persist

positive energy districts driven by citizens

Deliverable 4.1
Energy Transition Action Plan for PEDs

Driving Urban Transitions

Co-funded by the European Union

Contents

Executive Summary

"*Energy Transition Action Plan for Positive Energy Districts*" focus on a transformative vision for urban energy systems, addressing the urgent challenges posed by climate change, energy security, and sustainable development. Positive Energy Districts emerge as a **vital component of the Green Transition**, blending renewable energy, innovative technologies, and active community participation to achieve energy-positive and climate-resilient urban environments.

Throughout this report, we have explored how PEDs **redefine urban energy landscapes** by producing **more renewable energy** than they consume, promoting energy independence and optimizing energy efficiency. These districts serve as scalable models that align with global and regional sustainability goals, offering a **pathway to achieve net-zero emissions** while driving economic growth and improving the quality of urban life.

The assessment of PED progress across diverse European regions reveals a promising and complex landscape. From **innovative community-driven** projects in Romania to well-established frameworks in Spain and Norway, PED concept is **adaptable and impactful** across varied socio-economic and regulatory contexts. However, success is contingent upon addressing key barriers, such as regulatory ambiguity, high upfront costs, technical integration challenges, and limited public awareness.

To realize the **full potential of PEDs**, a multi-stakeholder approach is essential. Governments must establish **clear and supportive policies**, financial institutions must **mobilize investments** and researchers or innovators must advance technologies that **enhance efficiency and adaptability**. Equally important is the role of communities, whose **engagement and participation** ensure that PEDs remain inclusive and equitable.

PEDs are **more than a technical solution**; they represent a new paradigm for sustainable urban living. By integrating energy systems into urban fabric, they not only **reduce emissions** and energy costs but also **foster social cohesion**, promote green jobs and enhance overall resilience. Their development is a testament to how **local solutions** can address **global challenges**.

As the energy landscape evolves, PEDs offer a beacon of what is possible when **innovation, collaboration and commitment converge**. This report concludes with a call to action: to embrace the **transformative potential of PEDs**, prioritize their integration into urban planning and invest in the systems and communities that make them possible. By scaling up these efforts, we can create urban environments that are not just **energy-positive** but also sustainable, inclusive and prepared to develop in a rapidly changing world.

The **journey toward Positive Energy Districts** is a journey toward a more equitable, resilient, and climate-conscious future - **a journey we must embark on together**.

ABBREVIATION

ANRE	National Regulatory Authority for Energy
BREEAM	Building Research Establishment Environmental Assessment Method
CBAM	Carbon Border Adjustment Mechanism
CECs	Citizen Energy Communities
CO_2	Carbon Dioxide
DSO	Distribution System Operator
EC	European Commission
EED	Energy Efficiency Directive
EGD	European Green Deal
ESCOs	Energy Service Companies
ESG	Environmental, Social and Governance
EU	European Union
EU ETS	EU Emissions Trading System
EVs	Electric Vehicles
FME ZEN	Research Center for Zero-Emission Areas in smart cities
GHG	Greenhouse Gas
ICT	Information and Communications Technology
JTM	Just Transition Mechanism
KPI	Key Performance Indicator
LEED	Leadership in Energy and Environmental Design
M&E	Monitoring and Evaluation
NECPs	National Energy and Climate Plans
NGOs	Non-Governmental Organizations
PEDs	Positive Energy Districts
R&I	Research and Innovation
RECs	Renewable Energy Communities
RED	Renewable Energy Directive
RES	Renewable Energy Sources
SDG	Sustainable Development Goals
SECAP	Sustainable Energy and Climate Action Plan
SET Plan	Strategic Energy Technology Plan
TSO	Transmission System Operator

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1. Positive Energy Districts (PEDs): foundations, benefits and stakeholder dynamics

In the face of pressing environmental challenges, the global community has recognized the urgent need for a comprehensive energy transition, a fundamental shift away from traditional fossil fuel-based energy systems towards more sustainable and renewable alternatives. This transition, fuelled by a confluence of political, economic, and environmental factors, holds the promise of a low-carbon future, where the deleterious impacts of greenhouse gas emissions are mitigated, and the world moves towards a more sustainable energy landscape[1].

This energy transition represents a **significant shift in global sustainability**, as it aims to transform the way we produce, distribute and consume energy, ultimately reducing our carbon footprint and preparing the way for a greener, more resilient future.[1]

One of the primary drivers of this energy transition has been the implementation of government policies aimed at reducing greenhouse gas (GHG) emissions and promoting the use of renewable energy sources (RES)[2]. These policy initiatives, coupled with the declining costs of renewable technologies and the increasing cost-competitiveness of clean energy, have created a favourable environment for the transition to take hold[1]. Additionally, growing public awareness and concern about the environmental impact of fossil fuels have led to an increase in demand for clean energy solutions, further accelerating the pace of change[3].

General context

The energy transition is not merely a shift confined to individual energy sectors, but rather a far-reaching transformation of the entire energy system, including production, storage, transportation and final consumption[4]. This comprehensive transition aims to decarbonize the global energy landscape, reducing the heavy reliance on fossil fuels and instead embracing clean, renewable energy sources that can sustainably meet the world's growing and evolving energy needs[5]. By reshaping the energy system as a whole, the transition holds the potential to significantly mitigate the adverse environmental impacts associated with GHG emissions and foster a more sustainable energy future for the global community[6].

The energy transition is intrinsically linked to the broader sustainable development agenda, as evidenced by its strong alignment with the United Nations Sustainable Development Goals (SDG)[7]. Specifically, the shift towards renewable energy sources

[1] IRENA, Global energy transformation – A roadmap to 2025, LINK, 2019
[2] Alagoz, E., & Alghawi, Y. (2023, June 27). The Energy Transition: Navigating the Shift Towards Renewables in the Oil and Gas Industry. Science Publishing Group. https://doi.org/10.11648/j.jenr.20231202.12
[3] International Energy Agency. (2021). Renewables 2021: Analysis and forecast to 2026. International Energy Agency. https://www.iea.org/reports/renewables-2021
[4] Zhou, P., Gao, S., Lv, Y., & Zhao, G. (2022, July 29). Energy transition management towards a low-carbon world. Higher Education Press, 9(3), 499-503. https://doi.org/10.1007/s42524-022-0201-9
[5] Zhou, P., Gao, S., Lv, Y., & Zhao, G. (2022, July 29). Energy transition management towards a low-carbon world. Higher Education Press, 9(3), 499-503. https://doi.org/10.1007/s42524-022-0201-9
[6] Intergovernmental Panel on Climate Change. (2022). Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. https://www.ipcc.ch/report/ar6/wg3/
[7] https://sdgs.un.org/goals

and improved energy efficiency directly supports **SDG 7**[8], which calls for ensuring access to affordable, reliable, sustainable and modern energy for all. The energy transition aims to increase the share of renewable energy sources, making energy systems cleaner, more reliable and sustainable. By investing in renewable energy technologies like solar, wind and hydro, the energy transition supports universal access to affordable and clean energy, especially important in underserved and remote areas.

Moreover, the energy transition's potential to create new green jobs and stimulate economic growth aligns with **SDG 8**[9], promoting inclusive and sustainable economic development. The energy transition is an economic growth engine, creating new jobs in the renewable energy sector and promoting sustainable industries. Investments in clean energy and energy efficiency support job creation in areas like solar installation, wind turbine manufacturing, energy efficiency retrofitting, and sustainable innovation.

Aside from these direct connections, the energy transition also triggers a ripple effect on other SDGs, such as **SDG 13**[10] (climate action), **SDG 11**[11] (sustainable cities), and **SDG 12**[12] (responsible consumption and production). The energy transition is central to reducing GHG emissions, as the energy sector is the largest source of global emissions. Transitioning from fossil fuels to renewable energy sources mitigates climate change by decreasing carbon dioxide (CO_2) emissions and limiting global temperature rise. Also, it is focused on building sustainable cities through cleaner energy and more resilient infrastructure[13].

Figure 1. Main regulatory documents for PEDs

[8] https://sdgs.un.org/goals/goal7
[9] https://sdgs.un.org/goals/goal8
[10] https://sdgs.un.org/goals/goal13
[11] https://sdgs.un.org/goals/goal11
[12] https://sdgs.un.org/goals/goal12
[13] IRENA, Global energy transformation – A roadmap to 2025, LINK, 2019

Positive Energy Districts, smart grids and sustainable mobility solutions are examples of urban energy transition projects that support sustainable urban development. The energy transition promotes sustainable production and consumption patterns, reducing dependency on fossil fuels and decreasing overall energy demand. Through energy efficiency and clean energy initiatives, the energy transition enables more responsible energy use in homes, industries, and transportation.

The European Union (EU) has adopted several strategic documents to guide its energy transition towards a low-carbon, sustainable, and resilient energy system. These documents outline frameworks, targets and policies for energy efficiency, renewable energy, emissions reduction and energy security.

1. **European Green Deal**[14]**.** It is a comprehensive policy framework introduced by EU with the goal of transforming Europe into the first climate-neutral continent by 2050. It aims to decarbonize the EU economy, supporting sustainability and address the environmental challenges posed by climate change, pollution, and resource depletion.
   The key provisions of the European Green Deal (EGD) refer to:
   1. *Achieving climate neutrality by 2050*. The objective is to reach net-zero greenhouse gas emissions by 2050. The European Green Deal's long-term climate strategy aims to decarbonize the EU economy across all sectors, involving a transition to renewable energy, enhanced energy efficiency, sustainable transportation, and green industries.
   2. *Securing clean, affordable and reliable energy*. The objective is to transform the energy system to ensure a sustainable and secure energy supply. EGD advocates RES, reduced reliance on fossil fuels and investments in energy storage, hydrogen and cross-border energy interconnections. It also focuses on increasing energy efficiency across industries, buildings and transportation.
   3. *Transitioning to a circular economy*. The objective is to move towards a more sustainable, circular economy that reduces waste and conserves resources. It emphasizes the need to redesign production and consumption patterns to minimize waste, improve recycling and support the reuse of materials. It aims to promote product design that ensures longer life cycles and encourages sustainable consumption.
   4. *Mobilizing green finance and investments*. The objective is to leverage investments to fund the transition to a green economy. EGD seeks to mobilize private and public investments to finance climate action projects, green technologies and infrastructure. A key component is the EU Green Deal Investment Plan, which includes the Just Transition Mechanism to support regions and sectors most affected by the transition.
   5. *Pricing carbon and reforming the emissions trading system*. The objective is to ensure that carbon emissions are priced to incentivize reductions. Includes a reform of the EU's emissions trading system.

   It is a holistic and ambitious framework that aims to tackle climate change, protect the environment and promote sustainability across all sectors of the economy. By fostering innovation, sustainable practices and inclusive growth,

[14] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

it positions the EU as a global leader in the fight against climate change while ensuring a fair and just transition for all citizens.

2. **"Fit for 55" Package**[15] is a legislative initiative designed to support the EU's ambitious 2030 goal of reducing GHG emissions by at least 55% from 1990 levels. This package includes key policy reforms such as a revision of the EU Emissions Trading System (EU ETS), tighter fuel efficiency standards and significant promotion of electric vehicles to reduce dependency on fossil fuels and cut emissions across sectors[16]. A central aim of "Fit for 55" is to drive the EU towards achieving net-zero emissions by 2050, which aligns with the EU Green Deal's long-term climate neutrality objective. To support this, the package proposes stronger climate and energy legislation, including updates to the Renewable Energy Directive and the Energy Efficiency Directive to push for higher adoption of renewable sources and more efficient energy use[17]. Furthermore, the package introduces the Carbon Border Adjustment Mechanism (CBAM), an innovative tool designed to maintain fair competition by imposing carbon-related tariffs on imported goods from countries with less rigorous climate policies. This approach helps prevent carbon leakage and levels the playing field for EU industries[18]. Beyond emissions reduction, "Fit for 55" aims to foster economic growth, drive green innovation and create new employment opportunities in sustainable industries across Europe.
3. **European Climate Law**[19]**.** Adopted in 2021, is a landmark piece of legislation that establishes the EU's legal framework for achieving climate neutrality by 2050. The law enshrines the goal of net-zero GHG emissions across the EU by mid-century into binding legislation, making it a core pillar of the EGD. It sets the direction for all EU policies and strategies to be aligned with this long-term climate objective, ensuring that every sector, from energy to transport and agriculture, contributes to the transition. The law also mandates the European Commission (EC) to monitor progress toward the 2050 target and propose adjustments when necessary, ensuring that the EU remains on track to meet its climate ambitions.
   In addition to its long-term objectives, the European Climate Law strengthens the EU's short- and medium-term climate goals, including raising the 2030 emissions reduction target to at least 55% compared to 1990 levels. The law includes provisions for a Climate Action Progress Report that will be published every five years to assess the effectiveness of current measures and propose new actions if necessary. It also empowers EC to propose corrective measures if there are significant gaps between the emissions reductions expected and those achieved. With the European Climate Law, the EU is reinforcing its commitment to climate leadership, ensuring that the path to net-zero emissions is clear, structured and accountable.

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[15] https://www.consilium.europa.eu/en/policies/fit-for-55/

[16] European Commission. (2021). *Fit for 55: delivering the EU's 2030 Climate Target on the way to climate neutrality*. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. [COM(2021) 550 final]. https://www.eesc.europa.eu/en/our-work/opinions-information-reports/opinions/fit-55-delivering-eus-2030-climate-target-way-climate-neutrality

[17] European Parliament. (2021). *Fact Sheets on the European Union: The "Fit for 55" package*. https://www.europarl.europa.eu/factsheets/en/sheet/214/the-fit-for-55-package

[18] European Commission. (2021). *The new EU Emissions Trading System (EU ETS) and the role of the Carbon Border Adjustment Mechanism (CBAM)*. https://ec.europa.eu/commission/presscorner/detail/en/qanda_21_3662

[19] https://eur-lex.europa.eu/EN/legal-content/summary/european-climate-law.html

4. **REPowerEU Plan**[20], introduced in 2022 by the EC, is an ambitious initiative designed to reduce the EU dependency on Russian fossil fuels and accelerate the transition to clean energy sources. The plan was developed in response to the geopolitical crisis caused by Russia's invasion, which highlighted the vulnerabilities in the EU's energy security. REPowerEU aims to ensure a faster transition to renewable energy while maintaining energy security, boosting energy efficiency and diversifying energy supplies. Key aspects of the plan include increasing the deployment of renewable energy technologies such as solar and wind, improving energy efficiency across sectors and enhancing energy storage capabilities. It also seeks to reduce the EU's reliance on fossil fuel imports, particularly natural gas, through measures such as improving energy infrastructure, creating strategic energy partnerships with non-EU countries and promoting alternative fuels.
   To finance the transition, it proposes significant investments and new funding mechanisms, including reallocation of funds from the EU's existing budgets and mobilization of private sector investment. The plan aims to increase renewable energy capacity and energy independence by accelerating the construction of new infrastructure, such as renewable energy projects and cross-border energy connections. It also focuses on fostering the development of clean hydrogen, green technologies and carbon capture solutions. Additionally, REPowerEU emphasizes the importance of diversifying energy sources to prevent future supply disruptions, with a focus on renewable energy imports and the use of alternative fuels. By reducing the reliance on fossil fuels, improving resilience to energy crises and driving the clean energy transition, REPowerEU plays a pivotal role in the EU's broader goals of achieving climate neutrality by 2050.
5. **National Energy and Climate Plans (NECPs)**[21] are strategic documents that each EU member state must submit to the EC as part of the broader climate and energy governance framework. These plans are a key component of the EGD and the 2030 Climate and Energy Framework. The NECPs outline how each country intends to meet its binding climate and energy targets, including those related to greenhouse gas emissions, renewable energy and energy efficiency. They are required to cover a 10-year period, with updates submitted every five years and must include both national policies and measures to achieve the EU-wide climate and energy goals, ensuring consistency and coordination across member states.
   The key aspects of an NECP include the national targets for reducing GHG emissions, increasing the share of renewable energy and improving energy efficiency. These plans are designed to be flexible to accommodate each country's unique circumstances, energy mix and priorities. Member states are required to establish specific, measurable actions and investment strategies to meet these targets, such as expanding renewable energy capacity, improving grid infrastructure, promoting energy efficiency in buildings and supporting the transition to low-carbon transport. The NECPs also outline the mechanisms for monitoring progress and reporting on the implementation of these measures, ensuring transparency and accountability.
   In addition to meeting EU targets, NECPs are intended to help countries enhance energy security, foster innovation in clean energy technologies and

[20] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_en
[21] https://energy.ec.europa.eu/topics/energy-strategy/national-energy-and-climate-plans-necps_en

stimulate job creation in the green economy. The plans also highlight the importance of a just transition, ensuring that the social and economic impacts of the energy transition are addressed, especially in regions or sectors dependent on high-emission industries. Each NECP is expected to be aligned with the EU's overarching climate goals and legislation, such as the European Climate Law, and contribute to the EU's goal of achieving net-zero emissions by 2050. Through these plans, EU creates a framework for collective action while respecting the diverse energy systems and national contexts of its member states, driving toward a greener and more sustainable future.

