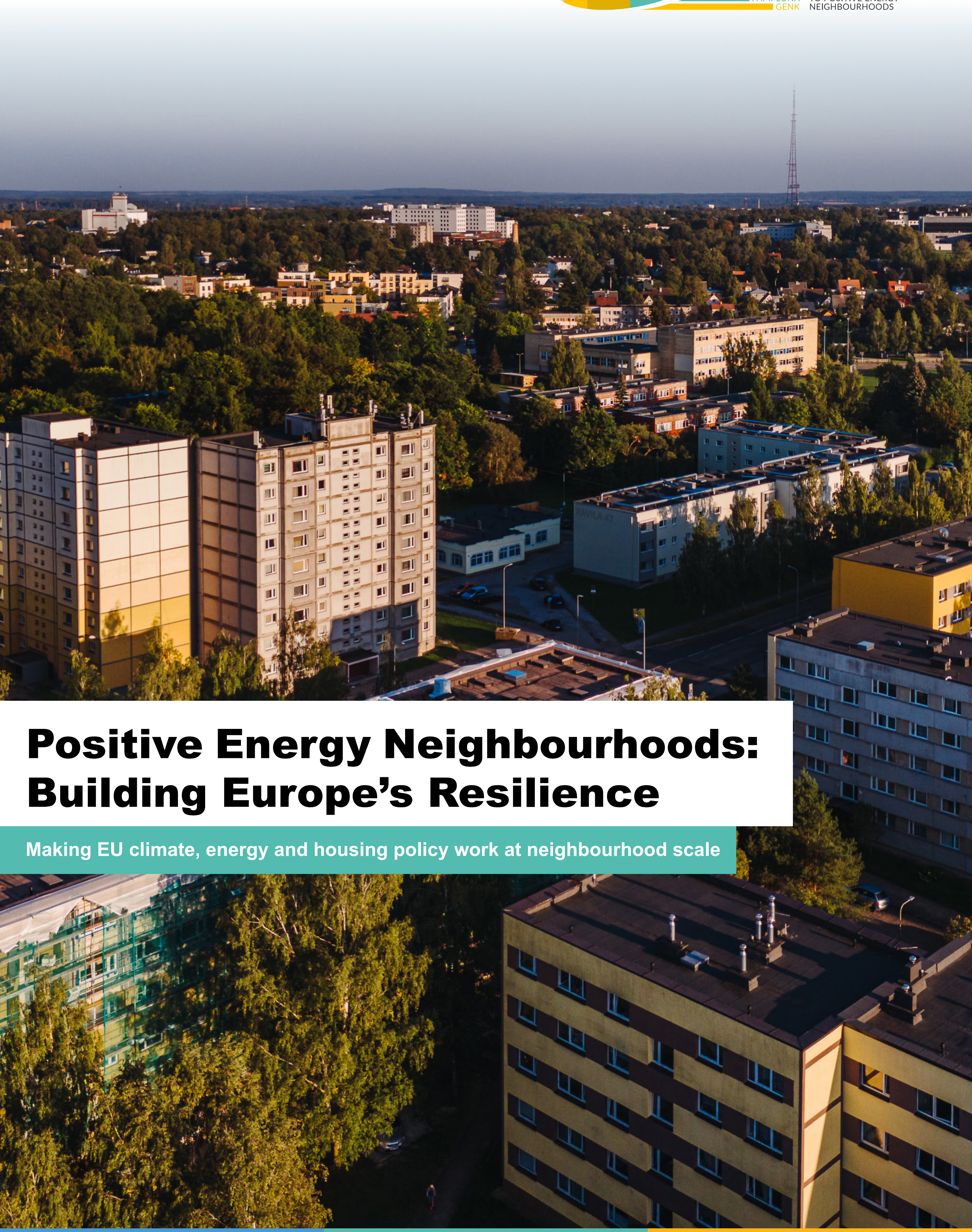
oPEN Lab

TARTU PAMPLONA GENK

LEADING THE TRANSITION TO POSITIVE ENERGY NEIGHBOURHOODS



Positive Energy Neighbourhoods: Building Europe's Resilience

Making EU climate, energy and housing policy work at neighbourhood scale

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Foreword

When the oPEN Lab project started in October 2021, Europe had just entered an unprecedented energy crisis triggered by Russia's war against Ukraine. The shock exposed how deeply Europe depended on imported fossil fuels, and how vulnerable both industry and households were to geopolitical events. Less than five years later, the situation has not stabilised. The war in Ukraine continues, new geopolitical tensions are emerging, and energy markets remain volatile. One crisis has followed another, repeatedly exposing the fragility of Europe's energy system.

These overlapping crises make one thing clear: energy security is experienced where people live, particularly in communities already facing energy poverty, poor housing quality and social inequality. Buildings sit at the heart of this challenge. Europeans spend most of their time indoors, yet three quarters of the building stock remains energy inefficient. Transforming neighbourhoods is therefore not only about decarbonisation and sovereignty. It is also about health, affordability and resilience.

> ***"Investing today in fossil-free neighbourhoods means investing in health, comfort and affordable energy in times of uncertainty - not in abstract climate goals."***

The oPEN Lab project explores how this transformation can happen in practice. Through Living Labs in Genk, Pamplona and Tartu, more than thirty partners have tested how existing urban districts can evolve towards Positive Energy Neighbourhoods (PENs). One lesson quickly became clear: the urban energy transition is not only technological. It also depends on governance, collaboration and trust. New energy systems must evolve together with new forms of participation, ownership and cooperation, supported by policy frameworks that allow innovation at scale.

> ***"Only at the neighbourhood scale can technology, policy and citizens come together to deliver the speed, system integration and social cohesion the energy transition requires."***

This policy roadmap builds on the experience of the oPEN Lab Living Labs and dialogue with policymakers at local, national and European levels. It shows that the neighbourhood scale is uniquely suited to address decarbonisation, energy security, affordability and social cohesion - integrating buildings, energy systems, mobility and public space while remaining close to citizens to enable participation and ownership.

> ***"Technology can enable the transition, but people and policy make it happen."***

Many of the regulatory building blocks for Positive Energy Neighbourhoods already exist within European legislation – such as the Energy Performance of Buildings Directive, the Renewable Energy Directive and the Renovation Wave. The challenge now is practical implementation. PENs provide a concrete way to translate these ambitions into action. For policymakers, the message is clear: supporting neighbourhood-based approaches is not about adding complexity to climate policy. It is about making existing policy goals achievable in practice.

The experiences in Genk, Pamplona and Tartu show that transformation is possible when cities, citizens, researchers, industry and policymakers collaborate in open innovation ecosystems. The next challenge is to scale these experiences beyond pilot projects and embed them in mainstream urban development.

Because resilient, affordable and fossil-free neighbourhoods are not only a climate objective. They are the foundation of a more secure and liveable Europe.

Maarten De Groote
Project Coordinator, oPEN Lab

oPEN Lab Tartu showed that Positive Energy Neighbourhoods start with people.
PENs emerge when residents are willing to invest time, trust and effort into improving their homes and community. Local governments play a crucial role by supporting residents in making renovation decisions and enabling the right conditions for change. In cold climates with long, dark winters – when energy demand is highest and solar production is minimal – the only realistic path to positive energy is ambitious energy savings through deep renovation.

oPEN Lab Genk shows that creating Positive Energy Neighbourhoods is only possible when technological and social innovation move forward together.
Working in vulnerable neighbourhoods demonstrates the value of rapid low-disruption renovation, real-life testing, and close collaboration with residents. By combining industrialised methods with user feedback, we learn which solutions are effective, inclusive, and scalable for a just energy transition.

In oPEN Lab Pamplona one of the city's most socially vulnerable districts is becoming a beacon of possibility.
Green offices guiding regeneration, collaborative murals strengthening identity, neighbours forming an energy community for affordable power, and deep home renovations that spark local jobs and dignity. Together, innovation and participation are turning challenge into momentum for a fairer urban future shared by all who live in Rochapea district and Pamplona today.

Buildings as the foundation of societal resilience

> ***"Resilience is the ability not only to withstand and cope with challenges but also to transform in a sustainable, fair, and democratic manner."***
>
> *European Commission, 2020, Strategic Foresight Report, EU Green Deal, the Recovery and Resilience Facility (RRF)*

The resilience of Europe's society and democracy is being tested under a growing number of crises including energy security risks, energy price volatility, climate impacts, political division, pandemics and other threats. With Europeans spending 80–90% of their time indoors, buildings need to be at the heart of any political action towards a society where – despite these crises – human well-being is high. The quality of EU homes, schools, offices and other buildings determines how well citizens can withstand financial stress linked to housing costs or energy expenditure, and health stress linked to climate impacts or air pollution.

As such, while neglect of the EU building stock weakens societal resilience, systemic investment into better buildings offers significant opportunities to improve well-being and strengthen community cohesion:

1. **Buildings and the energy crisis:** Three-quarters of the EU's buildings are energy-inefficient,[1] and 85–95% of these will still be standing in 2050.[2] Buildings consume 40% of the EU's total energy and 50% of its fossil gas,[3] primarily for use in heating and cooling. Already, more than 41 million people in the EU are struggling to keep their homes warm enough. As heatwaves intensify across Europe, heat-related mortalities and health risks are increasing, particularly among households living in poorly performing buildings.

   On a geopolitical front, the depth of decarbonisation and the level of energy consumption in our buildings determine the extent to which Europe is dependent on fossil fuel imports from countries outside the EU. **Renovating a home can reduce final energy demand for heating by 45% and shift gas use to electricity.[4] Efficiency gains since 2000 have already reduced final consumption by 29% and have saved EU households an estimated €540 annually.[5] Phasing out fossil heating could cut EU gas import expenditures by €15 billion in 2030 and €43 billion in 2050.[6]**

2. **Buildings and the climate crisis:** Buildings are one of the most significant contributors to the climate crisis due to their carbon footprints across their life cycles, making up around 41% of the EU's total emissions in 2020. **Between 2005 and 2022, efficiency improvements and renewable energy adoption reduced CO_2 emissions from EU buildings by 34%.[7]** Most of the EU's buildings were constructed before thermal standards were introduced, and are not suited to increased summer heat. Around 87 million people across Europe live in areas exposed to multiple natural hazards which are exacerbated by climate change, such as coastal flooding, river flooding, landslides and wildfires.[8] From 2021 to 2024, EU economic losses due to climate change amounted to €208 billion.[9] **Retrofitting ageing buildings improves structural safety and reduces downtime during extreme weather events.**

3. **Buildings and the housing crisis:** House prices rose by 47% in the EU between 2010 and 2022, and rents increased by 18%.[10] Many European cities suffer from misallocations of space, such as there being an oversupply of office real estate and a lack of affordable housing in urban centres. **Renovation, adaptive reuse and neighbourhood-scale regeneration can expand the supply of affordable housing and stabilise rents.[11]**

4. **Buildings and the democracy crisis:** When institutions fail to provide for basic needs such as housing, trust in democratic processes inevitably declines. In 2025, 49% of Eurobarometer respondents reported rising distrust in democratic institutions.[12] Poor housing quality, unaffordability and spatial exclusion deepen social divides. The built environment thus becomes a battleground for democratic resilience: inclusive, participatory processes in housing and urban planning can counteract distrust by empowering communities. **One Stop Shops for building-related advice are single points of contact that simplify complex processes for renovation, financing or tendering, and can provide a sense of security and accountability to citizens. One Stop Shops can provide credibility and reduce trust issues among homeowners.**

5. **Buildings and the health crisis:** Some 16% of EU citizens live in housing that could be deemed unfit for habitation.[13] One in four Europeans live in buildings with indoor air quality below national standards.[14] Most EU buildings also lack adequate thermal protection, making cool-conscious renovation essential for climate adaptation. **Repairing inefficient homes could save €194 billion in health and social costs each year.[15]**

6. **Buildings and the economic crisis:** The construction sector, contributing roughly 10% of EU GDP and providing employment for 16 million workers, is highly vulnerable to economic shocks. The recent increase in construction producer prices, which rose by 40% between 2010 and 2022,[16] has exacerbated financial pressures on households and businesses alike. However, strategic investment to increase operational capacity for renovation and repurposing represents a huge opportunity to make the sector more competitive. **Every €1 invested in energy-efficient renovation generates €2.2 in other sectors, making this one of the most effective public investments for economic stimulus.[17]**

Policies for better buildings are not solely climate policies: they go far beyond an environmental agenda and are at the core of energy security, economic competitiveness, public health and local community cohesion. To rebuild citizens' trust in democratic institutions, political leaders need to demonstrate their capacity to protect citizens from rising costs and growing risks. The 2025 Eurobarometer showed that 68% of respondents want the EU to play a stronger role in protecting citizens from global risks.[18] Few policy actions empower citizens to respond to crises as directly as investing in high-quality buildings and liveable neighbourhoods.

