "Scale Stockholm". The initiative "Scale Stockholm" strives for collective action, involving local businesses, social housing, and residents to bring change and to decentralise local energy pilots. Amongst other initiatives, social housing organizations are currently looking into opportunities to form local energy communities.

In the areas Hammarby Sjöstad (part of EU project RESCHOOL^{clxxix}) and Örebro, the city is working together with various organizations, housing associations and companies to set-up energy communities, which provides them with more experience in cooperative action and new governance models^{clxxx}. While current legislation in Sweden is not favourable for energy

sharing and energy communities (due to administrative complexity and lack of financial incentives) the Hammarby Sjöstad pilot provides a framework that is both accessible and beneficial for residents. Learnings of the pilot provide clear recommendations for further alignment between national and EU regulation^{clxxxii}.

Through EU project GrowSmarter^{clxxxiii}, the city gained valuable experience in retrofitting buildings, however, support from the biggest housing associations is crucial to scale the initiative in a way that lower income households can also reap the benefits of the energy transition as the costs can be significant^{clxxxiii}.

T - Technology (IRL 8)

When it comes to PEN-enabling technology, Stockholm's core strength is district heating. About 80% of the build environment is already connected to networks, while the city is developing a new plant to expand capacity^{clxxxiv}. Additionally, Stockholm is gained relevant knowledge for developing a Positive Energy District around their Royal Seaport, through the Smart Energy City project^{clxxxv} and EU project Cities4PEDS^{clxxxvi}. The districts of Hammarby Sjöstad (RESCHOOL) and Årsta (GrowSmarter) were used to pilot new technologies as well, like V2G, large scale heat pumps, and more.

Sweden has universal smart metering with a second-generation upgrade enabling hourly or 15-minute data and remote control. This supports EMS, battery control, and flexibility products at neighbourhood scale. Additionally, Stockholm is one of the leading European cities when it comes to the share of EVs driving within the city and is implementing new regulation to expand the EV charging infrastructure^{clxxxvii}. Grid constraints exist in hotspots, so PENs need to be designed for peak-shaving. To mitigate grid constraints, Swedish DSOs and TSOs teamed up to develop flexibility markets^{clxxxviii}.

How to improve PEN readiness in Stockholm?

The city of Stockholm has a high availability of the needed technologies to enable PENs and is slowly improving legislation to improve their viability. While financial and social foundations are still lacking, the city is betting on a city led initiative called "Scale Stockholm" to secure the needed funding and support through public-private partnerships. To fully exploit the potential for PENs, we recommend the following steps:

- Accelerate the introduction of improved energy sharing legislation, improving financial incentives and adoption.
- Leverage strongly rooted local organizations, like social housing organizations Stockholmshem and Tornet, to scale existing energy community and retrofitting initiatives further.
- Design PENs for peak shaving to mitigate grid congestion, as the rapid uptake of EVs might be demanding for the grid.

9. Surveying Europe's PEN Readiness, trends, and recommendations

The above assessment of 12 diverse cities reveals a European PEN sector that is broadly technologically mature but bureaucratically behind. While high-level political ambitions and climate strategies are widespread and could encompass positive energy neighbourhoods, the "last mile" of scaled and bankable implementation is stalled by a combination of administrative complexity and low societal buy-in (i.e. "societal readiness").

The priority for regional governments, including and beyond the 12 above, is to move from a technical to a socio-economic case that prioritises the formation of new local PEN markets through connecting the "supply" side of innovations and funding, with the "demand side" of homes, neighbourhoods, and cities capable to adopt and maintain PEN systems.

Core to such new PEN market making includes reducing the transaction costs of energy community formation and energy sharing, and in simplifying the end-user journey beyond obligatory volunteer-led community meetings, and in creating energy flexibility markets that reward not just generation but also load-balancing as a source of new revenue for homes.

Clustering city types by PEN readiness

The above analysis of 12 cities reveals several key factors which determine the cities that are more and less "PEN ready". Based on these common factors, below we propose three categories of city, and the key "Innovation", "Regulation", "Funding", and "Other" actions types to enhance PEN readiness for each city type:

Cluster 1: The "Advanced Follower"

These cities have the most favourable regulations and political will for neighbourhood scale clean energy systems (e.g., long-distance energy sharing) but are stalled in scaled PEN delivery due to administrative burdens and complexity.

From the followers above, the city we consider within this category include Pamplona, Barcelona, Madrid, Lisbon, Aarhus, and Ostend. All possess supportive local energy market design (e.g. a 5km energy sharing/collective self-consumption radius), legal support for energy community formation, and financial support for urban energy system development. However, such political support has not yet translated into standardised PEN processes, and they still rely on one-off pilots.