6. **Renewable Energy Directive (RED II and RED III)**[22]**.** Adopted in 2018, is a critical piece of legislation within the European Union's broader climate and energy framework, aiming to boost the share of renewable energy in the EU's energy mix. It sets a binding target for the EU to achieve a 32% share of renewable energy in its total energy consumption by 2030, with a review clause to potentially increase this target. RED II is part of the EU's strategy and is designed to accelerate the transition to renewable energy sources, such as wind, solar, hydropower and biomass. The directive includes provisions to enhance the sustainability of bioenergy, ensure efficient use of renewable resources and encourage cross-border cooperation on renewable energy projects. A key feature of RED II is the promotion of renewable energy in various sectors, including heating and cooling, transport and electricity, through various financial incentives, subsidies and obligations for member states to adopt national plans.
   RED III is an extension and revision of RED II, proposed in 2021, with the aim of further accelerating the EU's green transition and aligning with its more ambitious climate targets. RED III is part of the Fit for 55 package and includes an updated target of increasing the share of renewable energy to 40% by 2030, in line with the EU's enhanced climate goals under the European Green Deal. The directive proposes specific measures to address challenges in renewable energy integration, such as speeding up permitting processes for renewable energy projects, enhancing grid infrastructure and promoting more effective use of renewable energy in industry and transport. It also places a strong emphasis on the role of renewable hydrogen and the decarbonization of hard-to-abate sectors, including heavy industry or aviation.
   One of the key aspects of RED III is its focus on increasing the use of renewable fuels of non-biological origin (e.g. renewable hydrogen, synthetic fuels), alongside ensuring sustainability and circularity in the bioenergy sector. The directive encourages the adoption of advanced biofuels and promotes the expansion of renewable energy technologies that can decarbonize transport, such as electric vehicles and charging infrastructure. RED III also proposes stronger sustainability criteria for bioenergy and an emphasis on ensuring that renewable energy sources do not contribute to land-use changes that negatively impact biodiversity or food security.
7. **Energy Efficiency Directive (EED)**[23]. Proposed in 2021, as part of the Fit for 55 package, aims to strengthen the EU's energy efficiency framework and align it with the EU's updated climate and energy goals, particularly the European

[22] https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-directive_en
[23] https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficiency-targets-directive-and-rules/energy-efficiency-directive_en

Green Deal. The recast of the directive sets a more ambitious energy efficiency target for 2030, aiming for a 36% reduction in energy consumption by the end of the decade, with a review mechanism to potentially increase this target to 39%. This goal reflects the EU's commitment to cutting GHG emissions, reducing dependence on imported fossil fuels and improving energy security. The directive is central to achieving the EU's overall energy transition and decarbonization objectives, particularly as energy efficiency is recognized as one of the most cost-effective ways to reduce emissions and support the green transition.

A key aspect of the EED is the introduction of **energy savings obligations** for member states. These obligations require governments to ensure that energy savings are delivered across all sectors of the economy, from residential and industrial buildings to transportation and services. The directive mandates the implementation of national energy efficiency action plans, which include measures like renovating public buildings, encouraging energy-efficient appliances and lighting and expanding district heating and cooling networks. The EED also promotes the establishment of a framework to monitor progress, with regular reporting and independent assessments of energy savings across the EU. Additionally, the directive includes provisions for energy performance contracting and financial incentives to stimulate investments in energy efficiency projects.

It places a significant emphasis on the role of digitalization and data in improving energy efficiency. It encourages the use of smart meters, smart grids and digital technologies to optimize energy use in both buildings and industrial processes. Moreover, the directive promotes the integration of energy efficiency into public procurement, ensuring that the public sector leads by example in reducing energy consumption. Another important aspect is the focus on energy efficiency in the transport sector, which is one of the EU's most energy-intensive areas. The directive aims to reduce energy demand through measures such as promoting sustainable mobility solutions, encouraging modal shifts to public transport and supporting the adoption of low-energy vehicles. By strengthening these measures, the EED recast ensures that energy efficiency becomes a cornerstone of the EU's broader sustainability and climate goals, contributing to the EU's path towards net-zero emissions by 2050.

8. **Just Transition Mechanism**[24]. It is a crucial initiative designed to ensure that the shift to a climate-neutral economy is fair and inclusive, leaving no one behind and addresses the social and economic challenges faced by regions, workers and communities that are heavily dependent on carbon-intensive industries, such as coal, oil, and gas. Its primary goal is to provide financial support and targeted investment to help these areas transition to greener, more sustainable industries. The mechanism is structured around three main pillars:
    i. *Just Transition Fund* - a dedicated funding source aimed at supporting affected regions.
    ii. *InvestEU* - helps leverage private investment in green projects.
    iii. *Public Sector Loan Facility* - provides loans for large-scale transition projects.

[24] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/finance-and-green-deal/just-transition-mechanism_en

These instruments are designed to help diversify local economies, create green jobs and build new sustainable infrastructure in regions that face the greatest challenges due to the decarbonization process.

A key feature of JTM is its focus on ensuring that the benefits of the green transition are shared equitably. It emphasizes social dialogue and active participation from local communities, workers and other stakeholders in the planning and implementation of transition measures. JTM aims to support retraining and reskilling programs for workers who may be displaced by the closure of polluting industries, while also fostering the creation of new, sustainable job opportunities in renewable energy, clean technologies and other green sectors. By combining financial assistance, training and capacity-building, it ensures that the transition to a low-carbon economy can also be a driver of social inclusion, regional development and resilience, aligning with the EU's commitment to social fairness and environmental sustainability.

9. **EU Taxonomy Regulation**[25]**.** Established in 2020, sets a framework for determining which economic activities are environmentally sustainable. Its main goal is to direct investments towards sustainable projects and activities, supporting the EU's climate and environmental goals under the EGD. Taxonomy outlines specific criteria for classifying economic activities as environmentally sustainable, focusing on six key areas: climate change mitigation, climate change adaptation, sustainable use and protection of water and marine resources, transition to a circular economy, pollution prevention and control, and protection of biodiversity. This aims to prevent "greenwashing" and ensure investments genuinely contribute to the EU's sustainability targets.

   A crucial aspect of the Taxonomy is promoting financial transparency and accountability. It requires companies, financial institutions and investors to disclose how their activities align with Taxonomy's sustainability criteria. This enhances transparency in the financial sector and empowers investors to make informed decisions based on reliable data about the environmental impact of their investments. Furthermore, the regulation supports the development of green financial products, such as green bonds and funds, by establishing common standards for sustainable investment. This helps mobilize private sector capital needed to fund the transition to a low-carbon economy and supports the EU's goal of channelling at least €1 trillion in sustainable investments over the next decade.

10. **Strategic Energy Technology (SET) Plan**[26]. It is significant for achieving the EU's climate and energy goals, including its aim to become climate-neutral by 2050. Launched in 2007, the SET Plan accelerates the development and deployment of innovative energy technologies that can reduce greenhouse gas emissions, improve energy efficiency, and increase renewable energy use. The plan focuses on addressing technological challenges in key sectors like renewable energy, energy storage, carbon capture and storage, smart grids, and energy efficiency. The SET Plan aligns research and innovation across the EU, promoting public-private collaboration to drive innovation and maintain Europe's leadership in clean energy technologies.

    A core element of the SET Plan is its Technology Collaboration Platform, which brings together EU member states, industry leaders and researchers to identify and prioritize technology areas needing further development. The SET Plan

[25] https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/eu-taxonomy-sustainable-activities_en
[26] https://energy.ec.europa.eu/topics/research-and-technology/strategic-energy-technology-plan_en

coordinates EU funding and research efforts, enabling large-scale projects to accelerate the commercialization of breakthrough technologies. It outlines strategic priorities and action plans with specific R&D and demonstration goals for each technology area. By aligning these efforts, the SET Plan overcomes barriers like cost, scalability and efficiency, making clean energy solutions more accessible and affordable.

Another key aspect is the SET Plan's role in driving sustainable investment and ensuring the energy transition creates new jobs and growth opportunities across Europe. The plan encourages a competitive European energy technology market focused on clean energy innovation. It also supports public-private partnerships, like the European Battery Alliance and Clean Hydrogen Partnership, to advance energy technologies. As part of the European Green Deal, the SET Plan is integral to the EU's strategy for achieving net-zero emissions by promoting the rapid commercialization of cutting-edge clean energy technologies that can transform Europe's energy system and lead to a more sustainable and resilient energy future.

These documents guide policy, regulatory and financial frameworks across Europe to align member states' efforts with shared goals for a cleaner, more secure and resilient energy future. They also support sectors and technologies essential to achieving the EU's long-term climate objectives.

The global drive towards a low-carbon future is prompting a shift in the energy transition, from broad national and international policies to targeted, local actions that can generate tangible impacts on communities. This shift underscores the significance of PEDs - urban areas that produce more energy than they consume, achieved through a combination of renewable energy generation, energy-efficient design, and smart technology[27]. By localizing the energy transition in cities and neighbourhoods, PEDs bring sustainable energy solutions directly to communities, making them both contributors to and beneficiaries of clean energy advancements. These districts not only help achieve carbon reduction targets but also promote resilient, energy-independent urban environments, fostering economic growth and enhancing residents' quality of life. PEDs embody the practical, community-centred approach needed to fulfil the ambitious goals of the energy transition. By empowering local communities to take an active role, PEDs have the potential to drive a more inclusive and equitable shift towards sustainability, ensuring that the benefits of clean energy are distributed fairly across all segments of the population [28].

Furthermore, the decentralized nature of PEDs can enhance energy security and resilience, making communities less vulnerable to disruptions in centralized energy systems. As the global energy landscape continues to evolve, the widespread adoption of PEDs will be relevant in realizing the full potential of the energy transition and creating a more sustainable and liveable future for all[29].

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[27] Lindholm, O.; Rehman, H.u.; Reda, F. Positioning Positive Energy Districts in European Cities. Buildings 2021, 11, 19. https://doi.org/buildings11010019

[28] : Turci, G.; Civiero, P.; Aparisi-Cerdá, I.; Marotta, I.; Massa, G. Transition Approaches towards Positive Energy Districts: A Systematic Review. Buildings 2024, 14, 3039. https://doi.org/10.3390/buildings14103039

[29] https://smart-cities-marketplace.ec.europa.eu/sites/default/files/2021-06/Positive%20Energy%20Districts%20Factsheet.pdf

However, their successful implementation faces a range of technical, economic and social challenges that must be addressed. These include the need for innovative technologies, effective policy frameworks and community engagement strategies. Research efforts, such as those undertaken by the International Energy Agency's EBC Annex 83 and other initiatives, are important in identifying and addressing these challenges, paving the way for the widespread adoption of PEDs as a key driver of the global energy transition[30].

PEDs, which aim to maximize local renewable energy production and consumption while minimizing energy waste, are a prime example of how the energy transition can be leveraged to achieve multiple sustainable development objectives simultaneously[31]. This holistic approach to energy transformation demonstrates the interconnectedness between the energy transition and the broader sustainable development agenda, highlighting the potential for the energy transition to drive progress across a range of critical sustainability goals.

PEDs definition

"Positive Energy Districts are energy-efficient and energy-flexible urban areas or groups of connected buildings which produce net zero greenhouse gas emissions and actively manage an annual local or regional surplus production of renewable energy. They require integration of different systems and infrastructures and interaction between buildings, the users and the regional energy, mobility and ICT systems, while securing the energy supply and a good life for all in line with social, economic and environmental sustainability [32,33]*.*

They are the natural progression of energy communities, offering a transformative approach to urban energy management. Built on the foundational principles of energy communities, PEDs take the concept further by actively generating more energy than they consume. This surplus energy can then be used to support neighboring areas or integrated into broader energy networks, reinforcing energy resilience and sustainability.

Currently, the development of PEDs is most practical through the establishment of energy communities and cooperatives. These collaborative structures enable resource pooling, shared ownership, and strong partnerships among stakeholders. By facilitating collective investment in renewable energy projects, local energy production, and shared consumption, energy communities lay the groundwork for PEDs to thrive.

In essence, PEDs represent the next step in the evolution of energy communities, creating a new paradigm where urban areas become net contributors to the energy ecosystem while driving environmental and social progress.

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[30] Hedman, Å., Rehman, H U., Gabaldón, A., Bisello, A., Albert-Seifried, V., Zhang, X., Guarino, F., Grynning, S., Eicker, U., Neumann, H., Tuominen, P., & Reda, F. (2021, March 20). IEA EBC Annex83 Positive Energy Districts. Multidisciplinary Digital Publishing Institute, 11(3), 130-130. https://doi.org/10.3390/buildings11030130
[31] Kowalska-Pyzalska, A. (2017, November 14). What makes consumers adopt to innovative energy services in the energy market? A review of incentives and barriers. Elsevier BV, 82, 3570-3581. https://doi.org/10.1016/j.rser.2017.10.103
[32] Urban Europe, White Paper on Reference Framework for Positive Energy Districts and Neighborhoods. Key lessons from national consultations, 2020, LINK
[33] EU Smart Cities Information System, Positive energy districts solution booklet, 2020, LINK

Starting from the definition provided by JPI Urban Europe and the SET-Plan 3.2 Programme on PEDs, the core principle of this concept is to establish an area within city boundaries that generates more energy than it consumes, while remaining adaptable to fluctuations in the energy market. A PED should not only achieve an annual net energy surplus but also help reduce the strain on centralized energy networks. This can be accomplished by enhancing onsite load-matching and self-consumption, integrating technologies for both short- and long-term energy storage, and offering energy flexibility through smart control systems[34].

PEDs and similar concepts, it is essential to evaluate them against techno-economic, environmental and social criteria - recognized as the three fundamental pillars of sustainability. A holistic analysis grounded in these pillars enables a nuanced understanding of PEDs, capturing their broader impacts beyond energy production and consumption[35].

The framework for PEDs must consider the complexity and diversity of economic, cultural, and climate contexts across each region, city or country. Rather than relying solely on a calculation of energy inputs and outputs, proposed framework emphasizes four primary functions to guide urban areas within their broader regional energy systems (Figure 2).

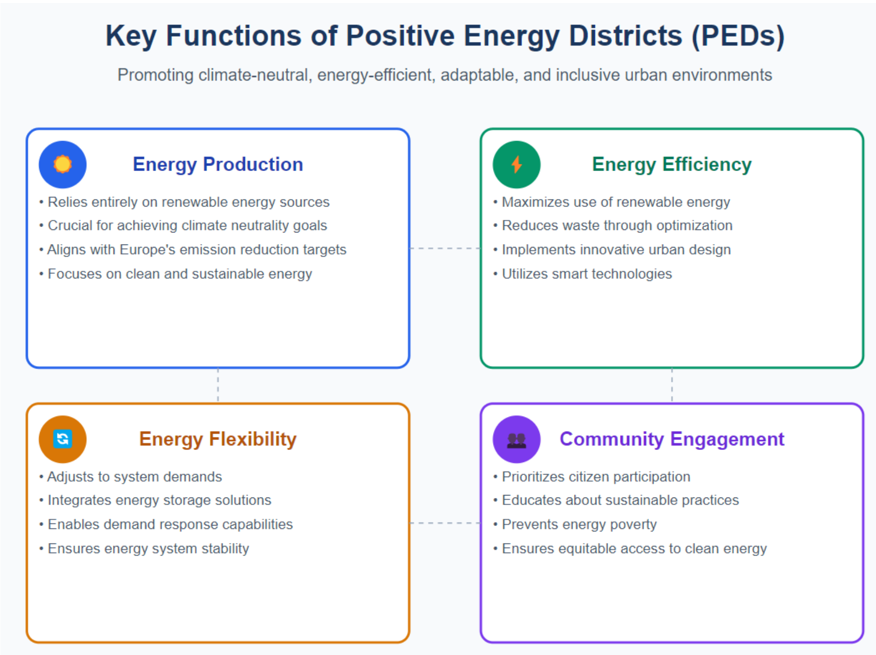

Figure 2. Key functions of PEDs

These functions are essential for promoting climate-neutral, energy-efficient, adaptable, and inclusive urban environments:

1. Energy production function - fundamental requirement for PEDs is to rely entirely on renewable energy sources. This dependence on clean and sustainable energy is

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[34] X. Zhang, S. R. Penaka, S. Giriraj, M. N. Sánchez, P. Civiero, and H. Vandevyvere, "Characterizing Positive Energy District (PED) through a Preliminary Review of 60 Existing Projects in Europe," *Buildings*, vol. 11, no. 8, Art. no. 8, Aug. 2021, doi: 10.3390/buildings11080318

[35] L. Casamassima, L. Bottecchia, A. Bruck, L. Kranzl, and R. Haas, "Economic, social, and environmental aspects of Positive Energy Districts—A review," *WIREs Energy Environ.*, vol. 11, no. 6, p. e452, 2022, doi: 10.1002/wene.452.

important to achieving climate neutrality goals and aligns with Europe's commitment to reducing GHG emissions.

2. Energy efficiency function - by prioritizing efficient use of energy, these districts can optimize renewable energy usage, thereby reducing waste and further supporting climate goals. In this context, the function underscores the importance of innovative urban design, smart technologies and practices that conserve energy.

3. Energy flexibility function - urban areas are inherently large consumers of energy, which can place a strain on energy systems and needs to operate in ways that benefit the overall energy system, contributing to energy stability and resilience. This includes adjusting demand, integrating with energy storage solutions and facilitating demand response capabilities to respond dynamically to fluctuations in energy availability and demand.

4. Community engagement and social inclusion function - to ensure a successful transition to sustainable urban energy systems, PEDs must prioritize citizen participation and community engagement. This function involves educating residents about sustainable practices, encouraging active involvement in local energy initiatives and fostering a sense of ownership in the transition to renewable energy. It also includes measures to prevent energy poverty by making renewable energy accessible and affordable for all community members, ensuring that the benefits of a clean energy system are shared equitably and inclusively.

Together, these functions create a holistic approach that balances the need for sustainable energy production, optimal use of available resources and adaptive consumption patterns, ultimately fostering resilient and climate-positive urban environments.

By talking about small scale urban areas such as districts or communities, **geographical boundaries** are essential to understand what is inside or outside of a given system. PEDs exploit this aspect due to the various definitions currently in place[36]:

- *PED Autonomous* means a self-sufficient district with defined boundaries, meeting all energy needs through internally generated renewables, with no imports from external grids; excess energy export is permitted.
- *PED Dynamic* is a district with defined boundaries generating more renewable energy annually than it demands, allowing interaction with external grids and other PEDs.
- *PED Virtual* is referred to a district that combines on-site and virtual renewable systems outside its boundaries, with total annual generation exceeding district energy demand.

According to JPI Urban Europe[37], **one of the primary goals of PEDs** is to have a surplus of renewable energy generation. Notably, it states that the surplus should be on an annual basis and either at a local or regional level. Hence, it is essential to understand the exchanges between the different grids and buildings in a PED to

[36] O. Lindholm, H. ur Rehman, and F. Reda, "Positioning Positive Energy Districts in European Cities," Buildings, vol. 11, no. 1, Art. no. 1, Jan. 2021, doi: 10.3390/buildings11010019.
[37] Urban Europe, "EUROPE towards POSITIVE ENERGY DISTRICTS, A compilation of projects towards sustainable urbanization and the energy transition". 2020, LINK

properly calculate the **energy balance**[38]. Given the complexity of the system examined, flexibility options are another key focus point. Thus, through demand-side management, storing energy and coupling of sectors, the PED serves the grid with the flexibility to achieve a resilient regional energy system.