Building societal resilience through an integrated approach for liveable neighbourhoods with people at their heart

From crises to opportunity: Neighbourhoods as the ideal level for intervention

While buildings are the foundation of societal resilience, their full potential can only be unlocked through an integrated neighbourhood approach. When buildings, public space and infrastructure act together, they create dynamic interactions between energy systems, and optimise resource use in a way no single building could achieve on its own. Through an integrated approach, neighbourhood interventions can unlock new forms of value such as demand-side flexibility, comfort, climate-resilience, affordability and trust that can only emerge when buildings act together.

Neighbourhoods represent the smallest and most accessible scale for public policy intervention, offering a high-potential lever for systemic change. A citizen-focused neighbourhood approach addresses affordability, decarbonisation and democratic participation by embedding solutions in the lived reality of communities. It enables shared infrastructure, collective investments in renovations and renewable energy, neighbourhood-level storage, smart energy management and shared-benefits models. These interventions reduce costs, increase comfort and shield residents from volatile energy prices. The neighbourhood scale is also where participation becomes more tangible, as residents can see and influence decisions that affect their homes.

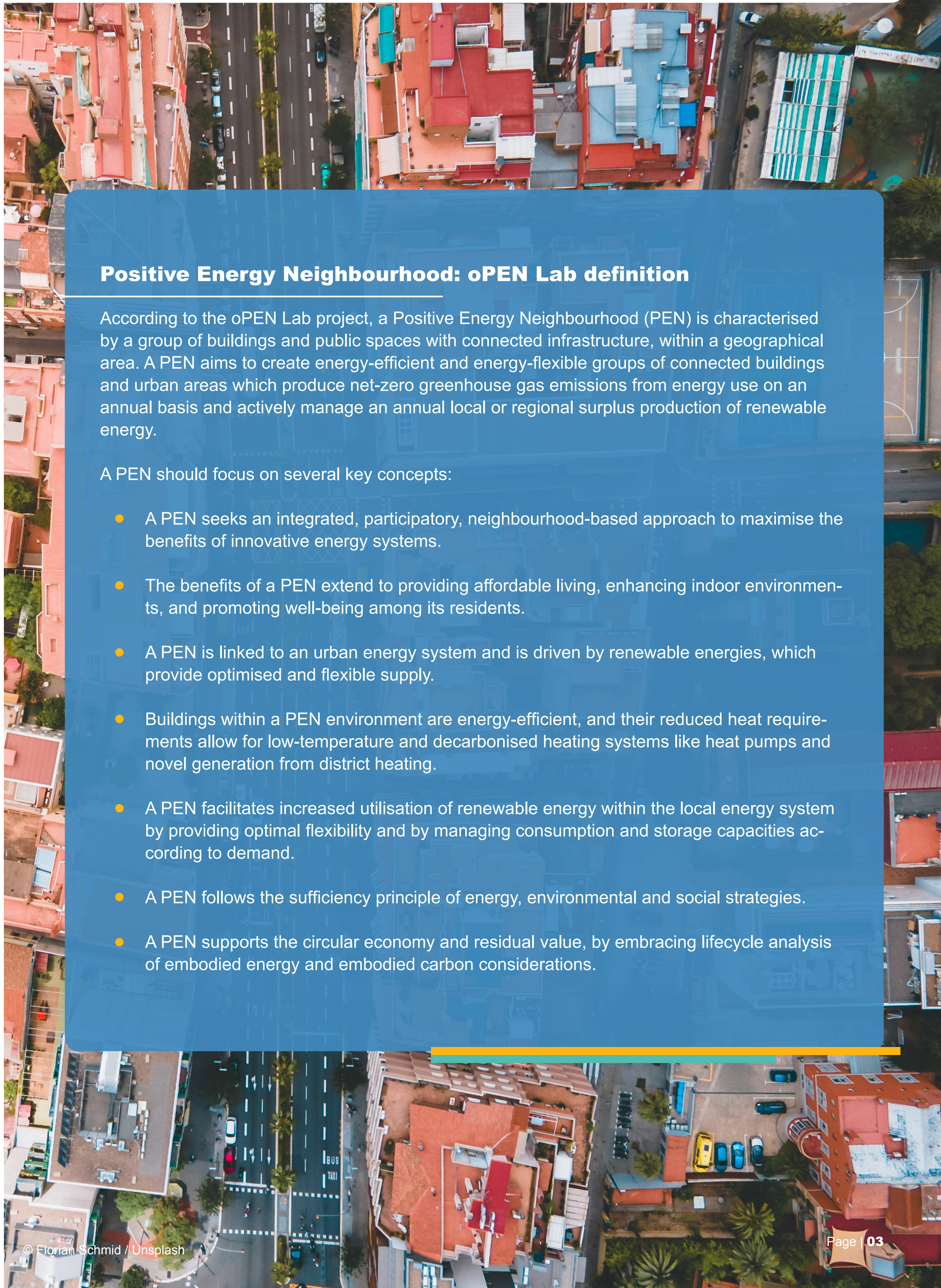
In recent years, the EU has increasingly recognised neighbourhoods as an effective level for place-based, citizen-led action. For example, the European Commission's Urban Agenda for the EU is a multi-level working method that uses a **district and neighbourhood approach** to address urban challenges. More detail on current EU policy can be found on page 10. The terms "neighbourhood" and "district" are often used interchangeably in policy documents, yet the distinction between the two matters as they differ in scale and social meaning. While "district" typically refers to larger urban areas, "neighbourhood" implies smaller, interconnected zones where social relations, daily life and local identity play a significant role. An overview of various definitions relating to Positive Energy Neighbourhood and district concepts and their nuances can be found in Outline of the oPEN-Lab policy roadmap (p.11).

oPEN Lab chose to use the neighbourhood approach. It was deemed to be the better fit for innovative citizen-centred renovation that strengthens community involvement, supports participatory decision-making and links energy objectives with social and environmental improvements, making it more likely that communities will take ownership of renovation efforts, and keep them maintained. This is the foundation for oPEN Lab's definition of **Positive Energy Neighbourhoods (PENs).**

An integrated vision: Positive Energy Neighbourhoods

PENs are a means to achieve energy, climate and social policy goals. They bring together innovations in social, technological and also governance processes, such as energy sufficiency and efficiency, flexible and aggregated demand, storage, collective ownership, shared spaces and services, sustainable mobility, prefabricated and circular construction, and new stakeholder networks. All of these can be adjusted to local contexts with no single configuration required.

The oPEN Lab project, funded under Horizon 2020, shows how the PEN approach can support the implementation of ambitious EU regulation by testing technologies, processes and governance models capable of creating neighbourhoods that produce more energy than they consume. This report illustrates how national, regional and local implementation challenges can be overcome by using a neighbourhood approach, summarising lessons learned and providing policy recommendations. It is intended for policymakers at all levels, as well as for practitioners implementing neighbourhood-scale solutions, and aims to clarify enablers, barriers and practical steps for effective rollout.



Positive Energy Neighbourhood: oPEN Lab definition

According to the oPEN Lab project, a Positive Energy Neighbourhood (PEN) is characterised by a group of buildings and public spaces with connected infrastructure, within a geographical area. A PEN aims to create energy-efficient and energy-flexible groups of connected buildings and urban areas which produce net-zero greenhouse gas emissions from energy use on an annual basis and actively manage an annual local or regional surplus production of renewable energy.

A PEN should focus on several key concepts:

- A PEN seeks an integrated, participatory, neighbourhood-based approach to maximise the benefits of innovative energy systems.
- The benefits of a PEN extend to providing affordable living, enhancing indoor environments, and promoting well-being among its residents.
- A PEN is linked to an urban energy system and is driven by renewable energies, which provide optimised and flexible supply.
- Buildings within a PEN environment are energy-efficient, and their reduced heat requirements allow for low-temperature and decarbonised heating systems like heat pumps and novel generation from district heating.
- A PEN facilitates increased utilisation of renewable energy within the local energy system by providing optimal flexibility and by managing consumption and storage capacities according to demand.
- A PEN follows the sufficiency principle of energy, environmental and social strategies.
- A PEN supports the circular economy and residual value, by embracing lifecycle analysis of embodied energy and embodied carbon considerations.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Positive Energy Neighbourhoods: flexible modular systems for place-based solutions and local needs

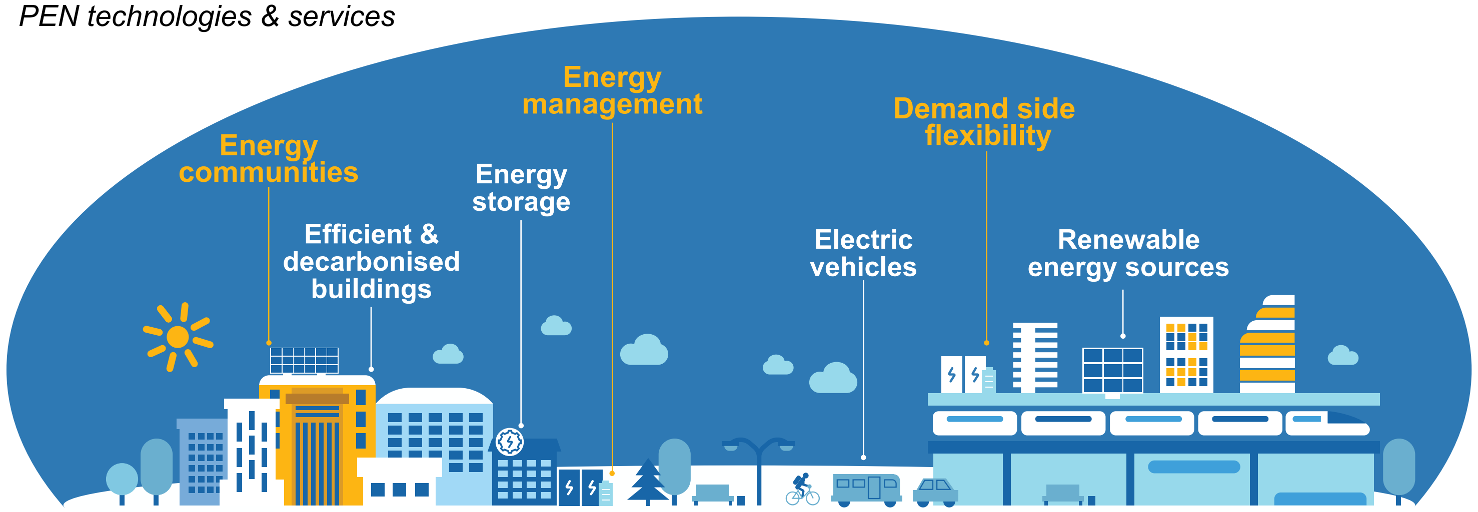
As demonstrated in the oPEN Lab Living Labs in Genk, Pamplona and Tartu, the neighbourhood approach can take different forms. PENs are not a fixed model, but a guiding approach towards achieving a net-positive energy balance on a neighbourhood scale. They are flexible, modular systems closely tailored to local needs, capacities, governance culture and existing infrastructure. **The following sections demonstrate how the PEN approach can be put into practice, with a focus on PEN technologies, organisational models, and the role of co-creation. For a deeper look at how these three elements were applied across the oPEN Living Labs in Tartu, Spain, and Genk, please refer to this report on PEN organisational models and this report on lessons learnt from occupant–technology interaction in nearly zero-energy buildings and districts.**

Positive Energy Neighbourhood technologies

A key element of each PEN are the technologies applied, even if their combination and configuration will be different for each neighbourhood. Broadly speaking, energy demand reduction and energy efficiency remain the starting points for any PEN approach. When overall energy consumption is minimised, PEN technologies also optimise where and when that energy is used in order to shift fossil fuel-based energy to renewables. Thus, technologies commonly associated with PEN development cover renewable energy generation, storage, mobility solutions, interoperability and smart energy management.