Recommendations for "Advanced Follower" PEN cities revolve around converting case-based learnings into standardised models to support efficient scale-up:



Figure 54: Thematic PEN development recommendations for cities with high political readiness but remaining administrative hurdles.

Cluster 2: The "Grid-Constrained" City

These cities demonstrate some of the highest technical capacity in Europe and access to significant levels of both public and private capital for new energy projects; however, grid congestion prevents new connections, delaying PEN development and reducing local stakeholder buy-in to new processes.

Cities within this cluster include Amsterdam, Mechelen, and Antwerp, all of whom demonstrate strong technical capacity and local ecosystems for service delivery, yet PEN roll-out is challenged by grid congestion, peak-shaving requirements, restricted electrification opportunities, and curtailed connections.

Recommendations for "Grid Constrained" PEN cities should focus on a "flexibility-first" approach to innovation, and enhanced political capacity of regional authorities drive long-term energy planning:



Figure 55: Thematic PEN development recommendations for cities with technical and investment capacity but significant grid constraints restricting scaled roll-out.

Cluster 3: The "Regulatory Laggard"

These city followers reflect the strong energy system and technical capacity of Cluster 2 cities above but are unable to advance a PEN sector due to outdated regulations limiting commercial opportunities for energy sharing and flexibility.

From the 12 cities assessed, the cities in Cluster 3 include: Munich, Stockholm, and Tartu, where energy sharing is geographically restricted, or taxed prohibitively, whereby energy communities are both physically, commercially, and legally unavailable at present.

Recommendations for Cluster 3 cities should pursue innovations which demonstrate the economic value of an energy community and energy sharing sector, as well as highlight the

legal, business, and contract models that could be adopted at scale to make such benefits possible.

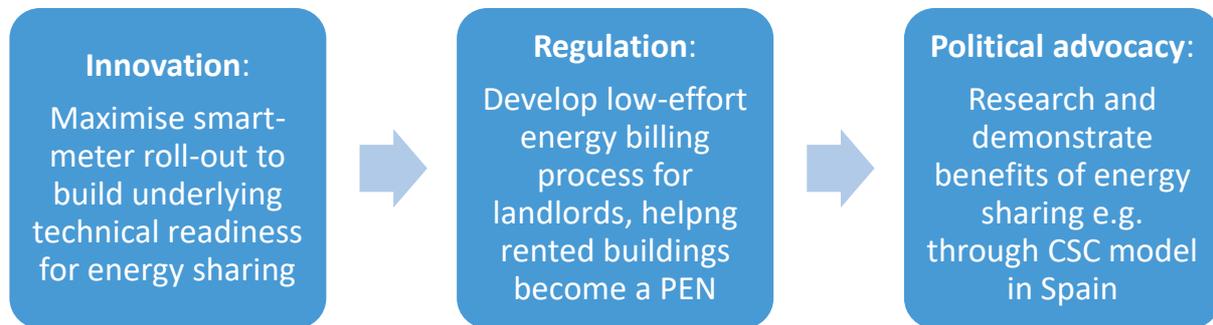


Figure 56: Thematic PEN development recommendations for cities with strong technical capacity outdated energy market regulations, in particular limiting commercially viable energy sharing locally.

The path ahead for Europe’s Positive Energy Neighbourhoods

To build a unified and mature European testbed for scalable PEN innovations, the above city analysis reveals a need to bridge academic research with urban planning and financial mainstreaming.

Towards an audience of metropolitan leaders, administrators and policymakers, we highlight three high-level strategic priorities:

1. Governance – Empowering cities as active local energy system integrators

Municipalities must move beyond their traditional role of neutral facilitators of innovation, to instead become the primary coordinators of local energy ecosystems. While national and EU institutions define legal and financial frameworks, only cities possess the local authority to integrate PENs with housing, transport, and social strategies. Cities should actively cultivate innovation ecosystems by connecting government, academia, industry, and civil society.

2. Expertise - Build local capacity and technical support

A significant barrier to scaling PENs is a lack of in-house urban expertise. We recommend establishing “National Competence Centres” or One Stop Shops, urban support hubs that provide technical advisory services, standardised legal templates for energy communities, and training programs tailored to urban administrative needs.

3. Funding - Strengthen municipal support

Cities frequently struggle to mobilise further financial resources beyond early-stage PEN pilot development and demonstration. Strategies must be developed to support municipalities in bridging the is gap, ensuring they can secure resources for later project preparation once technical innovations have been proven effective and organisational models shown to be viable at scale.

Actionable PEST Framework

Below we include specific recommendations for each domain of the “PEST” framework, introduced within the earlier chapters of this report.