A PED is required to have an annual **net-zero GHG emission** balance JPI Urban Europe[39]. The PEB concept does not include any emission goals or restrictions, apart from passively focusing on renewable energy generation.

Although the adopted definition of PEDs does not consider **land use aspects**, most current PED or PED-like projects focus on how to utilize the land in terms of activities and end-use. The issue is mainly on how to manage common areas, commercial activities and recreational zones[40].

In PEDs, **energy efficiency** is a core principle. A highly efficient building envelope is essential, along with active management of energy demand and integration with ICT to offer flexible, cost-effective solutions. This approach emphasizes building efficiency, both for new constructions and retrofitting of existing buildings. ICT solutions further enhance infrastructure efficiency and energy efficiency at both building and community levels is fundamental for achieving Zero Energy Community status[41].

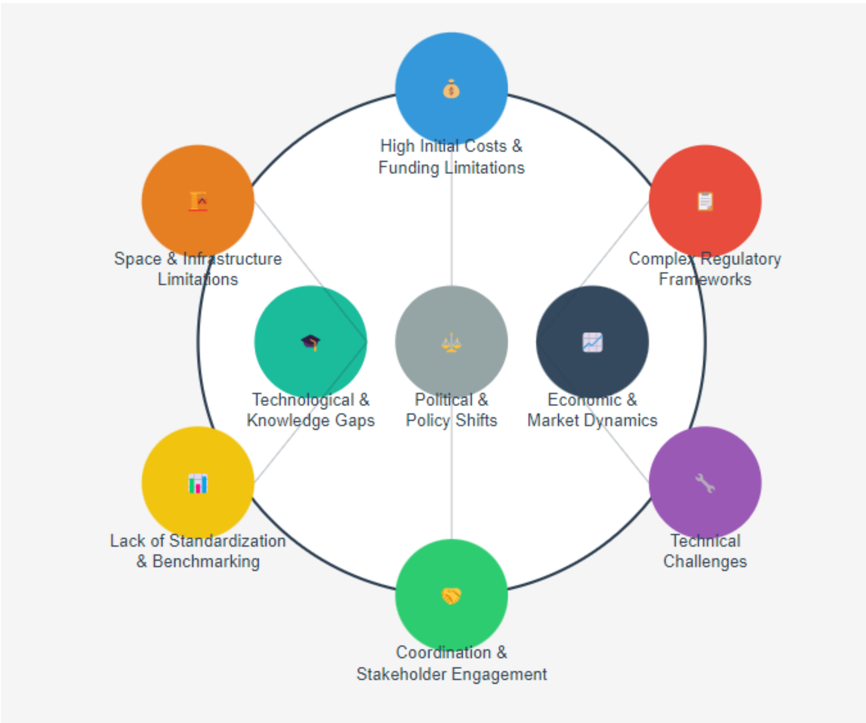

Figure 3. Key challenges for PEDs

[38] L. Bottecchia, A. Gabaldón, T. Castillo-Calzadilla, S. Soutullo, S. Ranjbar, and U. Eicker, "Fundamentals of Energy Modelling for Positive Energy Districts," in *Sustainability in Energy and Buildings 2021*, J. R. Littlewood, R. J. Howlett, and L. C. Jain, Eds., Singapore: Springer Nature, 2022, pp. 435–445. doi: 10.1007/978-981-16-6269-037.

[39] Urban Europe, "EUROPE towards POSITIVE ENERGY DISTRICTS, A compilation of projects towards sustainable urbanization and the energy transition". 2020, LINK

[40] S. Bossi, C. Gollner, and S. Theierling, "Towards 100 Positive Energy Districts in Europe: Preliminary Data Analysis of 61 European Cases," Energies, vol. 13, no. 22, Art. no. 22, Jan. 2020, doi: 10.3390/en13226083.

[41] L. Casamassima, L. Bottecchia, A. Bruck, L. Kranzl, and R. Haas, "Economic, social, and environmental aspects of Positive Energy Districts—A review," *WIREs Energy Environ.*, vol. 11, no. 6, p. e452, 2022, doi: 10.1002/wene.452.

PEDs encompasses the idea that the energy transition must be equitable, moving beyond a purely technical approach. This commitment is underscored through frequent mentions of **citizen participation, community engagement, transition, prevention of energy poverty** and similar initiatives. PEDs have the potential to lower energy costs by promoting self-production and supporting prosumers, while also reducing energy consumption overall, thereby directly limiting energy expenses.

Despite its significant potential to transform urban sustainability, implementing the PEDs concept in Europe is confronted by a range of substantial barriers that slows the adoption and scaling of these innovative, sustainable urban energy models. Some key challenges include[42,43,44,45,46,47]:

1. **High initial costs and funding limitations**

   PEDs require substantial upfront investment in renewable energy infrastructure, energy storage systems, smart grids, and retrofitting existing buildings but access to public and private funding can be limited, especially in smaller municipalities. Additionally, ongoing costs for maintenance and upgrades can strain budgets and deter long-term commitment.

2. **Complex regulatory frameworks**

   European countries have diverse regulatory landscapes, and existing energy policies may not fully support or incentivize the localized energy generation and distribution model central to PEDs. Regulatory restrictions on energy trading, grid access and self-consumption complicate PED implementation, especially when coordinating multiple stakeholders and jurisdictions.

3. **Technical challenges**

   Achieving a positive energy balance within urban areas is technically complex. PEDs require advanced integration of renewable energy sources, energy storage and digital management systems to balance production and consumption dynamically. Additionally, issues like energy intermittency, grid reliability and cybersecurity vulnerabilities can pose significant obstacles.

4. **Coordination and stakeholder engagement**

   PEDs involve collaboration among municipalities, energy providers, residents, developers and technology providers. This diverse set of stakeholders may have varying interests, which can lead to challenges in coordination and decision-making. Also, gaining community support and achieving a common vision can be difficult, especially if the benefits of PEDs are not clearly communicated or perceived.

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[42] Joint Research Centre (European Commission), S. Shnapp, D. Paci, and P. Bertoldi, *Enabling positive energy districts across Europe: energy efficiency couples renewable energy*. Publications Office of the European Union, 2020. Accessed: Nov. 08, 2024. LINK
[43] P. Clerici Maestosi, M. Salvia, F. Pietrapertosa, F. Romagnoli, and M. Pirro, "Implementation of Positive Energy Districts in European Cities: A Systematic Literature Review to Identify the Effective Integration of the Concept into the Existing Energy Systems," *Energies*, vol. 17, no. 3, Art. no. 3, Jan. 2024, doi: 10.3390/en17030707.
[44] Han Vandevyvere, ENERGY DISTRICTS – FACTSHEET, Smart Cities Marketplace, 2021, LINK
[45] G. Turci, P. Civiero, I. Aparisi-Cerdá, I. Marotta, and G. Massa, "Transition Approaches towards Positive Energy Districts: A Systematic Review," *Buildings*, vol. 14, no. 10, Art. no. 10, Oct. 2024, doi: 10.3390/buildings14103039.
[46] S. Bossi, C. Gollner, and S. Theierling, "Towards 100 Positive Energy Districts in Europe: Preliminary Data Analysis of 61 European Cases," *Energies*, vol. 13, no. 22, Art. no. 22, Jan. 2020, doi: 10.3390/en13226083.
[47] European Comission, JRC Scientific and Policy Reports, Background Report on EU-27 District Heating and Cooling Potentials, Barriers, Best Practice and Measures of Promotion, 2012, LINK

5. **Lack of standardization and benchmarking**

   With limited standardization across Europe, defining what qualifies as a PED and measuring its success can be challenging due to diverse climate conditions, energy demands and urban layouts that require flexible models, respectively the absence of universal benchmarks that complicate replication and scaling. This lack of consistency can also hinder cross-country learning and knowledge-sharing.

6. **Space and infrastructure limitations**

   Many European cities are densely populated, with limited space for new infrastructure. Integrating solar panels, green roofs and storage solutions within existing urban areas is often restricted by building codes, heritage preservation and spatial constraints and retrofitting older buildings to meet PED standards can also be costly and technically challenging.

7. **Technological and knowledge gaps**

   Although Europe has strong renewable energy and smart technology sectors, knowledge gaps in implementing integrated PED systems persist, particularly at the local government level. These impose a need for training, resources and information sharing on best practices and emerging technologies.

8. **Economic and market dynamics**

   Traditional energy markets are structured around centralized energy distribution, which can disadvantage decentralized models like PEDs especially because of fluctuations in energy prices, competing priorities and economic uncertainties. In addition, market incentives and pricing structures often do not yet favour PEDs, making it harder to compete with established energy sources.

9. **Political and policy shifts**

   As political priorities and policies can shift with changes in government and this uncertainty can make it difficult to maintain the consistent, long-term investment and policy support needed for PED success.

Addressing these barriers will require coordinated efforts across regulatory, technological and community engagement frameworks, as well as the creation of supportive policies and financial incentives at both the EU and national levels.

PEDs in the context of Green Transition

Integrating renewable energy generation, energy efficiency, and smart technology to create self-sufficient and resilient communities. As European cities strive to reduce their carbon footprints and achieve sustainable development, the concept of PEDs has gained increasing attention[48].

Defining positive energy districts remains an ongoing challenge, as there is no universally accepted definition. However, the core principles involve districts that generate more renewable energy than they consume, with active interaction between

[48] Gohari, S., Steemers, K., Konstantinou, T., Soutullo, S., Liu, M., Giancola, E., Prebreza, B., Ashrafian, T., Murauskaitė, L., & Maas, N. (2021). Positive Energy Districts: Identifying Challenges and Interdependencies. In S. Gohari, K. Steemers, T. Konstantinou, S. Soutullo, M. Liu, E. Giancola, B. Prebreza, T. Ashrafian, L. Murauskaitė, & N. Maas, Sustainability (Vol. 13, Issue 19, p. 10551). Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/su131910551

energy generation, consumption, and storage systems. This holistic approach to energy management at the district level seeks to improve flexibility and efficiency, moving beyond building-level solutions[49].

The potential **benefits of positive energy districts are significant**. By leveraging renewable energy sources, improving energy efficiency and implementing smart technologies, these districts can reduce GHG emissions and move towards more sustainable urban development. Existing buildings and urban patterns, rather than new construction, are a key focus, as the scale of new buildings is insufficient to significantly impact overall energy consumption trends in the short and medium term.

The IEA EBC Annex 83 program provides a critical platform for the international scientific community to discuss and advance the understanding of positive energy districts. The program addresses key challenges, such as defining the boundaries of positive energy districts, the role of virtual and geographical boundaries, and the integration of various technological and social components[50]. Successful implementation of PEDs requires overcoming several interdependent challenges.

They play a transformative role in the Green Transition by reshaping urban spaces into energy-positive and sustainable environments. They contribute significantly to reducing greenhouse gas emissions, improving energy efficiency, and promoting renewable energy use in urban areas.

PEDs can make significant contributions to support the actual efforts of Green Transition:

- Are designed to produce more energy than they consume, typically through on-site renewable energy sources like solar, wind and geothermal. This surplus energy can be fed back into the grid or shared with surrounding areas, supporting a net-zero or carbon-neutral energy balance at the district level. By scaling PEDs across cities, urban areas can drastically reduce carbon emissions, paving the way for more cities to achieve carbon neutrality in line with global climate goals.
- By integrating local renewable energy production with community energy storage, PEDs reduce reliance on centralized fossil-fuel-based power grids. This decentralization enhances energy security and resilience, particularly during peak demand or disruptions. PEDs can serve as models for local energy autonomy, showcasing how cities can support reliable energy systems that adapt to the increasing strain on traditional grids due to population growth and electrification.
- Prioritize energy efficiency in buildings, transportation, and infrastructure, often incorporating passive building designs, energy-efficient appliances, and smart energy management systems. These measures reduce overall energy demand, lower operational costs, and set standards for high-performance urban design. Technology such as AI-driven energy management systems

[49] Lindholm, O., Rehman, H. ur, & Reda, F. (2021). Positioning Positive Energy Districts in European Cities. In O. Lindholm, H. ur Rehman, & F. Reda, Buildings (Vol. 11, Issue 1, p. 19). Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/buildings11010019
[50] Hedman, Å., Rehman, H. ur, Gabaldón, A., Bisello, A., Albert-Seifried, V., Zhang, X., Guarino, F., Grynning, S., Eicker, U., Neumann, H., Tuominen, P., & Reda, F. (2021). IEA EBC Annex83 Positive Energy Districts. In Å. Hedman, H. ur Rehman, A. Gabaldón, A. Bisello, V. Albert-Seifried, X. Zhang, F. Guarino, S. Grynning, U. Eicker, H. Neumann, P. Tuominen, & F. Reda, Buildings (Vol. 11, Issue 3, p. 130). Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/buildings11030130

enables PEDs to dynamically optimize energy production and usage, improving efficiency across the district.

- Serve as testing grounds for new renewable technologies and integration methods, allowing developers to pilot innovative solutions that can later be expanded to other areas. They offer a framework for integrating renewable sources into urban settings, blending rooftop solar panels, community wind turbines, and geothermal systems into the existing urban fabric. This not only promotes clean energy adoption but also facilitates a broader cultural shift towards renewable technologies within cities.
- Encourage community participation in the Green Transition by involving residents, businesses, and local stakeholders in energy production, usage, and management. Many PEDs operate community energy initiatives where residents can invest in or benefit from local renewable projects, fostering a sense of ownership and engagement. Educating communities within PEDs about sustainable practices can create a broader cultural shift toward greener lifestyles and behaviours, which are essential for long-term environmental change.
- Many PEDs incorporate smart and sustainable transport systems, such as electric vehicle charging stations, bike-sharing services, and pedestrian-friendly zones. By promoting these mobility solutions, PEDs reduce emissions from traditional transport, contribute to cleaner air quality and create healthier, more accessible urban spaces. This integration demonstrates a shift from car-centric planning towards more sustainable urban development.

In the context of the Green Transition, PEDs embody the concept of "living laboratories" where sustainable urban solutions are developed, tested and refined. They accelerate the transition by reducing energy consumption, minimizing carbon emissions and building resilient, future-ready communities that exemplify the potential of sustainable, climate-positive urban living.

Benefits of PEDs

PEDs deliver a range of impactful benefits, seamlessly aligning sustainability objectives while significantly enhancing urban resilience (Figure 4) [51, 52,53].

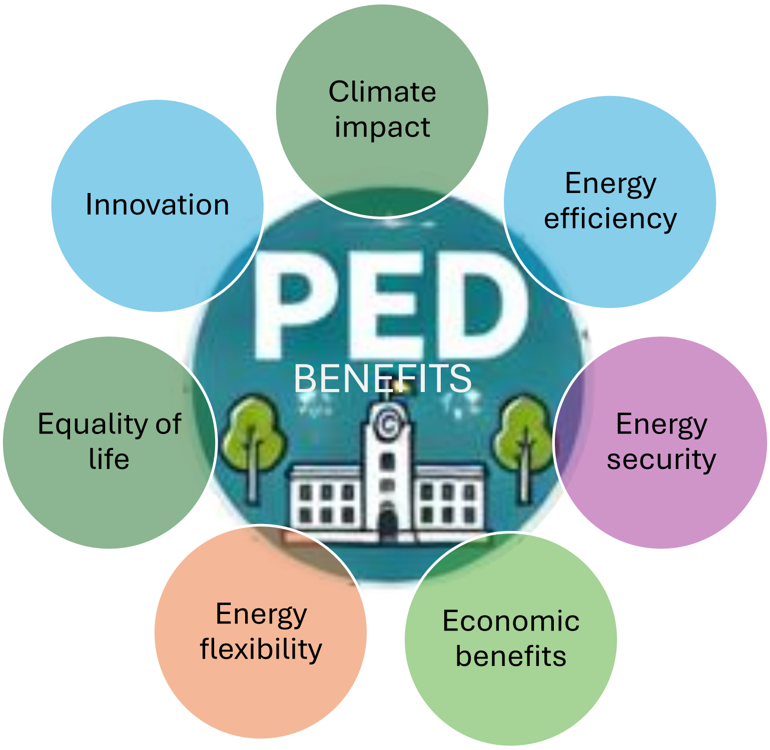

Figure 4. PED Benefits

Climate impact and carbon reduction

PEDs are essential for achieving climate objectives by prioritizing local renewable energy generation, reducing fossil fuel reliance and producing surplus energy to support carbon neutrality and global climate goals.

The local generation of renewable energy within PEDs - such as solar, wind and geothermal - substantially decreases the necessity to import energy from centralized fossil fuel-powered plants, which are typically major sources of GHG emissions. This localized strategy not only curtails carbon emissions but also reduces energy transmission losses that occur during long-distance energy transport. As a result, PEDs encourage the efficiency of each unit of energy produced, contributing to a lower carbon footprint for the entire city or region.

Beyond reducing emissions, PEDs increase climate resilience. By reducing reliance on fossil fuels and opting for renewable sources that emit zero emissions during operation, PEDs actively reduce air pollution, bringing environmental and health benefits to urban populations. Cleaner air and reduced pollutants lead to healthier

[51] U. Eicker, "Editorial: Positive Energy Districts: Transforming Urban Areas Into High Efficiency Districts With Local Renewable Generation and Storage," *Front. Sustain. Cities*, vol. 4, Apr. 2022, doi: 10.3389/frsc.2022.838899
[52] S. Ahmed, A. Ali, and A. D'Angola, "A Review of Renewable Energy Communities: Concepts, Scope, Progress, Challenges, and Recommendations," *Sustainability*, vol. 16, no. 5, Art. no. 5, Jan. 2024, doi: 10.3390/su16051749
[53] T. Healey Trulsrud and J. Van Der Leer, "Towards a positive energy balance: A comparative analysis of the planning and design of four positive energy districts and neighbourhoods in Norway and Sweden," *Energy Build.*, vol. 318, p. 114429, Sep. 2024, doi: 10.1016/j.enbuild.2024.114429.

communities, lower healthcare costs and an overall improvement in the quality of urban life.