It is the adaptability of PENs that makes them so suited to the EU's varying local contexts.
For example, a neighbourhood with a high density of apartment blocks may focus on low-temperature district heating, prefabricated renovation and managed EV charging. A suburban neighbourhood with lower densities may rely on rooftop PV, shared heat pumps and community-owned batteries.
In historic districts, PENs may focus on cooling strategies, indoor air improvements and heritage-friendly renovations. A PEN might begin with the renovation of a handful of inefficient buildings, or it may emerge from a renewable energy community experimenting with shared solar roofs or neighbourhood batteries. **Any configuration is valid if it helps residents to improve quality of life and achieve significant energy and emissions savings.** What matters is the collective logic, not the specific technologies. In addition, according to JPI Urban Europe, one of the most crucial enablers of PENs is political vision and a strong governance framework, combined with the active involvement of problem owners and citizens.

PEN technologies & services



Source: oPEN Lab

Positive Energy Neighbourhood organisational model

Another key element of a PEN is its organisational model – and this, too, depends on the local context. PENs can be initiated by municipalities, driven by citizen cooperatives, organised around social housing providers, or anchored in public-private partnerships. The form of governance depends on local capacities and culture. **What is essential is that residents – including vulnerable groups – are actively engaged in shaping decisions, sharing the benefits and understanding how interventions improve their homes and streets.** Projects on a neighbourhood scale are big enough to matter to the energy system and the energy market, small enough for democratic participation, and familiar enough to build trust.

For replicability and compatibility (monitoring), oPEN Lab partners have proposed three types of PEN to give a better understanding of what they can look like in reality: technologically driven, community-centric, and policy-driven. In practice, these categories are not rigid: successful PENs combine elements of all three, with public policy playing a key role in aligning the deployment of technology with community needs.

Other archetypes that have been suggested but are not further explained here include autonomous, dynamic and virtual PENs, with varying system boundaries.

For more information, you can explore this oPEN Lab report on organisational models.

Different archetypes of PEN

Feature	Tech-driven	Community-centric	Policy-driven
Core logic	Optimisation through advanced energy systems and digital control	Collective ownership and bottom-up governance	Public planning and regulation at neighbourhood or city scale
Energy infrastructure	Smart grids, AI, automation	Localised and shared renewable energy	Large-scale district heating, municipal incentives
Governance model	Private sector and research institutions	Community cooperatives and grassroots initiatives	Public sector, municipal planning
Strength	High decarbonisation potential, system efficiency, transferable technical innovation	High acceptance and trust, social inclusion, strong local resilience	Ability to scale, long-term stability, alignment with climate and social policy
Scalability challenges	High cost, dependent on investment	Small-scale, difficult to replicate at city level	Large-scale, but bureaucratically slow

Source: oPEN Lab

Co-creation chapter on modular PEN

Co-creation at the heart of Positive Energy Neighbourhoods

Governance and process innovation are key aspects of PENs that differ depending on the organisational model and the technologies employed. This means implementing PEN activities in new ways with new actor configurations and different protocols, and thinking outside the box of traditional governance structures and roles. New forms of cooperation are needed between municipalities, real estate developers, building owners, tenants, energy providers for electricity and heating, research institutes, mobility providers, energy system providers, information and communication technology companies, industry, small and medium-sized enterprises (SMEs), non-profits and non-governmental organisations, politicians, citizens and citizen organisations, and others.

Co-creation is the crucial tool to enable governance and process innovation of this kind, particularly including citizens who are usually excluded from daily decision-making. As homeowners and sometimes investors, as prosumers and users whose behaviour matters for the final energy balance, citizens are at the heart of PENs. Therefore, their involvement is crucial. This not only helps citizens to build their trust in PEN technologies and processes, and to use and feel ownership of the integrated energy and mobility solutions offered in their neighbourhood, but it also helps in harvesting their ideas, wishes and perspectives. Thus, social innovation and participatory culture are not just a “nice-to-have”, but are in fact key puzzle pieces in building a successful PEN.

PEN TECHNOLOGY

1. **Collective electricity generation** Neighbourhood-scale PV across buildings enables shared renewable energy production and reduces reliance on fossil fuels.
2. **Decarbonised heat systems** Heat pumps and low-temperature systems replace fossil heating and improve energy performance.
3. **Deep renovation** High-performance building envelopes reduce energy consumption and improve comfort and indoor air quality.
4. **Industrial renovation** Prefabricated elements enable faster, scalable renovations with less disruption for residents.
5. **District energy networks** Local heating and cooling networks connect buildings and integrate renewable and waste heat sources.
6. **Smart e-mobility** Electric vehicles and charging infrastructure integrate with the energy system and provide flexibility.
7. **Collective energy storage** Shared batteries store excess renewable energy and support grid stability at neighbourhood level.
8. **Smart energy management** Digital systems optimise energy use, storage and demand in real time across the neighbourhood.
9. **Climate adaptation** Green infrastructure reduces overheating, improves comfort and enhances urban resilience.
10. **Material reuse systems** Local hubs store, sort and redistribute reusable construction materials from renovations.
11. **Shared mobility hubs** Integrated mobility services reduce emissions and connect energy, transport and urban planning.
12. **Data-driven optimisation** Monitoring systems enable better planning, performance tracking and system optimisation.

ORGANISATIONAL MODEL

13. **Public-led planning** Municipalities plan, coordinate and align neighbourhood interventions with policy goals.
14. **Housing-led model** Social housing providers coordinate large-scale renovations and ensure inclusion of vulnerable households.
15. **Citizen energy ownership** Residents collectively own and manage renewable energy assets and infrastructure.
16. **Shared benefits** Costs, savings and revenues are distributed across the neighbourhood
17. **Innovation & validation** Research organisations test, monitor and validate technologies and system performance.
18. **One-stop shop support service** Local services guide and accompany citizens on renovation, financing and energy decisions.
19. **Circular value chains** Local actors manage material reuse, logistics and secondary material markets.
20. **Public-private partnership** Collaboration between public authorities, companies and communities.
21. **System operation** Grid operators and energy providers manage integration, flexibility and system stability.

CO-CREATION

22. **Co-creation processes** Residents shape solutions through workshops, consultations and neighbourhood activities.
23. **Active prosumers** Residents produce, consume and manage energy as active participants in the system.
24. **Multi-actor governance** Public, private and civic actors collaborate in new governance structures.

Positive Energy Neighbourhood ecosystems

Positive Energy Neighbourhoods in oPEN Lab

The oPEN Lab project aims to identify replicable, commercially viable solution packages to enable the creation of PENs within existing urban contexts. Various solutions have been tested and integrated into local energy systems in three lighthouse neighbourhoods: Genk (Belgium), Pamplona (Spain) and Tartu (Estonia). These have served as test beds for addressing technical, regulatory, financial and social challenges relating to PENs. Using a Living Lab approach, local communities, researchers, public authorities and industry partners have co-created solutions that integrate PEN aspects such as deep renovation, renewable energy, storage, e-mobility, and flexible demand systems. The project is building on the concept of open innovation ecosystems (i.e. collaborative networks of actors who are hierarchically independent yet interdependent) to design, implement and replicate PENs that are inclusive and adaptable to local needs. None of the lighthouse neighbourhoods so far meets the project's definition of a fully operational PEN. Instead, they are all at different points in their development, reflecting their local contexts, institutional capacities and policy conditions.

oPEN Lab also explores different aspects of governance, organisational and capacity-building models. For example, its organisational models use an approach that considers governance structure (roles and responsibilities), operational models (management of energy generation or distribution), financial models (mechanisms and business models) and ownership structures (for infrastructure).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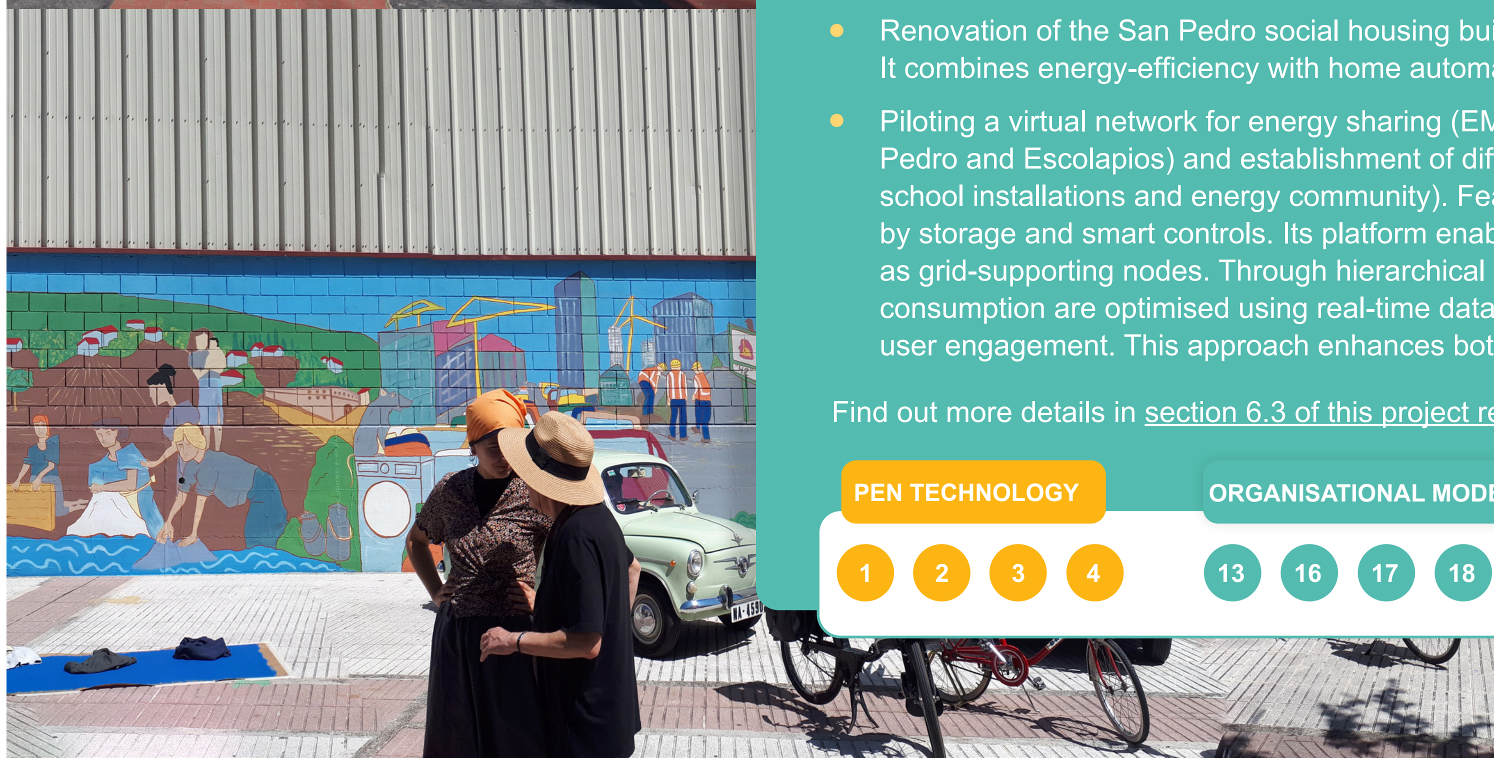


oPEN Living Lab Pamplona, Spain

Pamplona's Living Lab aims to activate a citizen-driven energy transition in the historic district of Rochapea through building retrofits, flexible energy systems, and a virtual local energy community that shares energy between two pilot sites: San Pedro (municipal social housing) and the La Compasión school. It links municipal climate planning with bottom-up governance that shows that the establishment of a PEN can emerge through a set of independent initiatives at a neighbourhood level.