Political

- **Mandate & Resources:** Empower municipal institutions with explicit mandates and dedicated budget lines specifically for supporting local energy communities.
- **Policy Integration:** Formally integrate PENs and energy community concepts into local climate plans (SECAPs) and broader urban planning documentation, ensuring they are not treated as isolated pilot projects.
- **Regulatory Sandboxes:** Advocate for and pilot Citizen Energy Community (CEC) regulatory sandboxes within municipalities to test new policies in a controlled environment before wider rollout.

Economic

- **Fiscal Levers:** Equip cities with the tools to offer local tax incentives, grants, and co-financing mechanisms specifically for PEN initiatives.
- **Ethical Finance Partnerships:** Facilitate formal partnerships between municipalities and ethical finance actors (e.g., cooperative banks, impact investors) to unlock patient capital.
- **Business Readiness:** Invest in upskilling municipal staff in “business readiness”—specifically financial planning, grant writing, and complex funding mobilization—to move projects from concept to bankability.

Social

- **Trusted Intermediaries:** Leverage established, trusted local organizations to build long-term community commitment, rather than relying solely on top-down municipal communication.
- **Streamlined Engagement:** Reduce “participation burden” by creatively integrating energy engagement into existing community events and rhythms, rather than creating new, separate obligations for residents.
- **Market-Driven Convenience:** Explore market-driven business models that prioritise cost and convenience for residents (e.g., “energy as a service”), acknowledging that not all citizens desire deep, hands-on participation in technical processes.

Technological

- **Grid & Digital Infrastructure:** Support cities in managing grid saturation issues through the deployment of smart digital tools and Local Energy Action Platforms (LEAPs) that align with urban climate strategies.
- **Asset Optimization:** Maximise the use of existing urban footprints—such as municipal rooftops and brownfield sites—for renovation and clean energy installation.
- **Co-Benefits:** Explicitly link technological energy interventions to tangible urban co-benefits, such as improved air quality, biodiversity, and urban cooling, to broaden public support.

10. Conclusions

For a primary target audience of PEN project initiators including local authorities, social housing developers, private service providers, policy makers and urban sustainability researchers, this document has explored pathways for transitioning Europe's Positive Energy Neighbourhoods (PEN) sector from subsidised R&D pilots to scalable, commercially viable urban infrastructures. It adapts Bax's Mission-Driven Innovation (MDI) methodology and Innovation Readiness Levels (IRL) to analyse the political, economic, social, and technical maturity of PEN projects and cities across Europe – and highlights recommendations to enhance their “PEN Readiness” towards rapid uptake, scaling, and standardisation.

Key Insights

A central finding is that Europe's PEN sector (including European-funded R&D&I urban sustainability projects as well as stand-alone private real estate developments) is technologically ready but bureaucratically stalled. The “pilot trap” describes projects which are unable to scale because they are designed as bespoke, high-engagement social experiments rather than standardised investment products which are recognisable and low-risk for the most typical investor types.

- **Reframing value:** As of 2025, the relevance of PENs within Europe has shifted to better align with Europe's latest strategic and territorial needs. This shift requires of PEN projects to clearly demonstrate their contribution to these strategic goals, beyond one-off local community initiatives, and instead representing sensible urban infrastructure supporting lower levelized costs (LLCOE), greater energy resilience, and securing regional economic competitiveness better than the centralised grid.
- **Towards PEN development standards:** Key PEN Typologies offer scalable design opportunities based on simplified and replicable ownership and governance structures. E.g. Single ownership Typologies, exemplified by large-scale social housing developments, can bypass the complex and time-consuming problem of engagement across fragmented privately owned dwellings. This enables faster permitting and renovation delivered more efficiently. PEN project initiators should prioritise such uniform neighbourhood types to leverage “quick wins” where possible⁴.

City Readiness Clusters

Bax “PEN Readiness” assessment of 12 cities reveals three distinct implementation stages and pathways within Europe, requiring tailored strategies:

1. **Advanced followers** (e.g., Lisbon, Barcelona): These possess mature laws for energy sharing but are slowed by administrative burden. Simplification of the end-user journey is needed.

⁴ Blended financing, while still evolving towards full maturity, should also be explored to deliver PEN works across neighbourhoods across diverse public, private, and citizen stakeholder types e.g. combining public grants and first loss guarantees with private loans as the main source of capital.

2. **Grid-constrained cities** (e.g., Amsterdam, Mechelen): These have high capital and technical capacity but are blocked by physical grid limits. A flexibility-first approach should prioritise storage and peak-shaving over generation.
3. **Legacy regulators** (e.g., Munich, Stockholm): These have strong infrastructure but outdated market rules. Policy advocacy should unlock energy sharing possibilities to make PENs and energy communities commercially viable.