Increasing energy efficiency

PEDs prioritize energy efficiency to foster sustainable urban development. By integrating energy-efficient building designs, advanced insulation, and energy-saving technologies, PEDs significantly reduce energy waste and optimize the use of RES. This focus on efficiency leads to lower energy consumption, decreasing reliance on external energy sources and alleviating pressure on regional and national grids.

Smart technologies play a very important role in PEDs by managing energy consumption based on real-time needs. Smart lighting, heating and cooling systems, together with smart appliances, dynamically adjust energy usage, reducing unnecessary consumption during peak hours and optimizing usage during periods of low demand. This approach not only improves energy efficiency in the district, but also contributes to grid stability by mitigating peak demand pressures.

Buildings in PEDs are often designed or retrofitted to meet high-performance standards, such as Passive House or Leadership in Energy and Environmental Design (LEED) certifications, which emphasize low energy consumption. Features such as energy-efficient windows, smart thermostats, heat pumps and energy recovery systems further enhance energy conservation, reducing the energy required for heating, cooling and operation.

In addition, PEDs can implement district heating and cooling systems that distribute thermal energy more efficiently across multiple buildings, minimizing individual energy requirements and maximizing collective benefits [54].

By reducing overall energy demand, PEDs provide economic benefits alongside environmental advantages, including lower operating costs for residents and businesses. Lower energy consumption can also extend the lifespan of infrastructure and equipment, as lower demand reduces wear and tear. In the long term, increasing energy efficiency within PEDs increases urban resilience, reducing the need for costly energy imports and insulating communities from price fluctuations in the energy market.

Energy security and independence

By his objectives to generate more energy than they consume, PEDs initiatives can protect cities from energy price volatility, supply disruptions and geopolitical risks, making urban areas more resilient to market fluctuations.

In addition, PEDs support grid stability through local energy distribution, which reduces transmission losses and reduces vulnerability to infrastructure failures following natural disasters or cyberattacks. With renewable technologies and diverse energy sources, PEDs create a robust and reliable supply.

Energy storage solutions, such as batteries, further support energy independence by storing surplus energy for use during peak demand or when renewable generation is low, allowing PEDs to efficiently balance generation and consumption. Smart grid technology and demand response systems enhance this flexibility, enabling real-time

[54] J. P. Gouveia, J. Seixas, P. Palma, H. Duarte, H. Luz, and G. B. Cavadini, “Positive Energy District: A Model for Historic Districts to Address Energy Poverty,” *Front. Sustain. Cities*, vol. 3, Apr. 2021, doi: 10.3389/frsc.2021.648473.

energy management and the potential to share surplus energy with neighbouring areas.

PEDs also promote regional resilience by creating networks of self-sufficient energy districts, reducing urban dependence on centralized infrastructure. Ultimately, PEDs contribute to environmental, economic and national security by reducing dependence on imported fuels and supporting sustainable, locally managed energy systems that strengthen urban resilience.

Economic savings and job creation

PEDs drive significant economic benefits by lowering energy costs and support local job creation. By generating renewable energy locally and improving energy efficiency, PEDs reduce reliance on costly, imported fossil fuels, leading to lower energy bills for residents, businesses, and municipalities. This translates into tangible cost savings for the community, allowing households to allocate more income to other needs and enabling businesses to reinvest in their growth.

Beyond cost savings, PEDs stimulate local economies by creating a range of job opportunities. The planning, construction and ongoing maintenance of PEDs require skilled workers in sectors such as renewable energy production, energy-efficient building design, construction, smart grid technology and energy storage systems. This demand supports a wide array of roles, from engineers and technicians to project managers and tradespeople, bolstering employment in both highly skilled and vocational fields.

Moreover, the long-term operation and advancement of PEDs necessitate expertise in data analysis, energy management and digital technology, encouraging innovation and drawing new talent into urban areas. As cities adopt PED frameworks, they create a foundation for sustainable economic growth, attracting investments and encouraging partnerships between public institutions, private enterprises and educational facilities focused on green technologies. These collaborations further expand the local workforce's expertise, strengthening the community's resilience and adaptability in the evolving energy landscape.

In sum, PEDs not only reduce energy costs and create various job opportunities, but also establish a self-sustaining economic ecosystem that supports long-term growth and enhances local prosperity through sustainable energy solutions.

Enhanced energy flexibility and stability

PEDs use advanced energy storage solutions and smart control technologies to create a dynamic and adaptive energy environment. By storing energy, such as batteries or thermal systems, PEDs can store surplus energy generated during periods of low demand and deploy it during peak periods, balancing fluctuations in energy availability. This storage capacity, coupled with smart control systems, allows PEDs to adjust energy demand and supply in real time, improving overall grid stability.

By reducing reliance on centralized grids and mitigating peak load pressures, PEDs provide critical support to the broader energy system, reducing pressure on traditional infrastructure. Smart control systems also facilitate demand response strategies, in which energy use can be modulated based on real-time conditions or price signals.

This adaptability not only improves the efficiency and reliability of local energy systems, but also helps mitigate the risk of outages or disruptions in the larger grid.

Ultimately, PEDs contribute to a resilient and stable urban energy ecosystem by balancing local energy generation, consumption and storage, making urban areas better equipped to efficiently manage energy demand while reducing pressure on centralized energy sources. This approach supports the transition to a more flexible, sustainable and reliable energy system that can dynamically respond to changing conditions.

Enhanced quality of life

PEDs significantly improve urban living standards by actively reducing air pollution, noise and GHG emissions.

PEDs also integrate green spaces and sustainable urban design, promoting natural environments within the urban landscape. Green spaces improve air quality, reduce the urban heat island effect and provide spaces for recreation and relaxation, enhancing residents' mental and physical well-being. PED designs often include infrastructure for walking, cycling and public transportation, which reduces noise pollution, reduces traffic congestion and promotes a pedestrian-friendly environment.

Community engagement is essential to the development of PEDs, ensuring that projects are designed with input from residents to reflect their needs and aspirations. This inclusive approach promotes a sense of ownership and pride, contributing to vibrant and connected neighbourhoods. With energy-efficient buildings, sustainable transportation and thoughtful urban planning, PEDs create environments where people feel connected, safe and supported, leading to a significant improvement in the overall quality of urban life.

Technological innovation and urban modernization

PEDs not only improve local energy generation and management, but also encourage the evolution of urban infrastructure, making cities smarter, more resilient and more environmentally sustainable.

PEDs create the foundation for future-ready urban environments, where technology continuously adapts to meet the needs of residents and businesses. By incorporating flexible and responsive energy systems, PEDs support the transition to low-carbon cities, reducing emissions while preparing urban spaces to adapt to future technological advances. This approach also encourages the adoption of IoT devices, real-time data analytics and artificial intelligence-based energy management, enabling cities to operate with increased efficiency, responsiveness and sustainability.

In addition, PEDs play a central role in transforming urban areas into hubs of sustainable innovation, attracting investment and stimulating economic growth. By working together with technology providers, policymakers and local communities, PEDs serve as testbeds for new energy technologies and practices, setting standards for modern, climate-neutral urban development that can be scaled up to other regions. In this way, PEDs accelerate the modernization of urban infrastructure and cultivate an ecosystem in which cities not only meet current energy and environmental goals but are also equipped to address future challenges in a rapidly changing world.

PEDs are a catalyst for urban innovation, incorporating the latest renewable energy, storage and smart grid technologies. This promotes the modernization of urban infrastructure and fosters an environment for future development.

In conclusion, PEDs advance **environmental, economic, and social objectives**, transforming cities into **sustainable, resilient, and highly liveable spaces** while aligning with ambitious **climate and energy goals**.

By using local renewable energy generation and reducing carbon emissions, PEDs directly contribute to environmental sustainability, helping cities achieve carbon neutrality and climate resilience goals. Economically, PEDs stimulate local job creation, attract green investment and reduce energy costs, supporting robust, self-sufficient urban economies that are less vulnerable to energy market fluctuations. Socially, PEDs improve the quality of urban life by promoting cleaner air, reducing noise pollution and creating healthier and more connected communities.

These districts encourage green spaces, sustainable mobility and community-led energy initiatives, fostering a sense of collective ownership and involvement in the transition to a low-carbon future. Through these combined impacts, PEDs become essential pillars in creating cities that not only meet current sustainability standards but are equipped to thrive in an equitable and climate-conscious future.

PEDs relevant stakeholders

The development of PEDs requires the active collaboration of diverse stakeholders, including municipal governments, energy providers, real estate developers, research institutions, non-governmental organisations (NGOs), financial institutions and local communities. Municipalities ensure regulatory alignment and infrastructure development, while energy providers manage renewable integration and grid stability.

Developers and researchers contribute innovative designs and technologies, supported by financing from financial institutions. NGOs advocate for inclusion and sustainability, engaging local communities to ensure that projects reflect their needs and gain public acceptance [55,56]. The involvement of this diverse group of stakeholders is essential for the holistic and sustainable development of PEDs, aligning technological advances with societal goals.

Table 1. Municipal authorities' roles and contributions

Stakeholder category: **MUNICIPAL AUTHORITIES**	
Role	**Contributions**
Urban planning and integration	▪ Oversee the spatial and infrastructural planning of PEDs, ensuring that they align with the city's overall master plan and local regulations. ▪ Facilitate the identification of suitable locations for PEDs based on criteria such as energy potential, connectivity and population density.
Policymaking and regulation	▪ Establish supportive policy frameworks (e.g. incentives for RES adoption, guidelines for sustainable building practices etc.) ▪ Ensure that PED initiatives comply with local, national and international (energy standards, emissions targets, urban design codes etc.)

[55] P. Clerici Maestosi, "Smart Cities and Positive Energy Districts: Urban Perspectives in 2020," *Energies*, vol. 14, no. 9, Art. no. 9, Jan. 2021, doi: 10.3390/en14092351.
[56] A. Kozlowska *et al.*, "Positive Energy Districts: Fundamentals, Assessment Methodologies, Modeling and Research Gaps," *Energies*, vol. 17, no. 17, Art. no. 17, Jan. 2024, doi: 10.3390/en17174425.

Infrastructure development	▪ Develop smart grids, renewables and energy storage. ▪ Align transport, water, and waste systems with energy-positive goals. ▪ Integrate green spaces and support multimodal transit networks to enhance sustainability and quality of life
Public financing and incentives	▪ Allocate funding or secure external grants for PED projects, making them viable for public and private stakeholders. ▪ Provide tax incentives, subsidies, or low-interest loans to encourage investment in sustainable technologies and energy-efficient buildings.
Facilitation of stakeholder collaboration	▪ Acting as mediators among various stakeholders - private sector players, utility companies, community organizations and residents - ensuring cohesive project execution. ▪ Host public consultations and stakeholder forums to build consensus, address concerns and incorporate diverse perspectives into the planning process.
Data acquisition and monitoring	▪ Collect, analyse and share data on energy consumption, emissions, and socio-economic impacts, helping to refine PED strategies and ensure accountability.
Advocacy and public awareness	▪ Lead public awareness campaigns about the benefits of PEDs, promoting community buy-in and participation.

Challenges

- ✓ Limited financial resources
- ✓ Bureaucratic hurdles, and resistance to change from stakeholders.
- ✓ Marginalized communities may have less access to participation opportunities leading to unequal representation in decision-making.

Opportunities

- ✓ Reduce household energy costs through energy-efficient designs and renewable energy systems.
- ✓ Implementation of green areas and nature based solutions
- ✓ Collaborative efforts among citizens, community groups and authorities build stronger, more cohesive neighbourhoods.
- ✓ Participatory models provide platforms for marginalized voices to be heard.

Table 2. Citizens & community roles and contributions

Stakeholder category: **CITIZENS AND COMMUNITY GROUPS**	
Role	**Contributions**
Fostering social acceptance and buy-in	▪ Educational campaigns and workshops can raise awareness about renewable energy, energy efficiency and sustainability ▪ Engaging communities from the planning stage ensures transparency, reduces resistance, and fosters trust, making it easier to gain support for changes like the introduction of renewable energy systems or retrofitting buildings.
Co-design and participatory planning	▪ Involving citizens in the decision-making process through public consultations, workshops or participatory design sessions ensures that solutions are inclusive and consider diverse perspectives. ▪ Community input helps identify specific needs and challenges unique to the area, leading to more tailored and effective designs. ▪ Local organizations, such as neighbourhood associations or advocacy groups, can act as intermediaries between policymakers and individual residents, facilitating smoother communication and representation. ▪ Residents often have a deep understanding of local climate, building traditions and community dynamics, which can inform better design and operational strategies.

	▪ Community groups can mobilize volunteers to support awareness campaigns, tree planting or maintenance efforts for green spaces within PEDs.
Encouraging behavioural change	▪ Implementing engagement programs that promote energy-saving habits and renewable energy adoption. ▪ Citizens can be involved in tracking energy consumption and production, creating a sense of responsibility and a collective drive to meet PED targets.
Promoting energy democracy	▪ Allowing residents to co-own or participate in these decentralized systems like solar panels or energy storage will lead to democratizes energy access and control.
Addressing equity and inclusion	▪ Engaging marginalized or low-income groups ensures that PEDs do not exacerbate existing inequalities and that all residents benefit from affordable, renewable energy. ▪ Community involvement ensures that cultural values and traditions are respected in the planning and implementation of PEDs.
Monitoring and feedback loops	▪ Residents can contribute to data collection and monitoring, such as tracking renewable energy production or environmental impacts. ▪ Establishing channels for ongoing feedback ensures continuous improvement of PED initiatives and maintains community satisfaction.

Challenges

- ✓ Limited time, knowledge.

Opportunities

- ✓ Fostering local empowerment, reducing energy costs, enhancing quality of life and strengthening community bonds.
- ✓ Engaging in PED projects allows communities to learn new skills, advocate for equitable urban development and influence sustainable practices.
- ✓ Support long term development.
- ✓ Supporting the tailoring of the urban transition to the real needs of end-users.

Table 3. Energy providers & utility companies roles and contributions

Stakeholder category: **ENERGY PROVIDERS AND UTILITY COMPANIES**	
Role	**Contributions**
Integration of renewable energy sources	▪ Assures the advanced planning the integration of RES into the local energy grid and optimization of energy production/ consumption.
Implementation of technologies to drive sustainability	▪ Implement smart grid technologies to monitor and optimize energy usage in real-time, ensuring energy is used efficiently. ▪ Manage energy storage systems, like batteries or thermal storage, to store excess energy during peak production and supply it during low production, ensuring grid reliability and consistent energy availability. ▪ Upgrading infrastructure to support advanced energy management systems and ensure resilience against potential disruptions.
Collaborative urban energy planning	▪ Collaboration with urban planners, architects, and local governments to co-develop infrastructure, adopt energy-efficient technologies and align energy strategies with the district's goals and urban design.
Community engagement, education and research	▪ Delivering initiatives to educate residents and businesses about energy-saving practices, the benefits of renewable energy, and participation in energy programs. ▪ Providing incentives for adopting energy-efficient appliances or installing renewable energy systems. ▪ Investing in research and development to pioneer new technologies such as advanced battery systems, smart metering devices and AI-driven energy management tools.

Supporting policy and regulation	▪ Utility companies can shape energy policies and regulations for PEDs, ensuring frameworks support innovation, scalability and financial viability.
Monitoring and reporting	▪ Continuous monitoring and transparent reporting of energy data by utility companies assures accountability and supporting data-driven decisions.

Challenges

- ✓ The need for costly infrastructure upgrades
- ✓ Lack of standardized policies for energy sharing or decentralized energy generation complicates operations.
- ✓ Financial risks and consumer adoption barriers.
- ✓ Difficulty to collaborate with local stakeholders (not financially interesting because it is more time consuming)

Opportunities

- ✓ Revenue diversification through innovative services like energy-as-a-service and peer-to-peer trading, enhanced grid resilience and leadership in smart technologies.
- ✓ Offering tailored solutions like dynamic pricing, renewable energy packages, and real-time energy usage data can strengthen customer loyalty.
- ✓ Educating consumers about smart technologies and sustainable practices opens new market opportunities.
- ✓ Active involvement in shaping regulations around PEDs ensures utility companies' interests are represented, paving the way for more favourable policies.

Table 4. Real estate developers and property owners roles and contributions

Stakeholder category: **REAL ESTATE DEVELOPERS AND PROPERTY OWNERS**	
Role	**Contributions**
Infrastructure development and design	▪ Incorporate sustainable materials, advanced insulation and architectural designs that maximize natural lighting and ventilation. ▪ Integration of RES technologies and smart home systems, energy management systems, and IoT-enabled devices to optimize energy usage. ▪ Replacing outdated systems with energy-efficient HVAC systems, LED lighting, and energy-efficient appliances ▪ Creating mixed-use developments that reduce the need for transportation and enhance community well-being
Collaboration and compliance	▪ Compliance with energy standards and urban planning requirements related to PED framework. ▪ Cooperation with municipalities and utility companies to facilitate shared infrastructure like district heating and cooling systems.
Leadership in market transformation	▪ Demonstrating the economic feasibility of energy-positive developments to encourage widespread adoption. ▪ Setting benchmarks for green certifications such as LEED or BREEAM. ▪ Higher property values, reduced operational costs and long-term savings for occupants.

Challenges

- ✓ High initial costs in developing or retrofitting buildings to meet PED standards
- ✓ Regulatory barriers
- ✓ Lack experience or technical knowledge about PED requirements, design standards and the integration of renewable energy technologies that lead to ppaperwork time consuming and sometimes difficulty in realize them.
- ✓ Uncertainty about demand for energy-positive properties or concerns about longer payback periods

- ✓ Collaboration with municipalities, utility companies and residents, which can lead to logistical and communication challenges

Opportunities

- ✓ Fostering local empowerment, reducing energy costs, enhancing quality of life, and strengthening community bonds.
- ✓ Engaging in PED projects allows communities to learn new skills, advocate for equitable urban development, and influence sustainable practices.