Technology

The innovation lies in the creation of a citizen energy community, supported by the city and region. The focus is on a Renewable Energy Community, which gives a share of their energy production to energy-poor residents. It also incorporates bioclimatic design principles, and has a strong emphasis on community engagement.

Organisational model

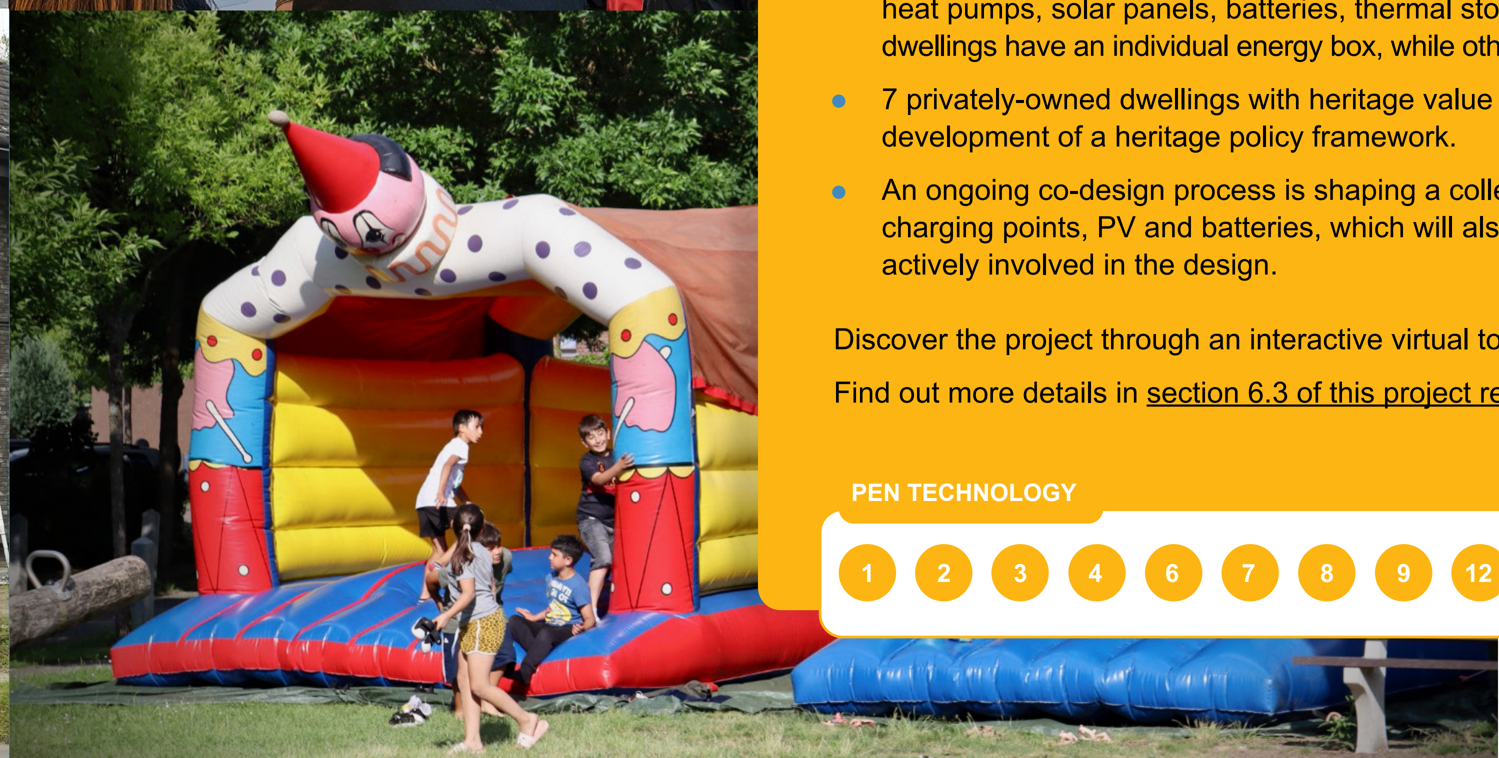
The key actors are Pamplona City Council who lead local policy integration and own the San Pedro building, and La Compasión Escolapios who own the school and make final decisions on renovation solutions. AHA is the local coordinator of the Living Lab. UPV/EHU is the academic partner leading on technical innovation, social innovation and citizen engagement (co-led with the city council). CENER is a research centre providing technical expertise in renewable energies and energy management. The industrial partner OBENASA supports the PEN development in retrofit delivery.

Achievements

- Creation of a citizens' energy community and an industrial energy community
- Activation of the local community and creation of an engaged and involved community including through collaborative murals to raise awareness about the need for change (energy and social transition needed in the district), and a community consultation on how to do it. Development of interactive local maps to collect data on citizens' views. Establishment of a local energy festival (by the district for the district) as an information and knowledge exchange hub for activities being carried out in the district.
- Promotion of new citizen-led local projects related to the transition of the district towards a PED, such as the project Txio Txio on local biodiversity, four new collaborative murals to continue the work of the first one, a vertical garden, implementation of new PV installations.
- Renovation of the San Pedro social housing building dedicated to people with disabilities. It combines energy-efficiency with home automation, and social inclusion. Find out more.
- Piloting a virtual network for energy sharing (EMS) between different buildings in the district (San Pedro and Escolapios) and establishment of different levels of energy coalitions in the district (e.g. school installations and energy community). Features a PV-dominant neighbourhood supported by storage and smart controls. Its platform enables collective energy sharing, treating buildings as grid-supporting nodes. Through hierarchical energy management, generation, storage and consumption are optimised using real-time data and forecasts, balancing technical efficiency with user engagement. This approach enhances both energy performance and occupant comfort.

Find out more details in section 6.3 of this project report on PEN organisational models.

PEN TECHNOLOGY	ORGANISATIONAL MODEL	CO-CREATION
1 2 3 4	13 16 17 18 20	22 23 24



oPEN Living Lab Genk, Flanders, Belgium

The Genk Living Lab is focused on industrialised deep renovation in two distinct neighbourhoods: Nieuw Texas, a low-income, post-industrial area; and the heritage value district of Garden City Waterschei. The city of Genk, the local social housing company, research institutes and local partners collaboratively designed a renovation strategy for houses. This strategy integrates technological innovations such as prefabricated modules with social innovations such as participatory design processes. The goal is to transform the existing neighbourhood into a PEN, improving energy performance, community cohesion and residential comfort.

Technology

Genk is piloting prefabricated façade modules, digitalised renovation workflows, optimal control of innovative building systems at both individual household and neighbourhood level, and micro-collective energy solutions (where one installation serves from two to four houses) within social housing blocks for heating and cooling. Within the Garden City district, the project has supported private homeowners from socioeconomically vulnerable backgrounds in renovating their homes to make them into energy-efficient A-label dwellings, while respecting the district's protected heritage framework.

Organisational model

Throughout the renovation phase there has been intensive collaboration between tenants, homeowners, public authorities (such as the City of Genk, the social housing company Wonen in Limburg, and Stebo), research institutions (VITO), and industrial partners. This co-creation approach has generated valuable insights into how different ownership structures and shareholders can be engaged and supported in the transition towards fossil-free, resilient neighbourhoods.

Ongoing accessible guidance has proved to be crucial for helping vulnerable residents through the renovation phase, and also in teaching them how to use advanced HVAC systems. Group sessions, personal home visits and simple tools like fridge cards build confidence and understanding, supported by a visible neighbourhood presence and trusted contact points. Together, these elements form a people-centred model that turns technical innovation into lasting social impact.

Achievements

- 27 social housing dwellings have been renovated to an A-label with state-of-the-art technological systems. Each dwelling has a unique set of technical systems installed in an energy box, including heat pumps, solar panels, batteries, thermal storage, ventilation and monitoring equipment. Some dwellings have an individual energy box, while others are shared between two, three or four dwellings.
- 7 privately-owned dwellings with heritage value are being renovated to an A-label, guided by the development of a heritage policy framework.
- An ongoing co-design process is shaping a collective neighbourhood infrastructure with EV charging points, PV and batteries, which will also function as an information point. Local artists are actively involved in the design.

Discover the project through an interactive virtual tour: Open Lab Project – Virtual Tour.

Find out more details in section 6.3 of this project report on PEN organisational models.

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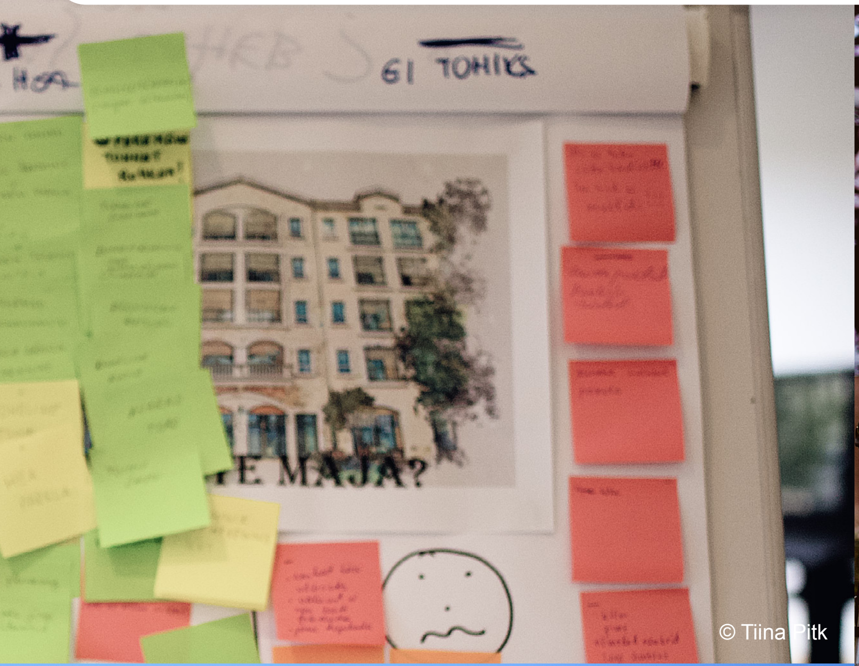
ORGANISATIONAL MODEL: 13 17 20