Overall, to unlock private capital and mass adoption of PENs, public authorities must find a way to shift from "project-push" methods (subsidizing volunteers) to "market-pull", creating clear value propositions. Reduced transaction costs of Collective Self-Consumption and renewable energy communities will be central to this, alongside supporting standardised investment opportunities, and treating PENs not as niche innovations, but fundamental energy backbones of a resilient European economy towards climate neutrality.

DRAFT

11. Appendix

The “City Energy Bill” – putting PENs within broader urban investment strategy

Applied to city energy strategy, measuring local levelized energy costs supports a clear case for long-term investment in an urban energy economy that is clean, local, and smart.

The City Energy Bill (CEB) is a concept developed by Bax that helps to quantify the economic benefits of local clean energy systems such as PENs for cities. It helps to reframe such an investment from a short-term cost that municipal governments “have to do”, to an enormous long-term opportunity that they will “want to do”, delivered through an integrated urban energy strategy developed closely with energy system operators and utilities.

The CEB concept reframes energy use from the fragmented level of the household, project, or business park to the holistic level of an entire city. It quantifies the local economic value that is currently spent – and therefore continually lost - by reliance on majority imported fossil energy, and by delaying clean energy action within that region^{clxxxix}. In this way, rather than seeing clean energy projects as simply costs or policy obligations, the CEB demonstrates how local energy investment bring enormous opportunities with both immediate and long-term benefit.

CITY ENERGY BILL			
Exemplary Dutch city of 100'000 inhabitants (47'400 households)			
	units/year	€/unit	€ / year
	118,5 GWh	0,32 €/kWh	38 M
	38M m ³	1,44 €/m ³	56 M
	66M L	2 €/L	132 M
TOTAL			€ 226 M

Figure 57: Bax’s “City Energy Bill” concept quantifies the potential economic value of a city local energy economy.

The annual energy bill per 100,00 inhabitants in the Netherlands is over €225m - not adjusting for inflation nor future expected increases in energy costs^{cxk}. Towards the country’s deadline for climate neutrality, this equates to €5.65bn in energy costs by 2050, yet with no local ownership or new jobs created. The CEB provides a crucial base of data to help municipal governments justify ambitious investments programmes that will save €100m’s annually, benefitting local homes, businesses and municipal sites. The CEB would support a transition from today’s per-project energy system approach to a more cost-effective and balanced local energy investment portfolio aiming at energy affordability for all city stakeholders.

PEN Typologies

PEN Archetype 1: High-rise apartment

This archetype is characterised by a high-density urban building type common across Europe’s cities, with both common spaces and a large number of single-family homes. Energy demand is centralised and the building stock is largely homogenous, since the apartments were built at the same time.



Parameter	Analysis & Key considerations
Example	Tartu’s Living Lab in oPEN Lab
Key pros and enablers	<p>High density: Aggregated demand enables efficient design and delivery of large-scale shared energy systems (e.g., geothermal, district heating connection)</p> <p>Facade: Despite relatively small roof space, building-integrated PV (BIPV) offers significant energy generation potential</p> <p>Economies of scale: Large single building represents lower costs through industrialised renovation workflows</p>
Key cons and barriers	<p>Roof space: Low rooftop PV capacity insufficient to meet dense demand</p> <p>Cost & complexity: Better suited BIPV and facade retrofits are significantly more complex and expensive than standard rooftop PV</p> <p>The "Condominium Problem": Fragmented ownership and decision making across building Homeowners' Associations (HOAs), also “split-incentive” problem</p> <p>Governance: Complex, slow collective decision-making processes.</p>

Ownership	Fragmented (Condominium / HOA): Multiple private owners of individual units, with collective ownership of common areas and structural elements
Governance Models	<p>Third-party energy asset ownership: An ESCO or utility owns and operates the central energy assets (elevators, lighting, façade renovation, HVAC etc.)</p> <p>Citizen Energy Community (CEC): Collective assets managed by CEC as single legal structure, oversees energy trading between units, and distributes benefits and costs</p>
Business Models	<p>Energy-as-a-Service (EaaS): An ESCO installs, owns, and operates the BIPV facade and HVAC.</p> <p>Energy Performance Contracts (EPCs): An ESCO guarantees a certain level of energy savings and comfort to the HOA. HOA pays only a monthly <i>service fee</i> for these contracted KPIs.</p>

PEN Archetype 2: Distributed suburban neighbourhood

This archetype represents the low-density, suburban "sprawl" urban development opportunity for PEN developers. Energy demand is dispersed, and building stock is often heterogeneous and characterised by extreme fragmentation across hundreds of individual private owners.

In some ways this archetype presents the opposite challenge of Archetype 1, in that the technology opportunity can be simple and cost-effective, but the distributed governance and business model challenges across disparate dwellings are significant.