Table 5. Research institutions and universities roles and contributions

Stakeholder category: **RESEARCH INSTITUTIONS AND UNIVERSITIES**	
Role	**Contributions**
Research and Development (R&D)	▪ Drive innovation by developing new technologies and methods to enhance energy efficiency. ▪ Innovation on renewable energy generation, storage solutions, smart grid technologies and advanced materials for energy-efficient construction.
Knowledge hubs	▪ Academic institutions serve as repositories of expertise, offering a multidisciplinary approach to solving challenges in PEDs. ▪ Integrate insights from engineering, architecture, urban planning, social sciences, and environmental studies, providing holistic solutions tailored to urban energy needs.
Policy and standards development	▪ Researchers can collaborate with policymakers to establish frameworks, standards, and guidelines for the implementation and operation of PEDs. ▪ Researchers can provide evidence-based recommendations to ensure that energy-positive solutions align with national and international sustainability targets ▪ Partnership with local governments, businesses, and communities to offer technical expertise during the planning and execution phases of PED projects.
Community engagement and behavioural studies	▪ Conduct research on user behaviour and community dynamics, facilitating strategies for citizen participation and acceptance of PED initiatives; ssupport local stakeholders engagement and raise awareness ▪ They can act as a neutral intermediary, which citizens trust. ▪ Social science researchers analyse the socio-economic impacts of PEDs, ensuring that the benefits are equitably distributed among residents ▪ Implementing workshops, training sessions and seminars to upskill stakeholders in sustainable practices and emerging technologies.
Pilot projects and testing grounds	▪ Universities frequently act as testing grounds for new technologies and PED concepts through living labs or research campuses designed to simulate real-world scenarios.
Funding and collaboration	▪ Securing funding from international, national, and private sources, acting as coordinators for large-scale research consortia. ▪ Foster partnerships across academia, industry and government, ensuring a collaborative approach to PED implementation.
Monitoring and evaluation	▪ Provide performance metrics for PEDs through rigorous analysis and evaluation methods to contribute to continuous improvement and scalability of these solutions. ▪ Development of tools and methodologies for lifecycle assessments, energy simulations, and carbon footprint analysis.

Challenges

- ✓ Securing sufficient funding for long-term PED research and development can be challenging, especially in competitive grant environments.
- ✓ Adapting research to align with local policies and navigating bureaucratic hurdles can slow down innovation
- ✓ Translating pilot project findings into scalable solutions for larger urban areas can be technically and logistically demanding.
- ✓ Testing and deploying new technologies in living urban environments may face resistance or unforeseen challenges.

Opportunities

- ✓ Innovation development of cutting-edge technologies, such as smart grids, energy storage solutions, and renewable energy systems.
- ✓ Research findings can inform local, national and international policies, bridging gaps between theory and practice.
- ✓ PED projects could offer a platform for integrating diverse fields to address complex urban challenges holistically.

Table 6. Financial institutions and investors roles and contributions

Stakeholder category: **FINANCIAL INSTITUTIONS AND INVESTORS**	
Role	**Contributions**
Capital mobilization	▪ Provide the initial and operational funding required to kick-start PED projects (e.g. banks, venture capital firms, private equity funds) ▪ Large-scale renewable energy installations, grid modernization and energy storage systems represent significant cost components, to be financed through loans, bonds or equity investments.
Promoting sustainable investment standards	▪ Financial institutions to adopt Environmental, Social and Governance (ESG) criteria to evaluate the sustainability of PED projects.
Enabling scaling and replication	▪ Beyond initial funding, providing resources for scaling pilot projects to full-scale districts or replicating successful PED models in other urban areas. ▪ Offering lines of credit for large-scale urban developments and supporting cross-border collaborations.
Capacity building and stakeholder engagement	▪ Support capacity-building programs to equip local governments, developers, and community organizations with the knowledge and skills required to develop PED projects. ▪ Engage with stakeholders to ensure transparency and foster trust in the financial mechanisms supporting the district.

Challenges

- ✓ Variations in local regulations and lack of standardized frameworks
- ✓ Long payback periods and uncertain revenue streams
- ✓ Need of multiple stakeholders' involvement, including municipalities, energy providers and communities, complicates project execution and risk allocation.
- ✓ Financial institutions may lack technical understanding of PED concepts and their potential financial benefits, leading to hesitancy.

Opportunities

- ✓ PEDs align with the global trend towards sustainable investments, offering attractive options for ESG - focused portfolios.
- ✓ PEDs generate long-term revenues through energy savings, surplus energy sales and increased property values.

- ✓ Access to grants, funding programs, and favorable loans from organizations like the EU, World Bank and EIB (European Investment Bank).
- ✓ Early adoption positions financial institutions as leaders in sustainable finance, building reputational capital.

Table 7. NGOs and advocacy groups roles and contributions

Stakeholder category: **NON-GOVERNMENTAL ORGANIZATIONS (NGOS) AND ADVOCACY GROUPS**	
Role	**Contributions**
Advocacy for sustainable development	▪ Advocacy organizations may push for legislation that incentivizes the use of renewable energy in urban districts or regulations that mandate energy efficiency standards in construction.
Community engagement and awareness	▪ Facilitating participatory workshops and consultations to involve residents in the planning process. ▪ Educating the public about the benefits of PEDs, such as reduced energy costs, improved air quality and enhanced urban life. ▪ Addressing potential community concerns, such as displacement, affordability or cultural preservation, to ensure inclusive development.
Ensuring social and environmental equity	▪ Advocate for equitable access to energy resources and benefits, ensuring marginalized communities are not excluded. ▪ Sustain the preservation of biodiversity and natural habitats within urban planning. ▪ Militate for climate resilience strategies that consider vulnerable populations most at risk from climate change impacts.
Capacity building and knowledge sharing	▪ Organizing training programs, workshops and knowledge-sharing platforms for various stakeholders, including policymakers, developers and community members.
Fostering multi-stakeholder collaboration	▪ Working as mediators between diverse stakeholders, including governments, businesses and communities (e.g. by organizing multi-stakeholder dialogue forums to align the goals of municipal authorities, private developers and residents).

Challenges

- ✓ Limited financial resources
- ✓ Policy and regulatory barriers
- ✓ Lack of technical knowledge required to contribute effectively to PED-specific innovations
- ✓ Effective collaboration with multiple stakeholders, including municipalities, private companies and residents, can be complex and time-consuming.
- ✓ NGOs may face challenges in being recognized as significant contributors to decision-making processes in projects dominated by government and corporate interests.
- ✓ Long-term engagement in PED projects can strain NGOs' capacity, given their reliance on donations, grants or temporary funding.

Opportunities

- ✓ NGOs can act as bridges between communities, governments, and private stakeholders, promoting trust and collaboration.
- ✓ Advocacy groups can ensure that the voices of marginalized and vulnerable populations are included in PED planning.
- ✓ By piloting small-scale community projects, NGOs can demonstrate innovative solutions that can later be scaled within PEDs.

2. Assessment of PEDs in project partners countries

This chapter provides a detailed analysis of PEDs across several European countries, including Romania, Switzerland, Spain, Latvia, Portugal, and Norway. It explores legislative frameworks, technological advancements, economic factors and societal dynamics that influence the development and implementation of PEDs. It represents a transformative approach to urban energy systems, emphasizing renewable energy integration, energy efficiency and community engagement, while addressing challenges posed by climate change and the energy transition.

They face significant regulatory and institutional challenges, including ambiguous legal definitions, complex permitting processes and insufficient national strategies. Economic barriers such as high initial costs for renewable technologies, limited financial incentives and regulatory gaps further slow their development. Technical issues, such as the integration of renewable energy into existing grids, the lack of sufficient energy storage solutions and the need for advanced smart metering and billing systems, add layers of complexity. At the same time, social dynamics reveal low public awareness of PEDs in many regions, despite the potential benefits demonstrated by existing projects. These benefits include reduced energy costs, decreased carbon emissions and stronger community engagement.

The findings highlight the transformative potential of PEDs in helping sustainable urban development and combating climate change. However, widespread adoption requires robust regulatory frameworks, enhanced funding opportunities, technological advancements and active community participation. By addressing current challenges and drawing from best practices, EU can accelerate the transition to positive energy systems, ensuring environmental sustainability and economic resilience.

Romania

Legislative framework, regulations and standards for PEDs

Given the novelty of the concept and its largely theoretical terminology, PEDs lack a dedicated legal framework at the national level in Romania. Establishing a PED requires navigating a complex legal process, starting with building and planning permits and culminating in environmental certifications and the integration of renewable energy sources into the National Grid. In the absence of specific legislation, project initiators must collaborate with a wide range of stakeholders, including local authorities, system operators, environmental agencies and other institutions involved in energy, construction and sustainable transport. This section therefore explores various thematic areas closely linked to PEDs.

- Law no. 121/2014 on Energy Efficiency, amended by Law no. 160/2016, incorporates the provisions of Directive 2012/27/EU on energy efficiency (EED).[57]
- Law no. 372/2005 on the Energy Performance of Buildings, republished through Emergency Government Ordinance no. 13/2016 and further amended by Law

[57] https://legislatie.just.ro/Public/DetaliiDocument/160331

no. 156/2016, transposes Directive 2010/31/EU on the energy performance of buildings (EPBD). [58]

- Law no. 325/2006 on the Public Service of Thermal Energy Supply is currently under review in Parliament. [59]
- Cogeneration Bonus: Government Decision no. 1215/2009 outlines the criteria and conditions for implementing a high-efficiency cogeneration support scheme based on useful thermal energy demand. This decision has been amended multiple times by Government Decisions no. 494/2014, 925/2016, 129/2017, and 846/2018. A new support scheme for the post-2023 period is presently under discussion in Parliament. [60]

Secondary legislation in Romania is mainly developed by ANRE (National Regulatory Authority for Energy).

In the **thematic domain of technical regulations on energy performance (Buildings)**, minimum energy performance requirements for both new and existing buildings have been established by MLPDA through Order no. 2641/2017, which amends the technical regulation *"Methodology for calculating the energy performance of buildings,"* initially approved by Order no. 157/2007. Additional standards include the *Norm on the Thermomechanical Calculation of Building Elements (C107-2005)*, approved through Order no. 2055/2005 and subsequently amended several times. Other updates to the *Methodology for Calculating Energy Performance* include amendments from Order no. 1071/2009 to Order no. 2641/2017. In the **thematic domain of energy performance certificates**, these requirements derive from Directive 2010/31/EU, incorporated into Law no. 372/2005. The methodology for calculating energy performance (Standard Mc 001-2006) provides comprehensive guidelines for creating energy performance certificates, defining their content, calculation methods, and procedural models.

In the **thematic domain of standards for equipment and labelling of household appliances**, Government Decision no. 55/2011 sets ecological design requirements for energy-related products. Meanwhile, Government Decision no. 917/2012 aligns Romanian practices with EU Commission Delegated Regulations (EU) No. 1059/2010 to No. 1062/2010, providing guidelines on energy labelling and standard product information for energy-impacting products.

In the **thematic domain of homeowners' associations**, Law no. 114/1996 mandates the establishment of homeowners' associations for residential buildings, enabling them to contract private management companies and oversee long-term repairs and maintenance. Law no. 196/2018 further governs the organization, administration and functioning of these associations.

In the **thematic domain of energy audits**, Law no. 159/2013, which republishes Law no. 372/2005, requires energy performance certificates (EPCs) for rented or sold properties. While energy audits are not mandatory for transactions, they are vital for energy renovation projects financed by public funds. Certified building energy auditors are responsible for ensuring compliance, maintaining records and submitting reports to MLPDA.

[58] https://legislatie.just.ro/Public/DetaliiDocument/66970
[59] https://legislatie.just.ro/Public/DetaliiDocument/73837
[60] https://legislatie.just.ro/Public/DetaliiDocument/113023

In the **thematic domain of energy service companies (ESCOs)**, Romania currently lacks a dedicated regulatory framework for ESCOs. ANRE is coordinating efforts to develop such a framework, leveraging the experiences of other EU member states. Energy performance contracts remain underutilized, primarily addressing energy supply systems rather than large-scale renovations.

In the **thematic domain of energy communities**, Directive 2019/944 and Law no. 123/2012 (Electricity and Natural Gas Law) introduce the concept of energy communities, further expanded by Law no. 121/2014. Emergency Ordinance no. 163/2022 recently refined the legal framework for promoting renewable energy use, defining the establishment and operation of energy communities and came into effect on December 6, 2022.

Energy communities with potential evolution to PEDs

In Romania, although there are no established PEDs, several energy communities show great potential to evolve into such districts. These communities exemplify the growing interest in sustainable energy practices and the application of renewable energy solutions. By building on their current initiatives and aligning with the principles of PEDs, these projects could pave the way for the development of Romania's first PEDs. Below are some notable examples of energy communities with this potential:

Table 8. Cooperativa de energie

<table>
<tr><th colspan="2">Name: Cooperativa de energie[61]</th></tr>
<tr><td>Location: Bucharest, Romania</td><td>Type of district: Commercial</td></tr>
<tr><td>Number of members: 984</td><td>Established: 2019</td></tr>
<tr><td colspan="2">Description: The cooperative functions as a consumer energy community, supplying energy to its members while also selling surplus energy on the market. This is achieved by acquiring a supplier to obtain a supply license.</td></tr>
<tr><td colspan="2">Technology & Infrastructure: It operates as an electricity supplier, providing 100% green energy certified with guarantees of origin.</td></tr>
<tr><td colspan="2">Funding: The cooperative entered the market as Romania's first 100% green energy supplier by acquiring the existing energy company Apuron Energy SRL. This was made possible through the financial contributions of its members.</td></tr>
<tr><td colspan="2">Governance Structure: The cooperative functions as a democratic organization owned and controlled by its members.</td></tr>
<tr><td>Challenges:
• The energy market in Romania is heavily dominated by large companies, limiting competition.
• Despite the country's considerable green energy potential, domestic consumers face limited access.
• To launch the initiative, over 100 members collectively invested 2 million lei in green energy, enabling the cooperative's market entry.</td><td>Successes:
• The cooperative exclusively supplies electricity from renewable sources such as solar, wind, and hydro, significantly reducing CO2 emissions and addressing climate change.
• Its democratic governance model allows members to actively participate in decision-making, invest in green energy projects, and contribute to the energy transition.
• It actively raises awareness through energy education campaigns, promoting the importance of green energy and responsible consumption.</td></tr>
<tr><td colspan="2">Current Status: The cooperative comprises 984 members and supplies green energy to 412 consumers. In 2023, it delivered a total of 2 GWh of electricity.</td></tr>
</table>

[61] https://cooperativadeenergie.ro/

Table 9. ÎntreVecini

Name: ÎntreVecini[62]	
Location: Bucharest, Romania	**Type of district**: Residential
Number of members: 9 communities	**Established**: 2021
Description: ÎntreVecini is a non-governmental, non-political, non-profit organization with no financial ownership purpose. The project provides financial support to tenants' associations for the installation of photovoltaic systems, designed to cover energy consumption for shared areas only, with any surplus generating income for the association.	
Technology & Infrastructure: The initiative involves installing photovoltaic panels on rooftops to capture solar energy. However, due to regulatory constraints, the energy generated is exclusively used in common areas, such as lighting and elevator operation. Any excess green energy is returned to the national grid, earning compensation for the owners' association from the energy provider.	
Funding: Funding for the project was provided by BRD Société Générale Bank, through the NGO "ÎntreVecini." The NGO initially organized a proposal competition for a specific area in Bucharest (now nationwide), with a grant of 10,000 euros, primarily used to cover photovoltaic system installation costs and to fund educational campaigns for residents.	
Governance structure: Romania transposed the RED II Directive into law in December 2022 through GEO.	
Challenges: • Ambiguity in legislation regarding energy communities and shared consumption, with the Romanian law allowing energy communities but imposing many restrictions not required by law, often due to a lack of specific legislative norms. • Resistance from property owners to joining an organization with their neighbours, a common issue rooted in cultural and historical factors.	***Successes:*** • Reduced energy costs for owners in common area. • The energy project helped neighbours who would not have interacted otherwise to come together. • The production of local green energy significantly reduced the building's carbon footprint. In 2022, ÎntreVecini organization transformed a typical apartment building into a "community of energy" called Grădina Apusului, demonstrating the potential for positive change and community unity.

Table 10. Grădina Apusului

Name: Grădina Apusului, Sector 6, Bucharest[63]	
Location: Bucharest, Romania	**Type of district**: Residential
Number of members: 60 dwellings	**Established**: 2022
Description: In 2021, the Tenant's Association applied for a grant provided by the ÎntreVecini Association, which offered both technical assistance and financial support for the installation of photovoltaic panels on the building. By 2022, the initiative delivered substantial benefits to the community. The project not only enabled the residents to generate their own energy but also fostered a sense of community, particularly through the creation of a garden in the block's courtyard where vegetables and shrubs were planted, sparking shared interest among neighbours. That same year, the community achieved "prosumer" status, producing green energy and feeding it into the national grid.	
Technology & Infrastructure: Photovoltaic panels covering an area of 40m² on the rooftop generate an average of 729kWh per month.	
Funding: The grant from ÎntreVecini provided the necessary budget for the panels, amounting to approximately 5,500 euros.	

[62] https://intrevecini.ro/
[63] Greenpeace, *Comunitățile de energie în România: De la aspirație la realitate. Resurse pentru cetățeni și autorități publice*,2024. Disponibil online: https://www.greenpeace.org/static/planet4-romania-stateless/2024/03/92dec3a9-comunitatile-de-energie-in-romania-de-la-aspiratie-la-realitate.pdf

Governance structure: Prosumer	
Challenges: • Ambiguity in legislation concerning energy communities and shared consumption. • Resistance from property owners to joining an organization with their neighbours, a common challenge rooted in cultural and historical factors.	***Successes:*** • Reduced energy costs for property owners. • The energy project fostered a sense of community among residents. • A significant reduction in the building's carbon footprint. Moreover, the success of this initiative is evident in the expansion of similar projects. In 2023, ÎntreVecini Association launched new energy communities, including Blocul Liric, Rose Garden, Vlaicu Vodă, Pridvorului and Broscuțele in Bucharest, as well as AM Social Space (twice).