CO-CREATION: 22 23 24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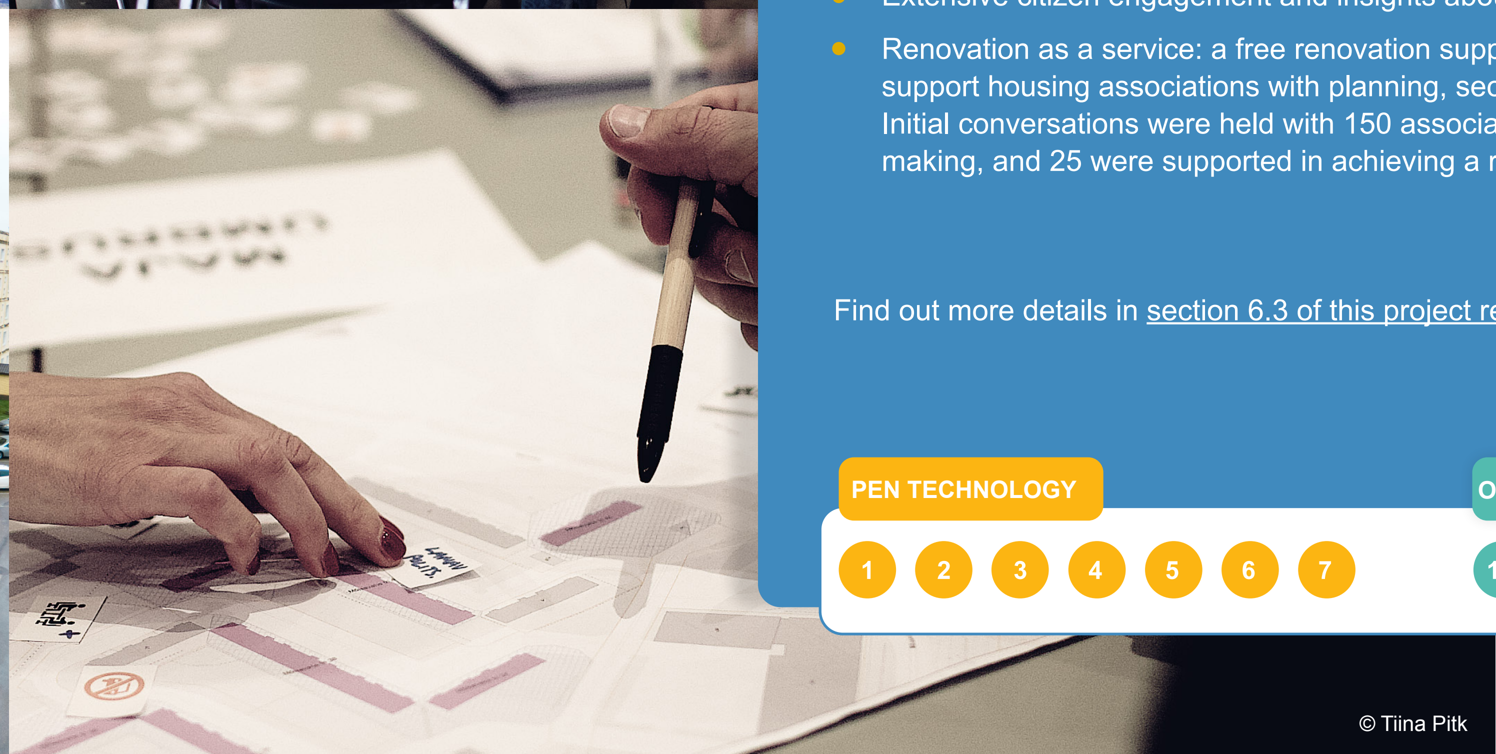
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oPEN Living Lab Tartu, Estonia

Tartu's Living Lab focuses on innovative industrialised renovation and prefabrication, as well as ventilation and smart digital energy systems, through deep renovation. The project places a strong emphasis on behavioural change, load management, and demand-side flexibility to maximise energy efficiency and resident engagement. The pilot buildings are both five-storey, Soviet-era apartment blocks in a critical state in Annelinn, the densest and largest district of Tartu, with buildings built between 1970 and 1990. 'Mõisavahe 67' is a city-owned social housing building which has had its renovations completed, and 'Uus 1' is a privately-owned building which is being renovated in the last year of the project (2026–2027). Both will produce and consume their own energy.

Technology

Both buildings are deep renovated using prefabricated panels to demonstrate their efficiency and feasibility for high-rise buildings. Thermal storage implemented to link with the local district heating area collects industrial residuals, surplus from air conditioning and renewables, and excess PV electricity that has been converted to heat; connected through a community heat network it acts as a buffer that balances generation and consumption, with its effectiveness increasing as the network grows and diversifies. Integrated PV is implemented for the first time in Estonia. PV panels are complemented with battery storage, smart metering, and EV chargers.

Tartu also aims to create a digital twin for a representative high-rise residential neighbourhood.

Organisational model

In a multilevel model, key actors include the City of Tartu which acted as initiator and catalyst, PEN coordinator, and facilitator of actors and information. Eesti Energia and TREA are the energy service providers and local energy advisors who support technical validation. TalTech provided research and technical support, especially on the prefabrication; while the Institute of Baltic Studies (IBS) and the University of Tartu led on the involvement of residents and co-creation activities. Housing associations hold final voting power on renovation activities.

Achievements

- Renovation of pilot building Mõisavahe 67 to EPC A, integrated PV panels on façade, joint electricity use inside apartments.
- Extensive citizen engagement and insights about social acceptance.
- Renovation as a service: a free renovation support service for apartment buildings which aims to support housing associations with planning, securing funding, capacity-building and information. Initial conversations were held with 150 associations, 50 associations were supported in decision-making, and 25 were supported in achieving a renovation.

Find out more details in <u>section 6.3 of this project report</u> on PEN organisational models.

PEN TECHNOLOGY: 1 2 3 4 5 6 7

ORGANISATIONAL MODEL: 13 16 17 20

CO-CREATION: 22 23 24

Positive Energy Neighbourhoods in the EU policy framework

During the 2019–2024 EU policy cycle, core work was done to set a framework that aligns European regulations and directives with stronger climate and energy targets. PENs themselves are not explicitly mandated in EU law, yet the neighbourhood is increasingly being recognised as an effective level at which to make interventions.

PENs represent a cross-sectoral approach to renovations, energy provision and urban planning whose value proposition rests on the synergies between these areas. PENs can help to achieve a range of policy goals, including climate mitigation, climate adaptation, increasing renovation rates and the share of renewable energy, supporting smart electricity grids and demand-side flexibility, reducing fuel poverty, and improving social cohesion and community engagement. As a result, PENs concern various policy fields and can guide their direction and ambition.

How the neighbourhood approach is already integrated in EU policy

Policy	Renovation Wave Strategy	Energy Efficiency Directive (EED)	Renewable Energy Directive (REDIII)	Energy Performance of Buildings Directive (EPBD)	Affordable Housing Plan (EAHP)
Date and type	**2020.** Communication	**2023.** To be transposed into national law by October 2025	**2023.** To be transposed into national law by October 2025	**2024.** To be transposed into national law by May 2026	**2025.** Communication
Relevance for PEN	Sets the intention for a 2% annual renovation rate. Has an entire section on placing an integrated, participatory and neighbourhood-based approach at the heart of the Renovation Wave.	Requires Member States to do a heating and cooling assessment (Article 25), identify the potential for efficiency in heating and cooling which includes considerations of economic and physical potential. Member States are also to take measures to develop district heating and cooling infrastructure. Article 26 sets out criteria for an efficient district heating and cooling system. Supports the creation of One Stop Shops (Article 22).	Requires renewable acceleration areas where permitting for PV and wind, storage and grid upgrades are fast-tracked. Encourages district heating decarbonisation, local flexibility, and different forms of energy-sharing.	Zero-emission buildings can achieve compliance at district level, facilitates installation of shared renewables. National Building Renovation Plans (NBRPs, draft versions were meant to be officially submitted to the Commission by the end of 2025 for review) require the promotion of neighbourhood approaches and the identification of neighbourhoods with the greatest renovation potential as well as energy-poor districts.	Regeneration of neighbourhoods and improved access to funding for community-led solutions are promoted via the New European Bauhaus. Renovations are prioritised over demolition to revitalise neighbourhoods. Neighbourhood energy communities and sharing are promoted.

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Positive Energy Neighbourhoods to close the current policy gap

EU policy could be implemented more effectively through a PEN approach. While the regulatory building blocks are in place, their effectiveness for mainstreaming PENs will depend on coherent national transposition, enabling market rules for actors, capacity on the ground and efforts for collective action, and the alignment of financial and governance frameworks. Member States have already indicated delays in implementing Fit for 55 policies such as the EED,[19] Emission Trading System 2 and the EPBD. Given the central role of quality buildings for societal resilience, this poses a serious risk. The construction sector depends on stable long-term signals, and regulatory uncertainty risks undermining renovation activity just when acceleration is needed. EU residents deserve to benefit from the various new social regulations and safeguards that these policies aim to put into place.

The EU policy framework has opened the door to neighbourhood-scale implementation of its core building policies. The next phase is to ensure solid operationalisation of PEN-like concepts to guide the implementation and ensure cost-effectiveness, citizen engagement, and the optimal combination of technologies and interventions to reduce whole-life-cycle emissions and increase building resilience.

Positive Energy Neighbourhoods for effective EU policy implementation

Four key sub-themes stand out that EU legislation could address through a PEN lens: inclusive energy renovation, decentralised and collective energy systems, demand-side flexibility and smart systems, and whole-life carbon decision-making.

For a detailed analysis of how these core principles are increasingly embedded in relevant EU policies and their compatibility with PENs, please consult Outline of the oPEN Lab policy roadmap.

Inclusive energy renovation

The revised Energy Performance of Buildings Directive (EPBD) marked a turning point by making it mandatory for Member States to promote the neighbourhood approach in their National Building Renovation Plans (NBRPs). Member States were meant to submit their draft NBRPs for review by the end of 2025 (although Spain is the only project country to have done so to date), and the final deadline is the end of 2026. Through mandatory requirements in Annex III of the EPBD for the NBRP template, Member States are encouraged to shift perspective away from individual buildings and towards the neighbourhood level. Minimum energy performance standards, the zero-emission building trajectory and mandatory smart technologies all create regulatory drivers for bundled renovations and integrated energy systems.

Decentralised and collective energy systems

The Renovation Wave, the Fit for 55 package, REPowerEU, and most recently the Citizen Energy Package, have gradually introduced and strengthened regulations and policy intentions to better enable neighbourhood-scale energy solutions (e.g. energy sharing, renewable energy communities). REDIII in particular improved this foundation by raising renewables targets and formalising frameworks for renewable energy communities and collective self-consumption. Although implementation challenges remain, the directive recognises collective production, sharing and system integration as legitimate pillars of the energy transition. The introduction of renewables acceleration areas aligns with the PEN approach.

Demand-side flexibility and system integration

The revised EED complements these measures by broadening the Energy Efficiency First principle to include demand-side flexibility and system integration. Its strengthened focus on energy poverty and public-sector leadership reinforces the social dimension of neighbourhood approaches, thus positioning PENs as key tools for a just transition.

Whole-life carbon decision-making

The revised EPBD introduces a harmonised methodology to calculate life-cycle Global Warming Potential, marking a first step towards integrating whole-life carbon into EU building policy, though it currently focuses mainly on new buildings. To facilitate the reuse and recycling of building components across the EU and reduce embodied emissions from virgin materials, the 2025 European Strategy for Housing Construction sets an intention to create a single market for secondary construction materials.

Towards inclusive energy renovation

Neighbourhood-level energy renovation can cut bills, emissions and health risks, but they need to be people-centred to be scaled.

Improving the energy performance of Europe's buildings remains one of the most effective ways to cut emissions, lower bills and strengthen energy security.[20] One in four Europeans live in homes with poor indoor air quality, and upgrading Europe's inefficient housing stock could reduce illness and deliver societal benefits valued at €194 billion.[21] However, renovations remain inaccessible for many who need them most; around one in three Europeans struggle with energy bills, and more than 41 million people are living in energy poverty.[22]

Collective approaches enable costs and benefits to be shared more fairly, enable joint procurement, link renovation with social services and provide targeted engagement, making it easier to reach the worst-performing buildings and low-income residents. Energy poverty, high upfront costs and limited access to information or financing are rarely individual problems. They are structurally concentrated in specific building types, tenure models and urban areas. Addressing them building by building risks excluding vulnerable households, increasing inequalities, and losing opportunities to make economies of scale. Clusters of poorly-performing buildings present a particularly strong opportunity for collective renovations in theory, but this is often challenging in practice due to fragmented ownership issues. The social housing sector provides a chance to test and upscale innovative renovation methods.

oPEN Lab shows that citizens need to be at the heart of neighbourhood innovations for them to be successful. Across all the Living Labs, citizen engagement emerged as a continuous process rather than as a one-off consultation. Building trust, gathering feedback and adapting solutions required dedicated time and resources.

In Tartu, it became clear that local cultural contexts shape acceptance levels and must be understood early in the process. In Genk, renovating while residents remained in their homes was possible, but only with high levels of communication, transparency and trust-building. Honest communication about expected disruptions, clear timelines and accessible contact points proved essential. Providing temporary quiet spaces during the most intensive works further reduced stress and improved acceptance.