Parameter	Analysis & Key considerations
Example	Genk's Living Lab in oPEN Lab

<p>Key pros and enablers</p>	<p>High roof space-to-demand ratio: Generous roof space enabling low-cost, effective solar PV generation.</p> <p>High citizen engagement: Strong potential for "bottom-up," citizen-led initiatives.</p> <p>Flexibility: High potential for aggregating V2G/V2H and distributed batteries, offering significant grid flexibility services.</p>
<p>Key cons and barriers</p>	<p>Ownership fragmentation: Legal building separation requires lengthy negotiations and high transaction costs to align owners.</p> <p>Physical complexity: Large number of mixed building types requires a costly and complex tailored renovation approach for each.</p> <p>Regulatory: Possible legal barriers to behind-the-meter energy sharing among so many separate buildings and owners.</p>
<p>Ownership</p>	<p>Fragmented Individual: Hundreds of distinct, private freehold owners.</p>
<p>Governance Models</p>	<p>Renewable Energy Community (REC): A <i>legally required</i> entity for separate citizens to collectively produce, consume, store, and share energy.</p> <p>One-Stop-Shop (OSS): An intermediary coordinates renovation, permitting, and financing across the separate homeowners.</p>
<p>Business Models</p>	<p>Collective self-consumption: CSC is the most likely model already recognised by policy in some Member States. Here the REC owns a community energy storage/generation asset and sell energy to members.</p> <p>Flexibility services: The REC (or its aggregator) sells aggregated flexibility (e.g., from V2G) to the grid operator.</p>

PEN Archetype 3: Social housing

This archetype may represent the most effective opportunity for PEN implementation, rapidly and at large scale.

Ownership of the PEN is defined by having a single entity owner - typically a publicly sponsored or a non-profit social housing association or developer. This single-owner model addresses the primary governance barrier governance that defines the above two PEN Typologies.

Meanwhile, physically social housing often consists of a homogenous building stock, which is ideal for cost-efficient and scalable retrofits. Finally, with a more socially-driven mandate than other typical owner types, social housing developers would have both a clear economic, social, and environmental interest in investing in positive energy solutions – delivering energy affordability, quality and affordable housing, and contributing to regional climate change mitigation.



Parameter	Analysis & Key Considerations (with Evidence)
Example	ASTER social housing association in Flanders (comprised of 42 publicly owned social housing companies)
Key pros and enablers	<p>Single-entity owner: Bypassing common fragmented decision-making barriers, this is a critical advantage to a social housing PEN model.</p> <p>Industrialised renovation: Largely homogeneous and large-scale building stock allows for mass-produced, prefabricated retrofits, lowering cost and time.</p> <p>Space: Large collective energy generation, storage, and V2G space available</p> <p>Economies of scale: Single projects can cover 1000s of units, creating economies of scale, benefitting many at once, and securing more affordable finance rates.</p> <p>Social impact: The owner has core mandate to deliver a range of positive outcomes aligned with EU goals, including economy, environment, and social wellbeing.</p>
Key cons and barriers	<p>Capital: Deep retrofits are capital intensive.</p> <p>Vulnerable tenants: Renovation can be highly disruptive for tenants, with additional sensitivities due to their often-vulnerable condition.</p> <p>Regulatory Barriers: Public-sector owners can be limited by public debt and procurement regulations.</p>
Ownership	Single entity: Public Social Housing Association, Municipality, or a non-profit Cooperative.

Governance Models	<p>Public-Private Partnership (PPP): For financing and executing the large-scale retrofit.</p> <p>Direct Public Management: The SHA manages the project directly, using public loans (e.g., from EIB) and EU/national grants.</p>
Business Models	<p>Energy Performance Contracts (EPCs): The SHA contracts an ESCO to deliver and guarantee the retrofit's performance.</p>

PEN Archetype 4: Industrial & commercial estates

This archetype represents one of the strongest potential business case Typologies for PENs, due to the high and often stable energy demand of commercial properties. Governance and ownership are typically done by a centralised point of contact like the social housing model above; and large space available for potential energy generation, storage, and flexibility services.

Physically it is characterised by a cluster of commercial, industrial, or logistic buildings within a common, and controlled managed property.

Unlike most residential-focussed PENs, industrial PENs can leverage their unique potential via a B2B business model, capturing and reusing waste energy, lowering collective energy costs, addressing corporate ESG goals, and building islands of energy security and regional grid resilience.