Table 11. Buteni Community

Name: Buteni Community[64]	
Location: Buteni, Arad	**Type of district**: Residential
Number of members: 900 households	**Established**: 2020
Description: In 2020, 107 households installed PV panels through the Green Photovoltaic House program, with some additional installations funded privately. Another 80 applications have been approved and are awaiting funds from the 2023 edition of the program. As a result, approximately 20% of the households are or will soon be prosumers. City Hall team facilitated the application process, providing guidance on the procedure, roles, responsibilities, and both short and long-term benefits. To date, the installed PV systems have a total capacity of around 800 kW, generating approximately 900 MWh per year. The investment, totalling EUR 1 million is expected to be recouped in about three years.	
Technology & Infrastructure: PV systems are installed on rooftops of individual households. The future energy community will use the national distribution grid to deliver green energy to system, and once legislation permits, share energy within the community.	
Funding: Green Photovoltaic House program	
Governance structure: Romania transposed the RED II Directive into national law in December 2022 through GEO 163/2022, which defines energy communities based on the European directive. According to this legislation, energy communities are entities that operate with open, voluntary participation and are controlled by their members. These communities aim to provide economic, social, or environmental benefits to members or local areas, rather than pursuing financial profits.	
Challenges: • Ambiguity in legislation related to energy communities and shared consumption. While Romanian law allows the formation of energy communities, numerous restrictions are imposed, which are often due to a lack of clear legislative norms. • Lack of awareness and basic technical knowledge among homeowners.	***Successes:*** • Reduction in energy costs for homeowners. • The energy project united neighbours who would otherwise not have interacted. • By generating green energy locally, the community significantly reduced its carbon footprint. The community's investment in photovoltaic panels, totalling approximately 800 kW in capacity and 900 MWh of annual production, has been a key factor in the community's progress toward energy sustainability.

[64] https://buteni.ro/

Table 12. Flamingo 50

<table>
<tr><th colspan="2">**Name**: Flamingo 50, Balotești, Ilfov</th></tr>
<tr><td>**Location**: Balotești, Ilfov, Romania</td><td>**Type of District**: Residential</td></tr>
<tr><td>**Number of members**: 27 members from 30 households, with 5 more in the joining process</td><td>**Established**: 2022</td></tr>
<tr><td colspan="2">**Description**: Flamingo 50, located in Balotești, Ilfov, is a newly established energy community developed with the participation of the neighbourhood. The goal was to create a platform where community members could share the energy they generate, with the added challenge of ensuring resilience and grid independence, as the area is geographically isolated and served by a single energy distributor. The community is represented by the homeowners' association. Members were inspired by the Greenpeace Community Guide, exploring ways to implement sustainable solutions and reduce reliance on traditional energy sources. About 25% of homeowners received funding from the "Casa Verde" program, while the remaining 75% financed the installation of photovoltaic panels independently. The energy generated is used for heating and charging electric cars, with the majority of the 51 adult residents working from home, resulting in higher energy consumption during the day.</td></tr>
<tr><td colspan="2">**Technology & Infrastructure**: Photovoltaic panels installed on each household's roof, along with electric car charging stations.</td></tr>
<tr><td colspan="2">**Funding**: Green Photovoltaic House program and private funding.</td></tr>
<tr><td colspan="2">**Governance Structure**: Electricity supplier</td></tr>
<tr><td>***Challenges:***
• The community is located in a remote area, making it difficult to access essential services such as quick repairs during power outages.
• Is still in the process of discussion and documentation, facing challenges in interconnecting with its members.
• Ambiguity in legislation regarding energy communities and shared consumption. While Romanian law allows the formation of energy communities, numerous restrictions exist, not all of which are legally required, but stem from a lack of detailed legislative norms.</td><td>***Successes:***
• The community is successfully supplying energy for heating and electric car charging.
• The energy portfolio has been diversified, reducing dependence on the region’s sole energy supplier.</td></tr>
</table>

Additionally, similar ideas for energy communities are emerging in early stages in locations such as Petroșani (Hunedoara County), Râmnicu-Vâlcea (Vâlcea County), Mediaș (Alba County), and Cluj-Napoca (Cluj County), as well as in other localities.

Current technological status

Smart metering

In Romania, the smart metering system is being rolled out in accordance with the stipulations of ANRE Order no. 177/2018, which approves the Framework Conditions for the national implementation schedule of smart electricity metering systems.[65]
The timeline for the nationwide rollout of smart electricity meters from 2019 to 2028 was approved through ANRE's President's Decision no. 778/08.05.2019 and is outlined below by region.

[65] https://www.reteleelectrice.ro/content/dam/retele-electrice/Contor-inteligent/Documents/Calendar-aprobat-dec2019.pdf

Table 13. Users integrated into the smart metering system

Electricity distribution service concession area	Total number of users integrated in the intelligent monitoring system per region	Approximate cumulative share of users integrated in the intelligent monitoring system in 2024	Approximate cumulative share of users integrated in the intelligent monitoring system by 2028
Distributie Muntenia	775,405	42%	65%
e-Distributie Banat	488,727	40%	60%
e-Distributie Dobrogea	411,466	47%	70%
Distributie Energie Oltenia	600,187	27%	41%
Delgaz Grid	397,464	34%	45%
SDEE Muntenia Nord	451,663	19%	35%
SDEE Transilvania Nord	403,242	20%	33%
SDEE Transilvania Sud	506,276	19%	39%
TOTAL	**4,034,430**	**31%**	**49%**

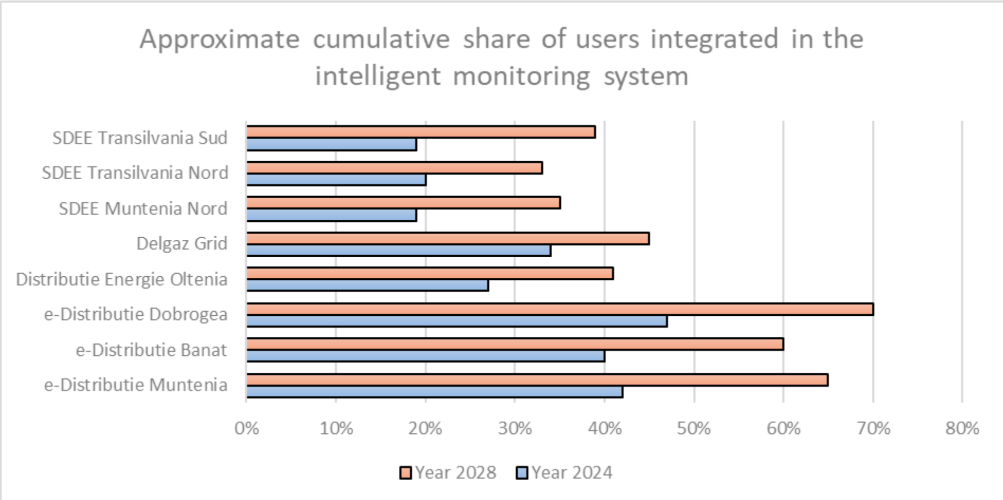

Figure 5. Evolution of users integrated into the smart metering system

In summary, Romania's smart metering implementation, guided by ANRE Order no. 177/2018, aims to modernize the electricity network by integrating nearly half of users into intelligent systems by 2028, supporting national goals for efficiency and sustainable energy management[66].

Green mobility solutions

In 2023, 2.35% of the Romanian car fleet was made up of electric vehicles (EVs) out of which 0.44% were battery EVs and 1.91% hybrid EVs. That accounts for over 42,000 electric cars with a year-on-year increase in the registration rate of 35%,

[66]https://www.reteleelectrice.ro/content/dam/retele-electrice/Contor-inteligent/Documents/Calendar-aprobat-dec2019.pdf

representing 16,800 new vehicles. And as for the charging infrastructure, Romania has a total of 782 charging stations accessible for use.[67]

Incorporation of electricity storage

The biggest industrial electric power storage facility started functioning this year, with a 50 MWh capacity. This being the first out of three stages to develop a total of 216 MWh of storage capacity. This solution being fully automatic, is developed by Monsson Alma SRL, and it employs a hybrid solar-wind plant to produce the energy that is stored in locally made Li-Ion battery cells.[68]

According to the latest information from the national regulatory authority, ANRE, Romania also has 2 MWh of battery storage installed. The flexibility of the energy system currently relies on hydroelectric power plants and the conventional generation assets based on coal and natural gas. NECP projects over 6 GW of new renewable energy sources by 2030, alongside the phasing out of conventional capacity, necessitating substantial grid upgrades and enhanced flexibility. However, there is a notable gap between the 2030 renewables target and Transmission System Operator (TSO) current grid development plans, though these plans are subject to biennial updates. While the NECP provides limited guidance on storage technologies, the Energy Strategy suggests a major role for large-scale storage post-2030, with the possibility of 1,000 MWh of pumped hydro storage by 2050. The forthcoming 2050 long-term strategy is expected to offer more detailed decarbonization pathways, informing a roadmap for storage development through 2030 and 2050[69]. And due to the government's photovoltaic program (Casa Verde 2024), funding is allocated to 67.000 households to install solar panels with electricity storage capacities, to increase self-sufficiency[70]. According to the instalment offers of Eon, the storage system in each household will have a capacity of approximately 5.5 kWh, overall adding a storage capacity of around 36.5 MWh[71].

Romania is advancing its energy storage with the launch of a 50 MWh facility, the first stage of a planned 216 MWh project powered by hybrid solar-wind energy. However, flexibility still relies on coal, natural gas, and hydro sources, with only 2 MWh of battery storage nationwide. The NECP aims for 6 GW of new renewable capacity by 2030, requiring substantial grid upgrades. Through the Casa Verde 2024 program, solar and storage installations in 67,000 households will add 36.5 MWh. While future strategies emphasize large-scale storage post-2030, immediate infrastructure efforts are critical to meet renewable targets.

[67] Analysis of electric vehicles contribution to CO2 reduction – case study
[68] https://www.digi24.ro/stiri/economie/energie/a-fost-pusa-in-functiune-cea-mai-mare-capacitate-de-stocare-a-energiei-electrice-in-baterii-din-romania-2752255
[69] https://www.enpg.ro/wp-content/uploads/2023/07/Storage_17-Dec_.pdf
[70] https://www.afm.ro/main/media/comunicate_presa/2024/comunicat_presa_24092024.pdf
[71] https://www.eon.ro/afm-casa-verde

Switzerland

Legislative framework, regulations and standards for PEDs

Switzerland is a non-EU member state, but Switzerland and EU have been closely cooperating for many years. Since 2007, Switzerland has been negotiating a bilateral agreement to achieve full compatibility between Swiss and EU electricity regulations[72]. [Extent to Swissgrid and ENTSO-E]

In Switzerland, the regulatory and legislative framework for PEDs is evolving to meet the demands of sustainable energy development. Although specific definitions and rules for PEDs are not yet established, Switzerland's alignment with EU regulatory frameworks suggests forthcoming changes, particularly in laws and ordinances governing energy communities.[73]

At the federal level, **the Federal Energy Law** (LEne) establishes the principles and objectives of Switzerland's energy policy, aiming to reduce carbon emissions, enhance energy security, and promote renewable energy. Recent amendments, effective from February 1, 2024, reflect Switzerland's commitment to adapting to new energy needs and technological advancements. **The Energy Ordinance RU 2017 6889 (OEn)** provides detailed regulations to implement the Federal Energy Law, with recent updates aimed at enhancing regulatory clarity and efficacy.[73]

Electricity Supply Law RU 2007 3425 (LAEl), updated as of January 1, 2024, ensures reliable and sustainable electricity supply, promoting renewable energy sources and improving the power grid. The companion **Electricity Supply Ordinance RU 2008 1223 (OAEl)** offers precise regulations for daily electricity supply operations, emphasizing efficiency and reducing bureaucratic hurdles. **Federal Law on Secure Electricity Supply with Renewable Energies [FF 2021 1667],** currently under referendum, aims to advance renewable energy sources while ensuring reliable electricity supply, potentially accelerating the adoption of clean energy technologies.[73]

In Canton Ticino**, the Cantonal Energy Law (Len)** and the **Energy Utilization Regulation (RUEn)** address regional energy issues. Recent amendments to these laws, effective from early 2024, promote sustainable energy initiatives and tackle local energy challenges, for the rapid development and deployment of renewable energy technologies and energy efficiency measures.[73]

It does not yet have a precise legal definition PEDs, but ongoing discussions highlight their potential to significantly reduce carbon emissions, enhance energy resilience, and foster community engagement. Establishing a PED involves several key steps, including obtaining approvals for **RES installations** and forming **Energy Communities**. This process requires collaboration among stakeholders, adherence to zoning and environmental regulations, and securing grid connections and contracts with ESCOs. Overall, Switzerland's evolving regulatory framework aims to support sustainable urban development and the integration of renewable energy, positioning PEDs as a promising solution for future energy systems.

[72] https://cms.law/en/int/expert-guides/cms-expert-guide-to-electricity/switzerland
[73] https://www.bfe.admin.ch/bfe/en/home.html

Energy communities with the potential to evolve into PEDs

In Switzerland, several energy communities with the potential to evolve in PEDs have been identified, showcasing the country's commitment to sustainable urban development and innovative energy solutions. These districts exemplify how communities can achieve energy efficiency, integrate renewable energy sources and foster collaboration among stakeholders to create energy-positive environments.

Table 14. Winterthur City

Name: Winterthur City[74]	
Location: Winterthur, Zürich	**Type of district**: Residential
Number of members:	**Established**: 2023
Description: The Winterthur City Council adopted the Municipal Energy Plan in 2013 (Energy Plan 2011). Since then, Stadtwerk Winterthur has significantly expanded the district heating networks, increasing their connection density by utilizing waste heat from the incineration plant. The city plans to phase out gas supply in Gotzenwil by 2026, aligning with stricter climate targets for achieving net zero CO2 emissions. Winterthur has committed to reaching this target by 2040, while Switzerland as a whole has set its climate neutrality goal for 2050.	
Technology & Infrastructure: **District Heating:** Eight thermal grids are operational in Winterthur, most of which rely on renewable energy sources. Three grids use waste heat from the incineration plant, while five are fuelled by wood. **Gas Network:** The residential area is predominantly connected to Stadtwerk Winterthur's gas pipeline network. **Oil and Wood Heating:** Data collected from chimney sweeps records all gas, oil and wood combustion heating systems in the city. **Data Management:** The Environmental and Health Protection Department (UGS) of Winterthur publishes an emissions register and a comprehensive municipal environmental report every four years, which includes energy balancing and greenhouse gas inventories.	
Goals for 2040 and legal framework: Winterthur follows the **2000-Watt Society**, a concept aimed at translating higher-level energy and climate goals into local actions. The city strives to: • Achieve **energy efficiency** with 2000 watts of continuous primary energy per person. • Attain **climate neutrality**, eliminating energy-related GHG emissions. • Transition to a **100% renewable energy supply** by 2050.	
Challenges: • A significant number of buildings are still reliant on oil and gas heating. Property owners are often challenged to find climate-neutral alternatives when these systems need replacement at the end of their lifecycle.	***Successes:*** • Winterthur has been recognized as an energy city since 1999. • City has earned the European Energy Award Gold four times, most recently in 2019.

Table 15. Green Village

Name: Green Village[75]	
Location: Geneva, Switzerland	**Type of district**: Residential
Number of members: 6 buildings	**Established**: 2011
Description: Situated in the municipality of Grand-Saconnex in the Nations quarter, Green Village represents Geneva's first real estate development to achieve SEED next-generation living certification. It is also one of only three pilot projects in Switzerland with this recognition.	
Technology & Infrastructure: Green Village aligns with the ten principles of **One Planet Living®**, incorporating: **Health and happiness:** Maximizing natural light and offering park views.	

[74] https://decarbcitypipes2050.eu/wp-content/uploads/2023/09/D4.4_Transition-Roadmaps-Winterthur.pdf
[75] https://green-village.ch/en/sustainability/

Equity and local economy: A daycare centre and spaces fostering user communities.
Culture and community: Facilities like the ecumenical centre and Brugger garden.
Land and nature: Green roofs and elements designed to support faunal diversity.
Sustainable water: Open-air water management systems and low-consumption taps.
Local & sustainable food: Features such as fruit trees and sustainable food options.
Travel and transport: Infrastructure including bike racks, soft mobility networks, and bus stops.
Zero waste: Implementation of waste sorting and elimination of single-use plastics.
Energy efficiency: Zero CO2 emissions, geothermal heating, and 100% renewable energy.

Every building in Green Village symbolically bears the name of the cities that have hosted international conferences on the environment and sustainable development, namely: Kyoto (2024); Montreal (2022); Rio (2026); Lima (2026); Durban, and Stockholm (2027).

Challenges:

Maintaining SEED certification is sustained through a fee system applied to all current and future residents.

- Two-thirds of the fees fund on-site activities, including sustainable development training, fostering intergenerational exchange and adapting the infrastructure to address climate change.
- The remaining portion is used for the certification process itself.

Successes:

- A robust offering, further boosted by the 2027 arrival of the Nations tramway.
- Safe access via two green bike lanes.
- Easy navigation through green neighbourhood spaces.
- Electrified squares and almost 300 underground parking spaces, with over 90% equipped for electric vehicle charging.

Table 16. Lucerne

Name: Lucerne[76]	
Location: Lucerne, Switzerland	**Type of district**: Residential & commercial
Number of members: -	**Established**: 2023

Description: The city of Lucerne integrates ecological, economic, and social dimensions of sustainability into various initiatives. Its achievements include earning the **Grünstadt** and **Energiestadt Gold** labels. Both the city and Lucerne Tourism are committed to fostering sustainable tourism by optimizing their operations and promoting natural and cultural attractions for business and leisure travellers.

Technology & Infrastructure: Lucerne Tourism emphasizes:

- Extending the average length of guest stays.
- Encouraging environmentally friendly transportation by motivating visitors to use public transport and adopt climate compensation practices.
- Systematically incorporating environmental and sustainability considerations into offer designs.
- Implementing environmental management systems compliant with ISO 14001, along with supporting employees and partners.

Social Goals:

- Managing peak demand by promoting better usage during off-peak seasons and weekdays.
- Educating and motivating tourism stakeholders to address social issues.
- Enhancing tourism awareness among locals through public outreach.
- Addressing the needs of specific guest groups, such as ensuring barrier-free travel.
- Preserving and sharing the region's culture, traditions, and history.
- Actively engaging diverse stakeholder groups in decision-making processes.