Prefabricated renovations to support people-centred PENs

Deep renovation can be delivered through a range of construction models, and the choice of approach has direct implications for cost, speed, social impact and scalability. Industrialised construction as alternative to traditional methods refers to an overarching construction approach that integrates increased elements of automation and mechanisation into construction processes. It describes an industry-wide shift from traditional, labour-intensive methods to a more standardised, product-based production process. This shift includes moving parts of construction from on-site to factory settings, increasing the use of digitalisation, automation and standardisation, and integrating processes such as quality control and health and safety directly into operations.

Nevertheless, industrial approaches currently face a competitive disadvantage against traditional building methods, such as high upfront costs, fragmented demand, or underdeveloped supply chains. Industrial renovation provides a number of benefits such as cost savings (standardised solutions reduce design and on-site costs) and on-site time savings (components can be built off-site). Time and cost savings are crucial for PENs. Thus, PENs provide a key market opportunity for industrial renovation, in particular prefabricated renovations. Especially in the case of social housing it's crucial that tenants can either stay in their homes or are displaced for a minimal amount of time only. The project found that prefabricated integrated timber walls, prefab-as-a-service, and the energy box in Genk emerged as promising solutions as they can be directly integrated into the market and also promote resident comfort during renovation work. Experience from the pilots also showed the relevance of user perception and the need for a high level of communication and information-sharing with residents and owners.

For more information, please consult [this report] on optimisation of the prefabrication process through digitalisation.

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Scaling inclusive energy renovations across neighbourhoods in the EU

Current barriers	Explanation	Policy solutions
PEN renovations involve high upfront costs and complex fragmented subsidy schemes.	Grants mostly do not prioritise the worst-performing buildings, which are often occupied by the most vulnerable people. If public funds were to prioritise this building category and social demographic, remaining funds could leverage private investment via green loans, zero-interest loans and pay-as-you-save schemes, allowing households to spread upfront investment costs and repay them from energy savings.	**The EU** should support MS in simplifying and harmonising renovation schemes and provide best practices on private finance mobilisation and public guarantees. **Member States** should ensure that NBRPs outline long-term renovation loans with state guarantees, low-interest rates, and clear criteria that prioritise low-income groups. **Municipalities** should ensure that neighbourhood One Stop Shops are accessible and provide technical and practical support for the entire cycle of PEN activities, including financial applications, tendering and execution.
Limited governance capacity in home-owner associations (HOAs) makes it difficult to reach agreements about renovations.	HOAs are often voluntarily run and should be more targeted for capacity-building and information campaigns to address the fears and questions of residents. You can find more information on the role of HOAs here.	**Member States** should plan long-term funding training for HOA boards and simplify collective decision-making. **Municipalities** should create municipal renovation support teams, and offer joint procurement assistance and mediation.
Vulnerable households are often excluded from renovation and energy projects.	Vulnerable groups are often unable to benefit from dedicated grants and subsidies because they are not able to access commercial loans. Residents may also fear debts. Dedicated financing solutions should be tailored to income and energy vulnerability, e.g. funding for the lowest income groups and the energy-poor, guarantees for loans for lower-income groups.	**The EU** should evaluate NBRPs to ensure they have clear tiered financial support for households of different vulnerability levels and prioritise subsidies for vulnerable areas with poor energy performance. **Member States** should design upfront grant schemes for low-income households. **Municipalities** should ensure that social services are integrated into renovation planning besides providing renovation advice and financing solutions.
Urban planning, heritage and energy regulations are not aligned.	Balancing heritage protection with innovative energy renovation measures and affordability remains complex due to conflicting aesthetic, technical and economic requirements.	**Member States** should coordinate heritage and energy efficiency rules and allow flexibility for deep renovation in protected areas. **Municipalities** should provide integrated permitting pathways for neighbourhood projects.
There is limited long-term citizen engagement and of trust-building mechanisms.	Residents often lack accessible information and tailored support, making it difficult to build engagement for collective renovation projects. Buildings with a resistant culture need a more individual, one-on-one approach with each apartment owner. Residents should have the option to play through all the scenarios themselves to address their fears.	**Member States** should prioritise an interpretation of Article 18 in the EPBD on One Stop Shops which enables on-site One Stop Shops that can tackle mistrust in democratic institutions as well as offering simple renovation advice. **Municipalities** should establish One Stop shop functions that integrate technical, financial and social guidance while connecting policymakers, technology providers and residents. **Municipalities** should plan budget and capacity for long-term engagement with residents prior to renovation.
Social tenants with financial difficulties who rely on heat pumps may face electricity power limitations or disconnections during winter, causing their heating systems to switch off. In contrast, households using gas heating are often legally protected from winter disconnection.	This unequal protection between fossil and electric heating systems poses an unnecessary market barrier for electric heating solutions.	**Member States** should extend winter disconnection protection to all primary heating systems, including electric heat pumps, and provide tailored financial and technical support to ensure uninterrupted heating for vulnerable households.
Current regulations and subsidies do not recognise the benefits of prefabricated renovations and provide no incentives to promote them.	Current building codes, subsidy schemes and especially procurement rules are largely designed around traditional on-site construction methods. As a result, industrialised renovation approaches such as prefabrication are rarely incentivised or systematically supported. This is despite their benefits of reducing costs, shortening renovation timelines and minimising disruption for residents. Lower permit fees for prefabricated renovations could create an incentive.	**The EU** should ensure that the revised Public Procurement Directive provides the blueprint for Member States to award the 'most advantageous' over the most economically favourable (see changes in Switzerland's public procurement law for inspiration). **Member States** should condition subsidies to favour market expansion of industrial renovation practices. **Municipalities** should better use public procurement to create targeted stable demand for industrial renovation solutions such as prefabrication. **Municipalities** should use tiered permit fees.
There is a lack of structural policy integration of PENs within national and local renovation strategies, as well as insufficient systematic screening of the building stock.	Many renovation strategies still focus on individual buildings rather than on neighbourhood clusters, and data on the worst-performing buildings is often incomplete or fragmented. Without systematic screening and explicit integration of neighbourhood approaches in renovation plans, opportunities to coordinate large-scale renovations and implement PENs remain largely untapped.	**Member States** should explicitly include the neighbourhood approach in NBRPs with long-term objectives, measurable indicators and methodologies to establish systematic screening and monitoring at neighbourhood level. **Municipalities** should link neighbourhood-oriented renovations to green infrastructure, the circular economy, sustainable mobility, and heating/cooling networks, so that renovations become part of a holistic urban development plan.

Towards decentralised and collective energy systems

Energy-sharing can turn neighbourhoods into clean, more self-sufficient energy hubs, but only when clear rules and fair governance allow citizens to collectively invest and share the benefits.

Decentralised renewable energy is becoming increasingly important to Europe's energy transition and security. As of 2022, the renewable energy share in buildings reached 28.9%.[23] The oPEN Living Labs show that neighbourhood-scale solar technologies, collective heat pumps and shared storage reduce dependence on fossil fuels. For example, Genk tested micro-collective energy solutions with one technical installation (heat pump, PV, battery, ventilation unit and buffer tank) connected to multiple houses (two to four). This supports the overall optimisation of energy production, storage and use, while reducing investment costs and increasing efficiencies. REDIII recognises this potential by strengthening collective self-consumption (CSC) and renewable energy communities (RECs), and by requiring Member States to create renewables acceleration areas where permitting must be fast-tracked. However, across the Living Labs, a lack of clarity in the legal framework and market confusion between RECs, CSCs and Citizen Energy Communities, regulated in the Electricity Market Design directive, made implementation difficult. National transposition remains inconsistent. In many Member States CSC remains limited to single buildings; this does not allow horizontal energy sharing with neighbours, which limits profitability. Only in a few cases, such as in Spain, was the geographical range for sharing extended. This fragmented and restrictive implementation, combined with unclear definitions and overlapping concepts, creates structural barriers and legal uncertainty for energy-sharing within PENs.

Collective energy systems require clear governance structures and administrative support. Under current national frameworks, energy-sharing across multiple buildings generally requires the establishment of a REC as a legal entity, which brings with it additional administrative burdens. The oPEN Living Lab shows that where municipalities or project partners take on coordination roles, complexity can be reduced. In Pamplona, the municipality led the formation of the REC and simplified legal and administrative matters; in Genk, project partners handled technical integration, shielding residents from legal procedures. In countries where energy-sharing rules are not well developed, homeowner associations require dedicated support, for example through One Stop Shops, to navigate the legal, technical and administrative complexities involved. Moving from individual to collective energy reshapes roles and responsibilities. Collective PV or storage requires new governance models that change the ways in which homeowner associations and municipalities, DSOs and utilities interact, with citizens becoming active prosumers and decision-makers.

Fair cost allocation and tariff reform are essential for socially sustainable energy sharing. There are concerns that CSC might create distributional issues that are often not addressed by current tariff design. Large volumes of locally shared energy can reduce the number of consumers paying volumetric grid fees. This shifts costs onto those unable to participate in energy-sharing models, who are often among the most vulnerable. This risk of unfair cost-shifting reinforces the need for grid tariff reform. Without tariff structures that recognise local system benefits, the business case for neighbourhood energy solutions remains limited. For more information, please consult this policy brief on fair allocation of energy network costs. With the Citizen Energy Package published in March 2026, the Commission is taking steps to ensure that network tariffs are lowered and to boost energy-sharing.

Overview of the different types of energy sharing in EU legislation that are relevant for PEN

Renewables self-consumers	**Article 21, REDII**	'A final customer […] who generates renewable electricity for its own consumption, and who may store or sell self-generated renewable electricity, provided that, for a non-household renewables self-consumer, those activities do not constitute its primary commercial or professional activity.'
Jointly acting renewables self-consumers (collective self-consumption)	**Article 21, REDII**	A group of at least two cooperating 'renewables self-consumers […] who are located in the same building or multi-apartment block' or, where permitted by a Member State, within other premises.
Renewable energy community	**Article 2(16), REDII**	A legal entity, based on open and voluntary participation, autonomously controlled by shareholders or members in proximity to renewable energy projects, consisting of natural persons, SMEs or local authorities, with the primary goal of delivering environmental, economic, or social community benefits rather than financial profits. They are limited to renewable energy systems (heat and electricity) and rooted in the local community.