Parameter	Analysis & Key considerations
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Example	Pamplona's initial Living Lab opportunity at the IWER industrial complex
Pros and key enablers	<p>Large space: Ideal for large-scale roll out of PV and storage.</p> <p>Significant energy recovery/sharing opportunity: Capturing industrial excess heat for on-site re-use, sharing, or export.</p> <p>Clear business case: Driven by energy cost reduction, resource efficiency, and corporate sustainability goals.</p> <p>Complementary load profile: High, stable industrial demand can balance nearby residential peaks, offering key grid services.</p>
Cons and key barriers	<p>Mixed industry: Different industries have unique energy needs and profiles requiring bespoke energy and business solutions.</p> <p>Disruption risk: PEN integration could interrupt industrial tenants' core business operations, with regional knock-on effects.</p> <p>Coordination: Requires coordination among multiple, competing, private companies, who may be unwilling to share energy and data.</p> <p>Capital cost: Especially for shared infrastructure (e.g., district heating network).</p>
Ownership	Central "Industrial Park Management" Entity: Can be a private developer, a Public-Private Partnership (PPP), or an Industrial Tenants Association.
Governance Model	<p>Public-Private Partnership (PPP): The public sector co-invests in the core infrastructure (e.g., heat network) to attract private tenants and generate significant new energy source for regional economic security.</p> <p>ESCO: A central Energy Service Company (ESCO) manages all financing and energy system delivery.</p>
Business Models	<p>Energy-as-a Service (EaaS): Park Management entity provides energy as a service to industrial tenants via a performance contract.</p> <p>Industrial Symbiosis: Formalised resource sharing contracts between tenants.</p>

Choosing the 12 follower sites

In line with the project's Grant Agreement, particularly within WP7, the regions assessed for this investment strategy include 12 total "follower" regions (Task 7.5). Of these, 2 are Spanish localities (as set out in Task 7.5.1.), 3 are within the project's existing Living Lab regions (as set out in Task 7.6), and the remaining 8 have been identified through the networks and clusters coordinated by project partners TREA and EnoLL (as set out in Task 7.5.2).

Engaging oPEN Lab project partner CENER and AHU to find Spanish PEN followers:

Positive energy models from Pamplona - specifically the One-Stop-Shop (OSS) and local energy communities ("CELS") — are already proving highly successful and replicable.

Success within Pamplona itself is already well-established and the original oPENlab OSS in the Rochapea district (Oficina Verde Rochapea) has been successfully duplicated with the creation of the Oficina Verde Milagrosa-Arrosadía. This pattern is mirrored by the energy communities; the process used to establish ArrotxaE (Rochapea) is now being actively replicated in other districts, leading to the formation of "Iturargi" in San Juan/Iturrama and "Ilargienea" in Milagrosa/Arrosadía.

A primary opportunity has emerged with the City Council of Manzanares el Real (Madrid). They are specifically interested in replicating Pamplona's CEL model for a "follower" project, which would involve adapting the model to engage their local stakeholders.

Building on this, a national dissemination strategy is underway. This involves sharing the model through presentations in cities like Vitoria and Getafe, creating informational videos, and planning a national conference for 2026.

The proposed next step is to organise a dedicated meeting or workshop with the Manzanares el Real council. This initiative will be coordinated by UPV-EHV (Alba) with support from CENER, aiming to formally present the Pamplona model and explore concrete pathways for its replication in their locality.

Engaging oPEN Lab project partner VITO to find Flanders PEN followers:

Based on the proactivity of the municipalities and existing progress made towards neighbourhood scale energy projects, VITO recommend Oostende and Mechelen as high priority PEN follower sites for exploration within Flanders.

VITO also suggest Leuven as an advanced area, but is still awaiting a formal project start.

Location	Technology focus	Ambition	Current status	Notes
MORTSEL Lieven Gevaertstraat	Residual heat Collective	Extension of existing network	First phase: 20 households and 2 schools Up to 190 households	Cooperations on board; process started (neighbourhood meeting planned first half of November)
LEUVEN Nieuw Kwartier	Geothermal Collective	New, in public domain	Up to 317 households, 1 school, 1 hospital	Neighbourhood information session here . One of the most advanced cases
OOSTENDE	Residual heat Collective	Extension of existing network	Up to 888 households	Very active municipality, working on mitigation and adaptation. Will collaborate in HEU SMARTER and DUT call, effectively working on PED
MECHELEN Kriekerijvelden	Geo Collective	New	Up to 190 households	Social housing context - houses will be replaced by energy efficient buildings. BEO on SH land as much as possible, potentially in public domain if needed. No real renovation context.
MECHELEN	TBD	TBD	TBD	Nekkerspoel; collective renovations planned

				Mechelen has a lot of experience already in supporting private renovations (including collective building permits etc)
BRUGGE Sint-Gillis	Geothermal Collective	New network	Up to 1929 households	In various phases, depending on roadworks etc. Major momentum in 2028 (?), as the industrial plant that would serve as a source is stopped for maintenance - would be the ideal moment to connect to a network.
GENK	TBD	TBD	TBD	Working on a more fleshed out version of the PED coach Have started heritage trajectory in Zwartberg (garden city next to Waterschei) and will commence renovation support there (through STEBO).
TURNHOUT	TBD	TBD	TBD	Papenbrugge - combination of social housing and more affluent neighbourhood; process ongoing. Begijnhof - heritage, process ongoing
VILVOORDE				
BONHEIDEN				
KONTICH				
KNOKKE-HEIST				