[76] https://www.gds.earth/destination/Luzern/2023/

Challenges:	Successes:
• Lucerne has not yet achieved a sustainable destination certificate.	• 79% of electricity is sourced from renewable energy. • 35% of waste is recycled. • 1,850 hectares of green space per 100,000 residents. • 12% of hotel rooms certified as sustainable. • 40% of venues are certified for sustainability.

Table 17. Campus Mythenquai

Name: Campus Mythenquai[77]	
Location: Zurich, Switzerland	**Type of district**: Commercial
Number of members: -	**Established**: 2019 (project initiated in 2017)
Description: Campus Mythenquai, the headquarters of Zurich Insurance Company, is a state-of-the-art sustainable development located on a 35,000 m² site, offering 23,000 m² of modern workspace for over 1,500 employees. The campus comprises three renovated and expanded buildings, designed to minimize environmental impact and reduce energy consumption. It has earned several prestigious certifications, including **Minergie-P-ECO**, **WELL**, **2000-Watt-Areal**, and **LEED NC v3 Platinum**, with an additional **WELL Certificate** expected in 2022.	
Technology & Infrastructure: Key sustainability features of the campus include: • Utilization of heat pumps powered by lake water for heating and cooling, eliminating the need for fossil fuels. PV panels installed on the roofs generate renewable energy, and any additional electricity is sourced exclusively from renewable origins. • The campus is designed to support Zürich's energy goals, aiming to reduce average primary energy consumption from 6000 watts to 2000 watts per person by 2050. • Rainwater collection systems capture, store, and reuse water for sanitation, contributing to efficient water conservation. • The campus is equipped with electric vehicle charging stations, supporting sustainable transportation.	
Challenges: • Balancing modern technological upgrades with the historic fabric or prior designs of the campus. • Achieving a net-positive energy balance for the site while relying on variable renewable energy sources, such as photovoltaic panels and lake water heat pumps.	***Successes:*** • The campus has attained multiple high-tier sustainability certifications, demonstrating leadership in environmental and social design standards (e.g., WELL, LEED Platinum, and 2000-Watt-Areal certification) • By meeting 2000-Watt site certification requirements, Campus Mythenquai serves as a flagship project in Switzerland, inspiring future Positive Energy Districts within the country. • The campus represents a link between the past and the future, between tradition and modernity[78]

[77] Campus Mythenquai | Swiss Re
[78] https://www.swissre.com/about-us/our-global-presence/campus-mythenquai.html

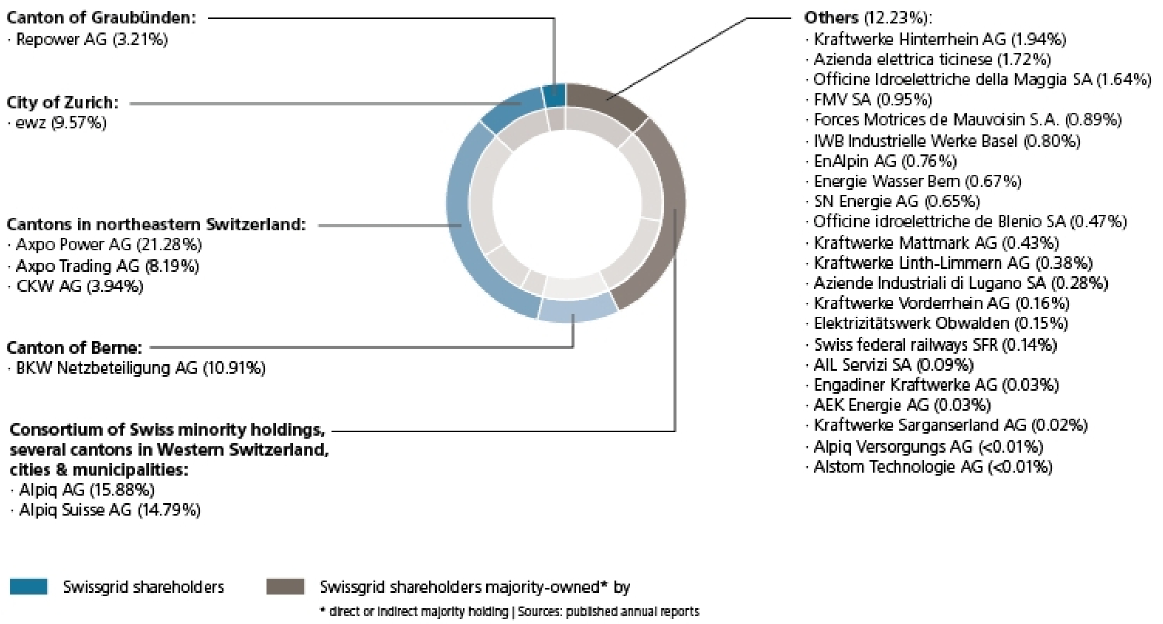

Figure 6. Swiss grid ownership structure[79]

Current technological status

Collective electricity generation and distribution practices

The Swiss electricity market is highly fragmented, there are 1032 entities reported as distribution system operators by the umbrella organisation of the Swiss electricity industry, from those 738 are reported the status “active” and the rest with the status “passive”. The Swiss high-voltage transmission network is operated by Swiss grid, a stock corporation owned by more than 20 Swiss electricity companies, as illustrated in **Error! Reference source not found.Error! Reference source not found.**.[80]

The regulations governing electricity networks are based on Article 91, paragraph 1 of the Federal Constitution, which authorizes the federal government to establish rules for the transmission and distribution of - -electricity [81]

Most of these imports consist of petroleum products, along with natural gas, coal, and nuclear fuels. Although energy consumption in Switzerland has slightly declined over the past decade despite population growth, it is still five times higher than in 1950. The largest share of energy use comes from transportation, accounting for one-third, followed by private households[82].

[79] https://www.report.swissgrid.ch/en/corporate-governance/#:~:text=Swissgrid%20is%20directly%20or%20indirectly,the%20cantons%20and%20the%20municipalities.
[80] https://cms.law/en/int/expert-guides/cms-expert-guide-to-electricity/switzerland
[81] https://www.bfe.admin.ch/bfe/en/home/supply/electricity-supply/electricity-networks.html

Generation

Switzerland's national electricity infrastructure includes significant hydroelectric power stations (556 facilities) and five nuclear power plants (Beznau I and II, Mühleberg, Gösgen, and Leibstadt). Together, these sources generate approximately 95% of the country's domestic electricity. Of the hydropower produced, 45% comes from run-of-river stations, while 55% is generated by storage stations[82].

Distribution (Transmission of electricity)

With the implementation of the Electricity Supply Act on 3 January 2013, Swissgrid became the operator of Switzerland's transmission system, overseeing the operation of the 6,700 km high-voltage grid (operating at 380kV and 220kV). Swissgrid is responsible for transporting electricity from generating stations to regional and local distribution systems via the transmission network. The technical principles and requirements for the operation and use of the Swiss transmission system, along with the roles of the involved stakeholders, are outlined in the Swiss Transmission Code 2010.[82]

Smart Metering and Billing Infrastructures

Smart meters installed at end users' locations are a fundamental element of the networks. By providing free access to meter data for users, these meters enhance energy efficiency and help conserve electricity and resources. They also enable the network's innovative capabilities. These advanced measurement systems are a key component of the Energy Strategy 2050.[83] The Federal Office of Energy (SFOE) is working intensively on the future of electrical networks. An impact assessment on the introduction of intelligent measuring systems has already been carried out. In parallel with the creation of the electricity grid strategy, the SFOE has also drawn up a Smart Grid Roadmap for Switzerland[83]. In addition, Swisscom provides critical infrastructure for smart metering in Switzerland, including IoT platforms that ensure data security and efficient management. These platforms assist utility companies by offering tools for secure data transmission, storage and billing automation, which are essential for Positive Energy Districts where decentralized energy sources are integrated.[84]

Demand Side Management Strategies

Switzerland currently benefits of a secure and cost-effective energy supply. However, economic, technological, and political developments both domestically and internationally are driving significant changes in the energy markets. To prepare for these changes, the Federal Council has devised the Energy Strategy 2050. This strategy aims to help Switzerland capitalize on new opportunities while maintaining its high energy supply standards. It also plays a key role in reducing the country's energy-related environmental impact.

[82] https://cms.law/en/int/expert-guides/cms-expert-guide-to-electricity/switzerland
[83] https://www.bfe.admin.ch/bfe/de/home/versorgung/stromversorgung/stromnetze/smart-grids.html
[84] https://www.swisscom.ch/en/business/enterprise/offer/iot/iot-solutions/smart-metering.html

To preserve quality of life, improve road safety, and ensure accessibility across Switzerland, cities like Basel, Zurich, Geneva, Lausanne, Lucerne, and Bern are embracing green mobility solutions. These initiatives promote sustainable transportation options, such as walking, cycling, and integrating various forms of transport for greater efficiency. Basel[85], for example, is committed to enhancing pedestrian and cycling infrastructure and encouraging multimodal transport options.

Similar efforts are taking place in other Swiss cities: Zurich is expanding cycling infrastructure and electric vehicle initiatives, Geneva[86] is advancing multimodal transport solutions, Lausanne is promoting electric mobility and bike-sharing systems, and Lucerne and Bern are focusing on reducing car dependence by improving public transport networks and walking-friendly urban spaces. These efforts contribute to broader national goals of reducing carbon emissions, improving urban mobility, and supporting sustainable development.

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Spain

Legislative framework, codes, and standards regarding PEDs

Positive Energy Districts (PEDs) are gaining traction in Spain as part of broader European goals to promote sustainable urbanization and reduce carbon footprints. In Spain, the progress of Positive Energy Districts is closely tied to an evolving legislative framework aimed at advancing renewable energy integration, energy efficiency, and sustainable development. *Key national laws* and regulations include:

- Royal Decree 244/19: This decree encourages collective energy initiatives by allowing community-driven renewable energy projects. It enables residents to jointly own and access generation facilities, promoting local energy production and reducing reliance on centralized sources.[87]
- Royal Decree-law 15/2018 on urgent measures for energy transition and consumer protection[88]
- Royal Decree-Law 23/2020, of June 23, approving measures in the field of energy and other areas for economic recovery.[89]
- Royal Decree 900/2015: It provides a framework for integrating PEDs into Spain's energy grid, covering administrative, economic, and technical aspects. This decree ensures smooth incorporation of PEDs into the national

[85] https://www.basel-unterwegs.ch/
[86] https://www.hug.ch/en/durabilite/realisations/promotion-sustainable-mobility
[87] https://climate-laws.org/document/royal-decree-244-2019-regulating-the-administrative-technical-and-economic-conditions-of-the-self-consumption-of-electric-energy_8775
[88] https://climate-laws.org/documents/royal-decree-law-15-2018-on-urgent-measures-for-energy-transition-and-consumer-protection_6548?id=royal-decree-law-15-2018-on-urgent-measures-for-energy-transition-and-consumer-protection_f838
[89] chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://cdn.climatepolicyradar.org/navigator/ESP/2020/royal-decree-law-23-2020-which-approves-measures-in-the-field-of-energy-and-in-other-areas-for-economic-recovery_031310c01f5e3017bef3097adb4a8e63.pdf

infrastructure by outlining grid connection procedures and technical requirements. [90]

- Royal Decree-Law 19/2021, of October 5, on urgent measures to promote building rehabilitation activity within the framework of the Recovery, Transformation, and Resilience Plan.[91]
- Law 24/2013 on the Electricity Sector: This law supports renewable energy and energy efficiency while facilitating the formation of energy communities within PEDs. It offers incentives and regulatory mechanisms for adopting renewable technologies and emphasizes community engagement in energy initiatives. [92]
- Law 3/2020 on Climate Change and Energy Transition: This law addresses climate change and promotes renewable energy adoption. It sets ambitious goals for decarbonization and provides support for PED projects, recognizing their potential to contribute to sustainability, job creation, and economic growth. [93]
- Royal Decree 235/2021: It establishes guidelines for developing sustainable urban areas, focusing on energy efficiency and renewable integration. The decree promotes sustainable urban planning and encourages collaboration among local authorities, urban planners, and developers.

Relevant *Law Passage Dates*:

- The Royal Decree 244/19 and Royal Decree 900/2015 were enacted prior to specific PED initiatives, serving as foundational legislation. Law 24/2013 on the Electricity Sector was passed in 2013, while Law 3/2020 on Climate Change and Energy Transition was enacted more recently in 2020. The Royal Decree 235/2021 and Law 8/2015 on Environmental Impact Assessment were introduced in 2021 and 2015, respectively.

Several *permits and approvals* are necessary to establish a PED:

- Urban planning approval: Ensures compliance with zoning and land use regulations.
- Environmental impact assessment: Assesses potential environmental effects and mitigation measures.
- Building permits: Required for the construction of infrastructure within the PED.
- Energy permits: Authorize energy generation, distribution, and consumption activities.
- Grid connection approval: Necessary to connect PED infrastructure to the electricity grid.

Streamlined process for PEDs:

- Currently, there is no streamlined process for establishing PEDs in Spain. Each PED project must navigate the requisite permits and approvals independently,

[90] https://climate-laws.org/document/royal-decree-900-2015-on-energy-self-consumption_d01f
[91] chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.sistemaelectrico-ree.es/sites/default/files/2024-03/ISE_2023.pdf
[92] https://climate-laws.org/document/law-24-2013-on-the-electric-sector_a1ce
[93] https://ppp.worldbank.org/public-private-partnership/sites/default/files/2021-09/Spain%20Royal%20Decree-law%203_2020.pdf

which can vary depending on local regulations and specific project requirements.

Limitations and regulations:

- While there are no specific limitations on PEDs, they must adhere to general regulations governing energy, urban planning, and environmental protection. Compliance with these regulations ensures PEDs operate within legal parameters while promoting sustainability and energy efficiency.

In 2020, Spain launched the **Integrated national energy and climate plan 2021-2030 (INECP),** which identified the challenges and opportunities across the five dimensions of the Energy Union: decarbonization, including renewable energy; energy efficiency; energy security; the internal energy market; and research, innovation, and competitiveness. The long-term goal of the Plan is to achieve carbon neutrality by 2050. To support this, the medium-term objective is to reduce emissions by at least 20% by 2030 compared to 1990 levels. The Plan forecasts that the proposed measures will result in a 23% reduction in emissions. The non-ETS sectors (residential, transport, agriculture, waste, fluorinated gases, and industry not covered by emissions trading) will contribute to this target with a 39% reduction by 2030 compared to 2005 levels, while the sectors covered by emissions trading will achieve a 61% reduction compared to 2005.[94]

At the same time Spain established a ***SET Plan*** which includes the action: *New services and technologies for consumers, cities and smart communities.* This action includes topics such as: *Smart solutions for the energy consumer, having the scope to improve and enhance the citizen's status as an energy consumer and Smart cities and communities which integrate the various technologies available in urban environments to improve sustainability and citizens' quality of life.*[94]

Spain has successful pilot experiences, involving city councils, citizens and service companies, in various cities under the PED framework and this should serve as an example to encourage innovation and replicate the best solutions[94].

Energy communities with potential evolution to PEDs

In Spain, the concept of PEDs is gaining momentum, with several projects emerging as examples of how urban areas can transition to energy-positive environments. The initiatives in Spain are not only contributing to reducing carbon footprints but also setting a model for future urban development. Below are examples of energy communities in Spain that have the potential to evolve into full-fledged PEDs, highlighting their innovative approaches to sustainable energy solutions.

Table 18. Coronacion

Name: Coronacion[95]	
Location: Coronación district, Vitoria-Gasteiz, Basque Country, Spain	**Type of district**: Residential
Number of members: 312 dwellings (with plans to expand to 700)	**Established**: 2021
Description: Located in the northwest of Vitoria-Gasteiz near the medieval quarter, the Coronación district is undergoing a transformation into a **Zero Carbon district**. The project focuses	

[94] https://energy.ec.europa.eu/system/files/2020-06/es_final_necp_main_en_0.pdf
[95] https://iea-ebc.org/Data/publications/Annex75_STC_WPC1_VitoriaGasteiz_Spain_202003233.pdf

on implementing energy reduction measures and deploying an efficient biomass-based district heating network. Initially targeting 300 dwellings, the long-term goal is to reach all 700 dwellings in the district.

Technology & Infrastructure:

Biomass district heating network: Equipped with biomass boilers, backup gas boilers, and a pumping system, the network provides efficient heating for the district.
Resource management centre: Oversees production and distribution of district heating, optimizing energy management.
Online energy monitoring: Residents can monitor their home energy consumption via a dedicated website.
Building retrofitting: Energy efficiency improvements are applied to residential buildings across the district.

Funding:

Local and regional public funding: **27%**
Private investment by dwelling owners: **49%**
European Commission funding: **24%**

Governance structure: **City Council** has granted a 40-year concession for the operation of the network. The operator, **GIROA**, is responsible for maintaining the infrastructure, which will revert to city ownership at the end of the concession. Energy is supplied directly to residents and building owners through contracts with GIROA.

Challenges:

- Initial participation fell short of the 750-dwelling target, with only **300 dwellings** adhering to the project, requiring a downsizing of the heating network and production facilities. The remaining portion is used for the certification process itself.

Successes:

- Reduction of installed power through simultaneity factors.
- Improved energy efficiency and system performance at the neighbourhood level.
- Lower maintenance and operation costs for residents.
- Enhanced safety by eliminating fuel storage in homes.
- Significant carbon emissions reduction and independence in energy supply.

Table 19. Orozko

Name: Orozko[96]	
Location: Orozko, Bizkaia, Basque Country, Spain	**Type of district**: Residential
Number of members: 430 residential dwellings, 1 school, and 1 sports centre (currently serving 80 dwellings)	**Established**: 2011
Description: Orozko, a municipality in the Biscay province of northern Spain, is developing a PED with a focus on an efficient biomass-based district heating network. While the installation was initially designed to serve 430 dwellings, only 80 dwellings are currently connected.	
Technology & Infrastructure: Incorporates biomass boilers, backup gas boilers, and a primary network pumping system to provide clean and efficient heating. Residential buildings in the neighbourhood are retrofitted to improve energy efficiency..	
Funding: The project is funded entirely by the **Orozko City Council**.	
Governance structure: The project covers the design, financing, construction, and operation of two production centres to meet the heating needs of the district for 20 years. **GIROA:** Handles energy management, maintenance, and total guarantee services. **Enerpellet:** Supplies the biomass pellets required for the heating system.	