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Enabling collective energy sharing across neighbourhoods in the EU

Current barriers	Explanation	Policy solutions
Legal ambiguity around collective self-consumption inhibits its attractiveness to citizens.	Clear and detailed national law that differentiates RECs and CSC is crucial.	**The EU** should clarify the different energy-sharing models in the energy community action plan, promised in the Citizen Energy Package. **Member States** should create a clear legal definition for CSC and RECs where these evidently remain confusing.
Vertical energy-sharing is not possible in some Member States, which only allow shared energy in communal spaces such as hallways.	Regulations need to allow for vertical energy-sharing and for CSC without requiring the entire apartment building to agree on one energy contract.	**Member States** should review their transposition of REDIII to legalise virtual and physical energy-sharing *within* buildings.
Horizontal energy-sharing across buildings is not included in the CSC concept.	While some countries already allow for vertical energy-sharing, horizontal sharing is not considered in many regions, including Flanders. As long as energy-sharing only works within apartment buildings due to restrictive regulation, there is no business case for PENs.	**Member States** should review their transposition of REDIII and legalise virtual and physical energy-sharing *between* buildings in direct proximity.
Municipal capacity is often too limited to support RECs, especially if governance between planning, housing and energy is fragmented.	Pamplona and Genk could support REC development but structural funding for RECs is needed to reduce the large dependency on project funding which keeps projects such as oPEN Lab in a pilot trap.	**Member States** should support resource availability for REC development via the long-term stable financial support of One Stop shops. **Municipalities** could create cross-department expert groups that can meet ad hoc on specific topics like RECs with a facilitator. Integration of a REC advice service into One Stop shops is crucial.
The banking system perceives PEN projects as innovative and complex – and thus financially risky.	Improved data collection at all stages of the PEN renovation process can also reduce investment risk. Special purpose vehicles, whether integrated within RECs or operating independently, can help to isolate risk and aggregate investment. For more information, please consult Enabling financing for neighbourhood renovations.	**Member States** should develop guarantee schemes for community energy, and support banks in providing standardised financial assessments.
Lack of access to ESG and blended finance for energy communities.	The social and environmental co-benefits of PENs and RECs are not acknowledged due to a lack of evidence-based and harmonised compliance methods. Identifying and quantifying social impacts through evidence-based tools and methods can support ESG compliance and reporting.	**The EU** should align REDIII implementation with the EU sustainable finance taxonomy and clarify the eligibility of RECs for green and social finance instruments. **Member States** should develop standardised social and environmental reporting templates for RECs, and enable access to national green banks and climate funds. **Financial institutions** should develop tailored financing products for CSC and community storage.
Energy-sharing frameworks do not automatically include vulnerable households such as the energy-poor.	Energy-sharing must integrate social inclusion by design.	**Member States** should mandate the inclusion of vulnerable households in community energy schemes and allow social tariffs within RECs. **Municipalities** should identify eligible households and facilitate their participation through local social services.
High network tariffs and market design limit the business case for energy-sharing.	There is limited recognition of local flexibility services. Market design and tariff structures must reward local generation and flexibility.	**Member States** should adapt grid tariffs to avoid double charging, enable dynamic pricing, and make local flexibility markets accessible to RECs. **DSOs** could develop mechanisms for neighbourhood-level flexibility procurement (e.g. batteries, aggregated demand response).
Administrative and regulatory fragmentation increases transaction costs.	Energy communities face complex permitting, grid access procedures and tax rules, grid connection delays, and licensing requirements that differ across regions. There is no reinforcement of DSO obligations to share data with active consumers and RECs.	**Member States** should develop standard contracts and model structures for the ownership and management of shared installations (e.g. 'energy boxes', neighbourhood batteries, micro-collective systems). **Member States** should impose time-bound grid connection processes with penalties. Cities should implement the renewables acceleration areas of REDIII for faster permitting processes. **Municipalities** should facilitate local coordination between planning, grid operators and energy communities.

Towards demand-side flexibility and system integration

Neighbourhood-scale aggregated flexibility can relieve grid stress and optimise energy consumption, but only if markets and grid tariffs reward communities for the system value they create.

Flexibility is becoming essential as electrification accelerates and grids age. Electricity demand is rising rapidly in the EU as heating, mobility and industry electrify. At the same time, around 40% of Europe's distribution grids are over 40 years old, and an estimated €584 billion in grid investment will be required by 2030 to modernise and expand infrastructure.[24] As variable renewable energy sources such as wind and solar grow, the challenge is no longer only to produce clean electricity, but to use it more intelligently. Shifting consumption towards periods of high renewable generation reduces the need for costly storage and avoids peak loads that strain local grids. Thus, flexibility as a strategy to optimise time and place of electricity use is becoming essential, particularly through demand-side flexibility (i.e. the ability of a consumer to react to an external signal to shift their consumption or generation pattern).

The neighbourhood scale is where flexibility becomes technically meaningful, but regulatory barriers limit its value. Aggregated demand response, smart meters, integrated energy management, shared batteries and EV charging can significantly reduce the need for grid reinforcement. Grid constraints typically occur at the low-voltage feeder or transformer level, thus local optimisation is needed. oPEN Lab aimed to provide energy flexibility services and include smart controls to realise this potential. However, flexibility as a service disrupts current power market dynamics. Coordination with the DSO is needed for active monitoring and energy-sharing, yet there are currently limited incentives for DSOs to invest in decentralised flexibility rather than in traditional grid reinforcement. In Tartu, cooperation with the DSO was ongoing but it highlighted the fact that regulatory barriers limit the monetisation of flexibility aggregation – and therefore the PEN business case.

Nevertheless, most Member States still lack accessible flexibility markets or tariff structures (e.g. dynamic tariffs) that reward active participation. Except for in a handful of Member States, distribution tariffs for households remain volumetric (€/kWh), offering no incentive to shift load to system-friendly times. Without accessible flexibility markets and tariff reform, communities cannot capture the system value they generate. In the future, DSOs could evolve from being passive grid operators to active system orchestrators that procure and coordinate neighbourhood flexibility as a core infrastructure service.

Digital integration, automation and citizen engagement must evolve together for system integration to succeed. Neighbourhood-scale flexibility is both a technical and a governance challenge because it requires digital integration, clear roles for communities, and regulatory frameworks that reward collective local flexibility. oPEN Lab experimented with the operational control and integration of multiple energy technologies to optimise system performance at a neighbourhood scale. In Genk, system-wide automation and control were deployed, but remained partly incompatible with existing regulatory processes and standard market rules, limiting scalability. An analysis across Living Labs showed that the smart integration of energy devices is not yet scalable due to the lack of harmonised interfaces and standard control protocols.

Genk focused on automated control systems to reduce the burden on tenants, yet a minimum level of manual control remained essential to ensure acceptance and trust. For example, residents must be able to override their ventilation system in case of smells or smoke in the neighbourhood. At the same time, user-friendly tools such as the Loomy Lamp, a lightbulb that changes colour depending on PV production, help residents shift consumption to periods when cheap solar power is available. A key finding across Living Labs was that user engagement is as critical as technical optimisation in determining the success of integrated energy systems. This underlines the need for user-centric design and closer collaboration with social scientists in the development of automated neighbourhood energy systems.

Unlocking neighbourhood-scale flexibility across the EU energy system

Current barriers	Explanation	Policy solutions
Flexibility potential in buildings exists but is often not activated due to regulatory ambiguity.	DSOs might prioritise larger industrial sites as hubs for flexibility over the decentralised and smaller aggregated capacity of flexibility from citizens.	**Member States** should clarify flexibility rules to include clear procedures, deadlines and responsibilities for CSC, and REC/CEC participation in energy markets. EMD and EED provisions for DSOs to consider flexibility in grid planning and investments should be implemented.
Grid tariffs fail to incentivise flexibility.	To strengthen the business case for PENs it is crucial that local flexibility is realised and monetised. For example, tariff structures can be adjusted so that collective batteries are not charged twice and can contribute profitably to local energy-sharing.	**Member States** should introduce cost-reflective tariffs, enable peak-reduction rebates, and remove double tariffs for energy storage. **Member States** should provide public guarantees for community storage.
Often citizens cannot legally participate in flexibility markets.	There are also concerns that benefits bypass vulnerable households.	**Municipalities** could set incentives for PENs/RECs to include energy-poverty programmes, for example by public financing for vulnerable households' share.
There is insufficient insight into the capacity of distribution grids at neighbourhood level.	This causes delays in investments in solar panels, charging stations and batteries.	**Member States** should require DSOs to publish transparent data on transformer capacity, in line with the EMD. This will give local authorities, energy cooperatives and citizens clarity on where additional generation or storage is possible.

Towards whole-life-cycle decision-making

Neighbourhood-scale renovation can significantly reduce emissions, but only if decisions for renovation depth, renewable investment and material choices are guided by Whole Life Carbon and not operational performance alone.

Operational energy savings alone are not enough to meet Europe's climate targets. The construction sector accounts for 50% of all extracted materials and generates over 35% of total EU waste.[25] Material-related emissions represent a substantial share of national greenhouse gas (GHG) emissions; greater material efficiency could save 80% of the emissions associated with the sector (5–12% of total national GHG emissions). The revised EPBD now requires Member States to calculate and report the whole-life-cycle global warming potential of new buildings using a harmonised methodology (delegated act adopted in December 2025). This is crucial, especially as under the Affordable Housing Plan a wave of new housing construction is expected. Yet a substantial part of any PEN intervention focuses on renovations, where there are no such mandatory assessments. Without systematic Whole Life Carbon analysis, there is a risk of burden-shifting, where deep renovation or large PV installations may reduce operational emissions while increasing embodied emissions. This fine balance needs to be carefully considered.

Whole Life Carbon assessment is essential to guide choices over renovation depth and technology. Results from internal oPEN Lab analysis have shown that a whole-life-cycle analysis is necessary to evaluate the trade-offs between operational energy savings and embodied impacts. In several cases, individual building elements such as roofs dominated the overall life-cycle profile, demonstrating how specific design decisions can significantly alter total emissions. PVs can reduce operational carbon but increase embodied impacts, depending on system size and material intensity. This makes collective neighbourhood energy infrastructure (e.g. sharing a neighbourhood battery) even more necessary.

Furthermore, green infrastructure in neighbourhoods can be integrated into PEN planning to contribute as a carbon sink and offset some additional emissions. Importantly, occupant comfort and social outcomes which are not captured in standard life-cycle analyses must be considered alongside carbon metrics. Ultimately, balancing operational performance, embodied impacts and social factors is key to climate-aligned neighbourhood design.

PENs can accelerate the use of secondary construction materials because neighbourhood projects create scale, predictable material flows, and shared infrastructure. Because PENs intervene across multiple buildings simultaneously, they generate more predictable material flows and create economies of scale for reused components that enable secondary material markets to emerge. While individual renovations rarely create sufficient demand for reused components, neighbourhood projects can justify investments in sorting, storage and reuse logistics. This creates the conditions for reducing embodied carbon at scale. However, markets for secondary materials remain underdeveloped. Recycled materials often lack recognised certification, creating reluctance among developers despite meeting technical standards. Pamplona decided against the use of second-life batteries, because they were more expensive than new ones and the city could not guarantee they would perform to the same level as new ones. In addition, the limited availability of skilled professionals trained in material assessment and low-carbon design remains a structural bottleneck. Pamplona tried to tackle this issue by suggesting the inclusion of a new actor: a waste management inspector for each renovation site to manage material flows and traceability. However, this was not yet implemented. The new EU Strategy on Housing Construction sets a clear intention to support the development of a secondary material market. Neighbourhood-scale PEN interventions should be recognised for achieving policy goals around secondary material markets.

For more information, please consult this report on integration of life-cycle perspective in PEN design.

Optimising Whole Life Carbon across neighbourhood interventions in the EU

Current barriers	Explanation	Policy solutions
Secondary materials are more expensive than new materials and are rarely readily available locally.	Designs of renovation projects mostly do not consider the use of secondary materials. Design optimisation could help to reduce material intensity and, whenever feasible, use materials with recycled content and suppliers providing verified Environmental Product Declarations (EPDs) to ensure transparency.	**Member States** can support local reprocessing facilities, provide tax incentives for recycled materials, and reduce VAT on low-carbon content products.
There is a lack of market confidence in secondary materials and a lack of financial incentives to use secondary materials.	Developers and contractors often hesitate to use secondary materials due to uncertainty about quality, liability and long-term performance. Without recognised certification schemes and financial incentives, reused materials struggle to compete with conventional products in construction markets.	**Member States** should introduce quality certificates for recycled components. Building on the goal to create a single market for secondary materials in the new European Strategy for Housing Construction, the EU Circular Economy Act (forthcoming) should include sector targets such as reused construction materials standards.
Infrastructure for material reuse and storage is missing.	Reusing construction materials requires logistics, sorting, storage and matching systems that connect supply and demand. In most regions, this infrastructure does not yet exist, making it difficult for builders to access reusable components at the scale needed for renovation projects.	**Member States** should have grants for regional material banks, support digital platforms for material matching (e.g. Madaster) and support municipalities to set up construction reuse hubs.
Public procurement mostly gives no advantage to projects that try to use secondary materials or conduct a life-cycle analysis for decision-making and material optimisation.	Public procurement is a key tool through which public authorities can incentivise and reward the use of secondary materials.	**Member States** and municipalities should include circularity requirements in public procurement.
Most Member States have no national methodology or requirements for embodied emissions.	While operational energy performance is widely regulated, embodied carbon from construction materials is rarely assessed or reported. The absence of harmonised methodologies makes it difficult to compare projects, guide low-carbon design choices or integrate embodied emissions into policy frameworks.	**Member States** should ensure a timely implementation of the delegated act on the calculation of life-cycle Global Warming Potential. **Member States** and municipalities should integrate whole-life-cycle criteria into public procurement and renovation funding schemes to prioritise low-carbon design and material choices.