Engaging oPEN Lab project partner TREA to find Estonian PEN followers:

Subtask 7.5.1: *“TREA, with the aid of Kredex and the Ministry for Economic Affairs (see LoS), will provide free technical and financing assistance to 2 housing associations in Estonia for the organisation of large-scale apartment block renovation using oPEN Lab Tartu innovations.”*

TREA has provided technical and financial assistance to 11 apartment buildings within the oPEN Lab project in the previous districts, but unfortunately none wished to proceed with the renovation. However, the consulting and guidance have taken place.

List of buildings:

1. Mõisavahe 35, Tartu
2. Mõisavahe 36, Tartu
3. Mõisavahe 37, Tartu
4. Mõisavahe 38, Tartu
5. Mõisavahe 42, Tartu
6. Mõisavahe 43, Tartu
7. Mõisavahe 45, Tartu
8. Mõisavahe 47, Tartu

9. Kaunase pst 80, Tartu
10. Nõlvaku 15, Tartu
11. Ravila 49, Tartu

Estimating renovation costs:

The renovation works and price (slightly more than €1,000/m²) were similar for all buildings since, to receive EIS renovation support from KredEx specific works are required, including insulation of the foundation, facade, and roof, replacement of the heating system, heat recovery ventilation system, replacement of windows and exterior doors, reconstruction of balconies or loggias, replacement of water and sewage pipelines). Building typologies were the same, all being built between 1988-1992.

An example:

- **Building:** Mõisavahe, 43
- **Size:** 4,989,8 m² and 2 staircases
- **Renovation cost:** €5,302,448, (or €1,063 / m²).

Engagement process with Tartu residents:

- Prepare a survey for apartment owners to understand their financial capacity and building wishes
- Present technical reports to owners demonstrating that the building is outdated and needs renovation (<https://tartu.ee/et/annelinnpluss#hooneraportid>)
- Generate renovation cost estimates using TalTech's cost calculator (below), and quotes gathered from local contractors
- Engage with building residents to explain works and process of renovation-as-a-service.
- Prepare procurement documents to achieve the best price for the best work

D7.5: Implementation plans for 12 sustainable investment programmes towards PENs

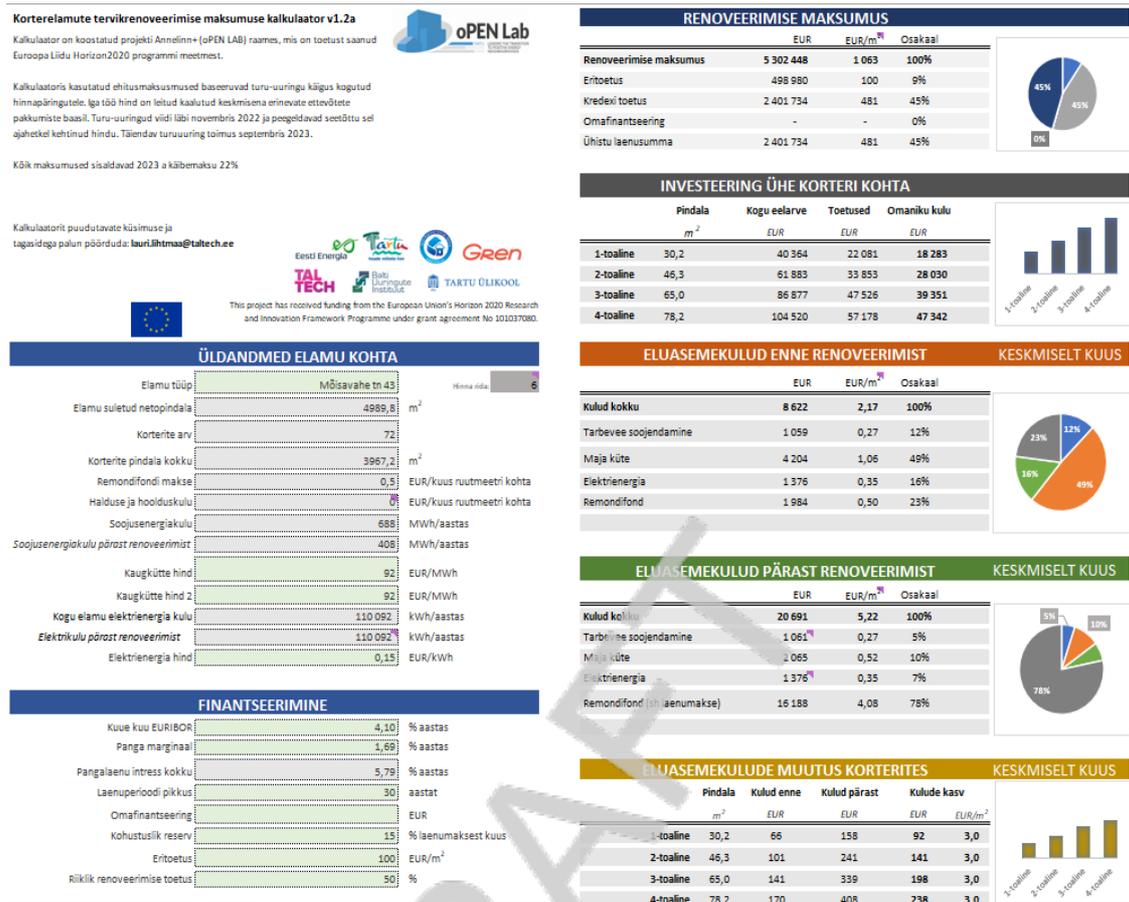


Figure 58: TalTech's renovation cost calculator

Why resident engagement for PENs in Tartu failed:

1. Geopolitics

The 2022 Ukrainian invasion severely impacted the project by driving up construction costs. This was primarily caused by:

- Labour shortages, as many Ukrainian builders returned home.
- Supply chain disruptions for materials to Estonia typically from Ukraine, Belarus, and Russia.

2. High energy prices

Estonia's high inflation significantly outpaced the European average in both 2022, adding major financial strain:

	Estonia	Europe
2022	19,4%	9-10%
2023	9,1%	5,4-6%

3. Local resistance

There was little motivation among residents to proceed:

- Despite benefitting from renovation, the pilot buildings were in sufficiently good condition.
- With some of Estonia's lowest district heating prices, high heating bills (and energy bill savings) were not a priority concern.
- Residents felt a fear of the future due to ongoing economic and geopolitical uncertainty and therefore found it difficult to commit to such extensive future developments of their homes.
- Residents also felt like "guinea pigs" for this research project and were overwhelmed by the sheer scale of the work required without a clear idea of future benefits.

Lessons learned in Tartu, and insights for future PEN delivery and replication:

The experience in Tartu highlights that successful, large-scale renovation requires permanent and local support structures, and a creative approach to resident engagement. Key is establishing state-supported One-Stop-Shop (OSS) facilities and/or Renovation-as-a-Service (RAAS) delivery models – providing on-hand and long-term project management and advice to apartment associations, and beyond temporary, project-based funding.

Effective communication of the renovation/PEN value proposition must be strategically layered. While Apartment Associations require in-depth technical training to champion the project, most residents should see tangible and short-term benefits like a better indoor climate, improved aesthetics, and enhanced comfort. Outreach must also accommodate minority language groups.

Towards broader European replication, two aspects are vital: financial barriers must be lowered through state-guaranteed and low-interest loans, especially in rural or low-value areas where traditional financing is unobtainable. Secondly, renovations should be approached on a neighbourhood level, with municipalities investing in the public spaces *between* the buildings to foster community pride, buy-in, and galvanise further interest.

Finally, low-disruptive renovation methods like the use of prefabricated elements and emphasizing quality-of-life improvements, such as mechanical ventilation for better air quality, can help create a more compelling and replicable model for renovation roll-out.

EU-wide followers:

Subtask 7.2.5: *“EnoLL will carry out the above described process with 6 building owners, working with 13 innovation clusters across the EU. ENoLL will run a series of “cities engagement workshops” to promote project results and find “followers”. ENoLL’s oPEN Living Lab Summit will be used as a platform for these insights, activities, and involve representatives from local authorities and local stakeholders e.g. SMEs and building owners. An implementation plan for each of these follow-up project initiators will be delivered.”*

To identify viable PEN follower's, ENoLL coordinated two key knowledge-sharing and engagement workshops in both 2024 and 2025:

1. Energizing Tomorrow: Innovative Collaboration Models for Climate and Energy Transition (Timisoara, September 2024) Energizing Tomorrow: Innovative Collaboration Models for Climate and Energy Transition (Timisoara, Romania, September 2024)
2. OpenLivingLab Days (Andorra, September 2025)

While the first event in Romania was attended by 39 participants and covered broad topics like financing and policy, the 2025 OpenLivingLab Days in Andorra produced a clear frontrunner. Amsterdam emerged as the most high-potential replication site, based on unanimous feedback.

Participants specifically highlighted Amsterdam's "[Urban Living Lab Way of Working Handbook](#)" as a very clear, structured, and relevant guide with concrete examples, making it the most interesting and applicable approach to be explored further by oPEN Lab.

DRAFT

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