Scaling Positive Energy Neighbourhoods in the EU

PENs are a tangible way to make Europe's climate, energy and housing policy targets achievable. PEN readiness depends on three success factors: breaking the pilot trap, enabling investment in collective solutions, and embedding sustained community engagement as core democratic work, not an afterthought.

The pilot trap

The necessary EU policies and directives to enable various elements of PENs are in place, such as deep renovation (EPBD, EED), local renewable generation (REDIII), energy-sharing and storage (REDIII, EMD) (for a detailed analysis please consult Outline of the oPEN-Lab policy roadmap). However, their slow and inconsistent transposition into national and local law creates significant barriers to realising the full potential of PENs. While much public money is invested in testing solutions, pilots may fail to break out of the pilot trap: projects depend on short-term subsidies, operate in regulatory sandboxes and cannot demonstrate long-term viability because enabling regulations are not in place. When regulation lags behind innovation, each new pilot encounters the same obstacles: unclear rights for CSC, slow grid connection processes, fragmented renovation incentives, and no flexibility market access for small actors. This keeps PENs 'innovative' rather than 'investable'. Where supportive local regulation does exist, limited capacity among municipal actors and delivery partners restricts uptake. oPEN Lab also explores different aspects of governance, organisational and capacity-building models. For example, its organisational models use an approach that considers governance structure (roles and responsibilities), operational models (management of energy generation or distribution), financial models (mechanisms and business models) and ownership structures (for infrastructure).

This report has shown how EU, national, regional and local policymakers could create benefits for people and the economy on a local level by implementing PENs. It has also shown what is needed from the regulatory side to better enable PEN process innovations to become mainstream. This includes policy recommendations for saving projects such as oPEN Lab from the pilot trap.

Financing collective solutions

With buildings playing a decisive role in the extent to which EU citizens are resilient to a growing number of crises, an investment in better, longer-lasting and more affordable homes is a direct investment in safeguarding Europe's future and security. As this roadmap has shown, PENs are flexible and modular concepts that combine innovative technologies with citizen engagement and ownership. However, upfront investment is required in order to realise the long-term social and environmental co-benefits of future-proof buildings and neighbourhoods.

Financing PENs is fundamentally different from financing single-building renovation. PENs require bundled renovation, shared assets, collective ownership models, and new types of system value, none of which fit with existing financial instruments. New business models need to recognise that value can also come from social, environmental and governance values.

The development of new economic models remains a key barrier for the diffusion and uptake of PENs across Europe.

Deep renovation is the largest cost component of a PEN. oPEN Lab shows that inflation, interest-rate volatility and supply chain disruptions have made renovation loans significantly more expensive, reducing willingness to invest. The business case for PENs remains challenging especially due to the extremely high upfront costs of deep renovation, which cannot be recovered through energy savings within a bankable 15 to 20-year time horizon.

Green loans, where available, entail significant administrative burdens and have not proved a viable alternative. Unfavourable or unstable energy regulations undermine expected returns from PV, storage and flexibility; while existing financial instruments often do not recognise the broader co-benefits of PENs, such as health, comfort, resilience or avoided grid reinforcement – this too reduces investor appetite.

Even though tools exist to monetise PENs (see the syn.ikia MBx tool), they often translate to avoided costs rather than cash flow.

The individual technologies required for PENs (e.g. renovation materials, heat pumps, PV, batteries, smart controls) are mature and widely available. The core challenge is no longer technological innovation but the cost and complexity of integrated neighbourhood systems, the lack of skilled labour and supply chains for scaled delivery, and the difficulty of monitoring and optimising systems across multiple buildings and users. Government-backed guarantees and climate funds could de-risk private lending by leveraging the mortgage market, enabling widespread PEN-related investment.

This report shows how public policy needs to incentivise private investors to focus on financing, integrating and scaling proven solutions, alongside inventing new technologies. In addition, since user engagement and capacity-building have been found to be of central importance to the success of PENs, investment decisions must be based not only on individual technologies

Engagement, inclusion and social acceptance

PEN renovation community engagement often relies on extensive resident motivation, which can initially be high but rarely sustains itself once subsidies end. Across the Living Labs, many residents were very happy with the final look and improved comfort of their homes (you can read interviews on this subject with residents 1 and 2 in Genk), although some residents struggled to see long-term value beyond modest savings.

PENs require intensive, long-term democratic work: trusted messengers, repeated conversations, co-design processes, site visits to renovated neighbourhoods, local governance capacity, and support for vulnerable households. This effort is rarely funded or institutionalised, even though it is essential. Without resourcing for community engagement, benefit-sharing and transparent decision-making, PENs fail to scale up.

This report highlights lessons learned on the social side of PENs, including the role of communities and how social barriers to technologies can be overcome by better engaging users.

The oPEN Lab Toolbox

Throughout the past five years of the oPEN Lab project, best practices and lessons learned have been collected in the oPEN Lab Toolbox.

The Toolbox has filters for each Living Lab, PEN implementation phase, and topics such as business models, policy, technology and public participation. Here we list some tools, many of which can provide a good understanding of how the development of PEN might look like in detail.

Heat Pump Switch Calculator

This tool assists architects, homeowners, energy auditors in choosing between a heat pump or a gas boiler for the renovation. The worksheet provides a quick financial check for switching a private home's heating from gas boiler to a heat pump. It offers a practical way to explore different scenarios and assess the potential business case.

Audience: Asset Managers, Homeowners

2 **PEN implementation phase:** Planning & prototyping

Click here to learn more

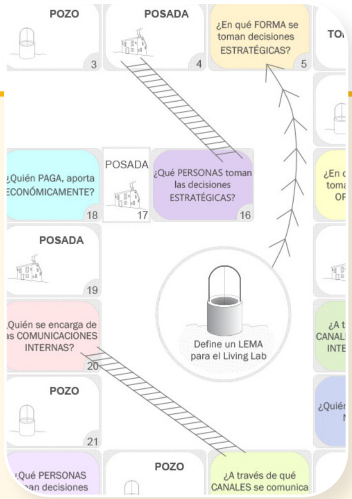
Co-creation Toolbox

The Co-creation toolbox is a set of cards integrated into a participatory gamified workshop that was co-designed and tested during the oPEN Lab project. The toolbox can be used to identify the most appropriate methods and tools to use in assessing a specific challenge, analysing stakeholders or holding ideation sessions.

Audience: Asset Managers, Homeowners

2 **PEN implementation phase:** Planning & prototyping

Click here to learn more



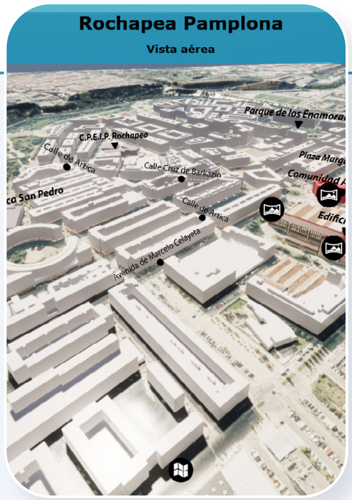
Governance Model Game of stakeholder roles

This tool comes at the beginning of establishing a PEN and puts the steps of the governance model canvas into a board game. Its main objective is to get participants to think outside the box. Participants take on a stakeholder role different from their own. They roll dice to land on a question, answer it from their assigned role's perspective, and then five other participants, each representing different stakeholders, discuss and respond to their answer.

Audience: Civil society/NGO

1 **PEN implementation phase:** How to get started

Click here to learn more



Click here to learn more

3D Viewer for overview of neighbourhood interventions

This tool is a 3D Viewer that allows citizens to navigate within the oPEN Lab pilot neighbourhood Rochapea to find out about any planned or ongoing intervention to enable its evolution into a Positive Energy Neighbourhood. For each intervention, more detailed information can be obtained through videos or informative documents. It is an example of how to engage citizens in the PEN process. The tool is only available in Spanish.

Audience: Civil society/NGO

1 **PEN implementation phase:** How to get started

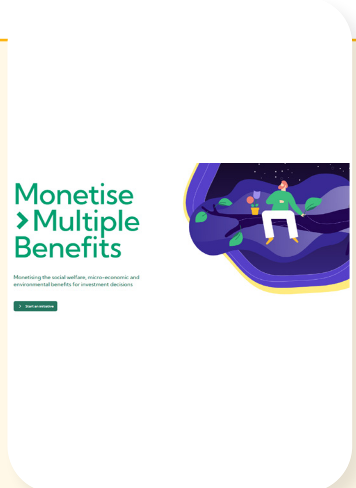
Click here to learn more

Capacity Building Handbook and Mentoring Report

This handbook serves as a reference for projects and organisations interested in adopting a Living Lab methodology. Key insights include setup processes, co-creation, stakeholder management, governance, and business models, supported by relevant examples and templates. The accompanying mentoring report addresses the needs and lessons learned from the oPEN Living Labs, presenting a valuable source for knowledge sharing and transfer.

Audience: Living Labs, Public sector

1 **PEN implementation phase:** How to get started, Planning & Prototyping, upscaling & replication



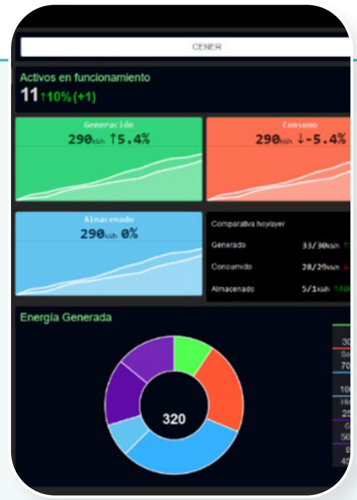
Click here to learn more

Multiple Benefit Tool (MBx)

Monetising the social welfare, micro-economic and environmental benefits for investment decisions. MBx tool, is a step forward in quantifying and monetising the social welfare, micro-economic and environmental benefits of projects, by considering the added values of the PEN approach. This decision-making tool for policymakers and investors uses Social Cost-Benefit Analysis (S-CBA) method to compare the benefit-cost ratio and return-on-investment of PEN against that of business as usual. MBx tool can help investors identify ESG investment opportunities and future-proof real estate assets.

Audience: Public sector

2 **PEN implementation phase:** Planning & prototyping



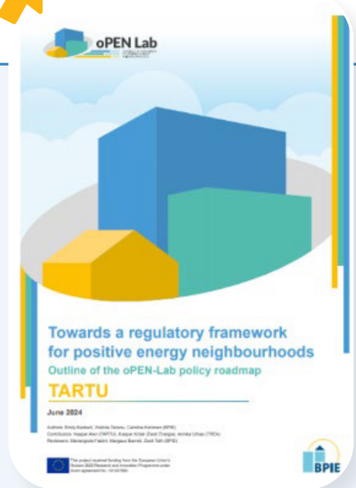
Click here to learn more

Blockchain platform

The blockchain platform is part of the CENER Blockchain Laboratory focused on exploring, testing, and implementing digital blockchain-based solutions (secure and transparent online ledger) with AI analytics for energy sector and sustainability applications that deal with renewable integration in urban, industrial and rural areas, enabling secure, transparent, trustworthy and decentralized energy transactions. This platform serves enterprises, researchers, and policymakers to advance blockchain adoption in the energy sector.

Audience: Private sector

4 **PEN implementation phase:** Evaluation & operational phase, monitoring



Click here to learn more
Spain Estonia Flanders

Report on regulatory framework for PEN in Estonia, Flanders and Spain

These three country reports for Spain, Flanders (Belgium) and Estonia, analyse national and regional implementation of EU policies relevant for enabling the positive neighbourhood approach to building renovation.

Audience: Public sector

2 **PEN implementation phase:** Upscaling & Replication

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