[96] https://projects2014-2020.interregeurope.eu/fileadmin/user_upload/tx_tevprojects/library/file_1643357544.pdf

Challenges:	Successes:
• Expanding the district heating network to include more of the initially planned dwellings.	• P-Economic Savings: Citizens connected to the network benefit from over 15% reduction in energy costs. • Environmental Impact: Annual CO2 emissions are reduced by 520 tons. • Space Optimization: Usable space in connected buildings is increased by eliminating the need for individual energy generation systems. • Improved User Experience: • Clean and odourless heating with no associated dust or smoke. • Safety: Eliminates the need for chimneys and pressure devices in individual buildings. • Renewable Energy Usage: Over 80% of energy production is sourced from biomass, a renewable energy source.

Table 20. Pamplona

Name: Pamplona [97]	
Location: Pamplona, Navarra, Spain	**Type of district**: Mixed residential and urban redevelopment project
Number of members: Not specified - Focused on a pilot district in Rochapea, covering specific buildings including the IWER building and San Pedro colony	**Established**: 2018-2022
Description: Pamplona is advancing its Positive Energy District (PED) initiatives as part of its broader Energy Transition Strategy. The Rochapea district serves as a testing ground for energy-efficient solutions integrated with the city's energy systems, with the goal of replicating successful technologies across other areas.	
Technology & Infrastructure: **-Renewable energy systems:** Incorporation of solar photovoltaic installations, district-level energy storage, and microgrid management. **-Energy retrofitting:** Residential and public buildings in Rochapea are being modernized for improved insulation, reduced energy loss, and higher efficiency. **-District heating:** Pilot projects focus on clean heating solutions that align with energy transition goals.	
Funding: The initiative benefits from local municipal funding and EU grants, including €60,000 from the European City Facility to develop investment concepts for PED projects.	
Governance structure: The city collaborates with EU-funded programs such as OPEN LAB and European City Facility. These programs guide the design, execution, and future scalability of energy projects in Rochapea and other districts.	
Challenges: • Scaling successful technologies citywide. • Aligning community involvement and awareness with technical goals.	***Successes:*** • Increased energy cost savings for local residents. • Significant progress in renewable energy integration and reduced CO2 emissions. • Development of replicable models for energy-positive districts.

[97] https://openlab-project.eu/living-labs/pamplona/

Current Technological Status

Collective electricity generation and distribution practices

A series of these dominant operators: E.ON, Endesa Group, Iberdrola Group, EDP / Hidrocantábrico Group and Gas Natural Fenosa Group, by means of their subsidiary companies, are among the key operators in the generation, distribution and supply sectors in Spain.[98]

The energy sector in Spain in 2023 experienced a 3.5% decrease in electricity generation compared to the previous year, following two consecutive years of increases, with growth of 3.4% in 2021 and 6.3% in 2022. Regarding the energy generation balance by type, renewable generation in the national electricity system in 2023 increased by 15.1%, reaching a historic production record of 134,321 GWh. This increase was mainly due to higher hydroelectric and photovoltaic solar production, which grew by 41.1% and 33.8%, respectively. In 2023, renewable energy production accounted for the majority of the national energy mix for the first time in history, with a share of 50.3% compared to 42.2% in 2022[99].For the first time in history, renewable energy contributed more than half of Spain's national energy mix, accounting for 50.3% in 2023, compared to 42.2% in 2022. The energy mix also included wind power at approximately 24%, nuclear energy at around 20%, hydropower close to 20%, and solar energy near 18%, showcasing a diversified and increasingly sustainable energy profile. On the other hand, fossil energy sources still account for about 17% of Spain's electricity, with natural gas being the largest portion at more than 15%, followed by biofuels at 2% and coal at just over 1%.[100]

Smart metering and billing infrastructures

The long-term strategy for building renovation, outlined in Article 4 of the Energy Efficiency Directive, was published in 2014 by the Ministry of Public Works (now the Ministry of Transport, Mobility, and Urban Agenda, MITMA). Directive 2010/31/EU introduced a new Article 2a, focusing on a long-term strategy to support the renovation of both residential and non-residential buildings, including public and private properties. A new target was set to make the building stock highly energy-efficient and decarbonized by 2050, enabling the cost-effective transformation of existing buildings into nearly zero-energy buildings. These decarbonization goals for the housing stock by 2050 are incorporated into the INECP Plan, which includes objectives such as improving energy efficiency (thermal envelope) in 1,200,000 homes over the decade and upgrading thermal heating and DHW systems in 300,000 homes annually.[101]

In the last few years, Spain completed the deployment of smart meters with more than 28 million new devices installed in homes that offer significant advantages over old

[98] https://cms.law/en/int/expert-guides/cms-expert-guide-to-electricity/spain
[99] chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.sistemaelectrico-ree.es/sites/default/files/2024-03/ISE_2023.pdf
[100] https://lowcarbonpower.org/region/Spain
[101] https://energy.ec.europa.eu/system/files/2020-06/es_final_necp_main_en_0.pdf

ones. This replacement, carried out by electricity distributors, has been done at no additional direct cost to the customer[102][103].

Demand side management strategies

The large-scale deployment of renewable energy generation requires careful planning for its integration into the system. The traditional model of base and peak generation is being replaced by one focused on variability versus flexibility. Electricity demand management involves a range of actions taken by consumers, public administrations, energy distribution and marketing companies, energy service providers and independent aggregators to adjust consumer energy demand. These actions aim to alter the timing or level of energy consumption, contributing to cost reductions, lower environmental impact, enhanced competitiveness for consumers and improved efficiency in the use of generation, transmission and distribution systems.[104]

Green mobility solutions within PEDs

- Spain has been actively promoting green mobility solutions within its positive energy districts. Barcelona, Valencia and Seville are just some examples of initiative:
- **Barcelona** is the city where the Superblock programme is taking a step ahead and becoming the street transformation model for the entire city, with the aim of reclaiming for citizens part of the space currently occupied by private vehicles. The goal is to create a healthy, greener, fairer and safer public space that promotes social relations and the local economy. [105]
- The **Sustainable Metropolitan Mobility Plan for the Valencia Area** (PMoMe) is a strategic document that outlines the principles and action strategies for the region's transportation and mobility system over the next 12 years. It will cover 90 municipalities and serve a population of around 2 million people. The PMoMe will include actions and initiatives to promote more sustainable forms of displacement (walking, cycling and public transport), combining economic development, social welfare and environmental quality[106].
- **Seville** is one of the Spanish cities most committed to promoting cycling. Cycle-Lane Network in Seville is 180 km long and has 8 lines that connect the peripheral neighbourhoods with the historic centre. With the creation of the bike lane, cycling in Seville increased considerably, going from 0.6% (12,000 users) to 9% (70,000 users). This means that, in just 4 years, the number of cyclists has increased by 58,000 people.[107]
- The City Council of **Pamplona** plans to promote the acquisition of 680 electric vehicles, each paired with a corresponding charging point, which will involve an investment of €32,500 per vehicle and €1,500 for the installation of a private charging point. Based on short-, medium-, and long-term evaluations, electric vehicles prove to be more cost-effective after 5 to 10 years of use, though initial

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[102] https://www.boe.es/diario_boe/txt.php?id=BOE-A-2024-7589)
[103] https://aelec.es/sobre-aelec/principios-aelec/principios_aelec_contadores_inteligentes/
[104] https://energy.ec.europa.eu/system/files/2020-06/es_final_necp_main_en_0.pdf
[105] https://ajuntament.barcelona.cat/superilles/en/
[106] https://mediambient.gva.es/documents/163211567/166352847/Plan+B%C3%A1sico+de+Movilidad+del+%C3%81rea+Metropolitana+de+Valencia/8d049bd2-7e53-413a-bcdf-f1675a238617.
[107] https://biketourseville.com/cycle-lane-network-in-seville/

years incur higher costs. To enhance the financial feasibility of purchasing electric vehicles, public subsidies will be necessary. Additionally, for collective investments, a model will be developed where both the vehicles and charging points are owned and managed by the energy community. This community will not only cover the investment but also oversee its operation, generating income through usage. The total investment for the 680 vehicles and their charging points amounts to €34,000 per vehicle and charging point, financed via a 7-year bank loan and revenue from community members' use.

Incorporation of electricity storage

Energy storage systems in Spain are essential in the fight against climate change as they aid the energy transition. They increase the flexibility of renewable energy production, supporting its integration into the Spanish electricity grid. With over 20,000 megawatts of capacity, Spain leads Europe in the number of energy storage systems by power and ranks second in total projects, with 128, just behind Germany's 169. [108]

Storing electrical energy presents challenges, but various technologies are available today to facilitate this process: hydroelectric pumping, batteries, thermal storage, supercapacitor, fly wheels and hydrogen fuel cells.

By advancing the implementation of these crucial technologies for the energy transition, Spain is aligning with the EU's directives, which have encouraged Member States to help the development of energy storage solutions. [109]

[108] https://www.statista.com/statistics/1419494/leading-countries-by-energy-storage-capacity-in-the-eu/
[109] https://energy.ec.europa.eu/system/files/2019-06/ec_courtesy_translation_es_necp_0.pdf
https://clean-energy-islands.ec.europa.eu/system/files/2022-12/Regulatory%20barriers%20in%20Spain%20findings%20and%20recommendations%2020221214.pdf

Latvia

Legislative framework, regulations and standards for PEDs

In Latvia, energy communities are a relatively new concept, with their implementation still in progress. The general legislative framework for energy communities was approved by the Latvian Parliament on July 14, 2022, and definitions of these communities have been incorporated into national legislation through amendments to the Electricity Market Law[110] and the Energy Law[111].

The general definition for energy communities that is included in the Amendment to the Energy Law is the following (article 17):

(1) *the energy community is a legal entity that is engaged in the production, trade, sharing, consumption and storage of energy - mainly electricity obtained from renewable energy resources and other types of renewable energy, provision of demand response services, electric vehicle charging service, energy efficiency services or other provision of energy services*.

The Energy Law also specifies that a REC operates in the renewable energy sector, and it owns, develops or manages territorially related renewable energy production facilities, while the CEC operates in the electricity sector. Still, several elements of the definitions need to be further elaborated on what they mean at the national level.

An energy community can be an association, foundation, cooperative society, partnership, capital company or other civil law society. The **primary purpose of the energy community is not to make a profit**. Moreover, total installed RES capacity within energy community must not exceed 15 MW[112]. This limitation is established to support small- and medium-scale projects that promote the decentralization of the energy system and the enhancement of energy efficiency.

Currently, there are no detailed regulations in Latvia for RECs, PEDs, or jointly active customers. Key provisions, including energy sharing conditions, relationships between community members and stakeholders, and registration criteria for energy communities, are absent. However, the content of the anticipated regulation aligns with Latvia's updated National Energy and Climate Plan (NECP) for 2021–2030[113], suggesting that the final regulation will largely reflect the existing draft. The Cabinet of Ministers is expected to issue these regulations by the end of 2024 to clarify specific aspects of the legislative framework, such as requirements for registering RECs in the Energy Communities Register and provisions for electricity sharing.

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[110] https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Flikumi.lv%2Fwwwraksti%2FVVC_TULKOJUMI%2FLRTA%2FLIKUMI%2FELECTRICITY_MARKET_LAW.DOC&wdOrigin=BROWSELINK

[111] https://likumi.lv/ta/id/49833-energetikas-likums (in Latvian)

[112] State Chancellery of the Republic of Latvia, Cabinet of Ministers of the Republic of Latvia, "23-TA-691: Rules for registration and operation of energy communities" [in Latvian], 2024.

[113] Cabinet of Ministers of the Republic of Latvia, "Order of the Cabinet of Ministers No. 573: The updated National Energy and Climate Plan for 2021-2030" [in Latvian], 2024.

In Latvia establishing energy communities is seen as a foundational step toward the development of PEDs. These communities lay the groundwork for local collaboration, renewable energy integration, and the broader transition to decentralised and sustainable energy systems.

Energy communities with potential evolution to PEDs

Several projects in Latvia are being implemented to research, support, and promote the development of PEDs, with a stronger geographical focus on Riga. One of the most important projects, **ATELIER**[114], is a European Commission-funded initiative aimed at introducing energy-positive districts in multiple European cities. As one of the participating cities, Riga is adopting innovative approaches and solutions for the creation of such districts, with plans for the sustainable integration of energy resources and active involvement of local residents. Within the framework of the ATELIER project, the development of the Skanste district as Riga's first PED has already begun. This district has been selected to test the integration of RES and the engagement of residents in smart energy management systems. The goals of ATELIER in focus of Riga are:

- Gain new knowledge, experience, and skills while adopting innovative strategies for the development of PEDs, a concept newly introduced to Riga.
- Establish a "Bold City Vision 2050" to address the city's energy transition challenges, integrating this vision into all levels of urban planning, including updating the city's SEAP-2020 to SECAP-2030.
- Identify and develop new financing mechanisms, such as incentives and business models, to support sustainable urban development, including energy-efficient retrofitting of residential and commercial buildings.
- Build a network of local stakeholders committed to participating in smart urban transformation initiatives.
- Increase public awareness of sustainability issues and smart city principles among the local community.

The **Co2mmunity** project, part of the Interreg Baltic Sea Region initiative, has been instrumental in promoting and supporting the development of RECs across the Baltic region, including Latvia. The project focuses on empowering communities to collaboratively produce and use renewable energy, aligning with EU sustainability goals and fostering energy independence. The detailed information is presented in Table 20.

Table 21. Marupe municipality

Name: Marupe municipality[115] - **Co2mmunity**	
Location: Mārupe Municipality, Latvia	**Type of district**: Small-scale community energy demonstration
Number of members: 36 households	**Established**: 2020
Description: Co2mmunity is a collaborative pilot project developed through the joint efforts of public stakeholders (Ministry of Economics, Riga Planning Region, and Mārupe Municipality), local private energy service providers, and residential households. The project's objective was to showcase the	

[114] https://smartriga.lv/projects_cases/atelier-a-path-towards-positive-energy-districts/

[115] https://www.interregeurope.eu/good-practices/first-energy-communities-in-latvia-small-scale-demonstration-projects-at-marupe-municipality

practical implementation of the **prosumer approach** and demonstrate the operation of renewable energy communities within Latvia's existing, underdeveloped regulatory framework.

Technology & Infrastructure:
Installation of **28 solar panels** (9.3 kW) for electricity generation.
Deployment of **solar thermal collectors** for hot water pre-heating, enhancing energy efficiency for the households involved.

Funding: Pilot 1: **€16,000 |** Pilot 2: **€15,000**

Governance structure: No specific governance structure outlined.

Challenges:	***Successes:***
• Navigating an underdeveloped regulatory framework for establishing and operating energy communities in Latvia.	• Both pilots are fully operational and have provided a valuable model for understanding the technical, practical, and institutional processes involved in forming energy communities. • The initiative serves as an inspiring example for overcoming barriers to energy cooperatives in Latvia. • Electricity Cost Savings: Pilot 1 achieved annual savings of 10%. Pilot 2 achieved annual savings of 30%. • Payback Period: Expected to be 6-7 years, demonstrating the economic viability of community energy projects.

Table 22. ExPEDite Project & Samrt Riga

In Riga, under the leadership of Riga Technical university, the international project **EXPEDITE**[116] is being implemented, focusing on the use of digital twin technology to analyse and optimise energy flows on a city-wide scale. This technology will enable Riga to plan and manage energy demand and production in real time, helping to utilize resources more efficiently and advance toward climate neutrality. The Pilot District will be deployed in the RTU smart student city, in Ķīpsala, Riga, Latvia, which covers an area of 17.5 ha. The district comprises 15 buildings with a total floor area of 119,264 m2: 12 faculty and laboratory buildings (maximum occupancy of 10,000 people), 2 dormitories (permanently housing 850 residents), 1 is an Olympic-size swimming pool.

Smart Riga is an initiative by the Riga City Council aimed at transforming the city into a smart, sustainable, and innovative urban environment. Launched in spring 2021, the initiative established three smart city living labs in the VEF district, the Riga Technical University campus in Ķīpsala, and the University of Latvia territory in Torņkalns. These living labs serve as experimental spaces for developing and testing innovative solutions to urban challenges. Among the projects funded by Smart Riga are: *sCOOL2walk: Promoting Walkability for Children and Youth; Smart lights in Ķīpsala, I-NERGY: Artificial intelligence for next generation energy, A smart bicycle parking facility and BSR ELECTRIC*[117].

The **StartSun** project, initiated in November 2023, aims to facilitate the establishment of solar energy communities across the Baltic Sea Region, including Latvia. By providing tailored start-up packages and implementing pilot projects, StartSun seeks to empower local authorities, small and medium-sized enterprises (SMEs), and citizens to collaboratively produce and manage renewable energy[118]. In Latvia, the project involves key partners such as the Zemgale

[116] https://expedite-project.eu/pilot/
[117] https://smartriga.lv/about-smart-riga/?utm_source=chatgpt.com
[118] https://interreg-baltic.eu/project/startsun/?utm_source=chatgpt.com

Regional Energy Agency (ZREA) and the Society "Green Liberty". These organizations are instrumental in developing resources and facilitating the creation of energy communities within the country[119], [120].

A notable pilot initiative under StartSun is planned in the Jelgava City Municipality, where efforts are underway to establish a solar energy community. This pilot aims to serve as a model for similar projects throughout Latvia, demonstrating the practical benefits and feasibility of community-led renewable energy solutions[121].

Through these collaborative efforts, StartSun aspires to enhance energy independence, promote sustainable practices, and support the transition to clean energy in Latvia and the broader Baltic Sea Region.

Current technological status

In 2024, Riga continued its commitment to energy efficiency and sustainability, building upon the foundations laid in previous years. The Riga Energy Agency (REA) played a pivotal role in this progression, managing an internal fund dedicated to implementing measures outlined in the city's Sustainable Energy and Climate Action Plan (SECAP). One of the key strategies to save energy during the winter months was optimizing public lighting. The city achieved a 16% reduction in energy use for public lighting by transitioning to LED lights, dimming streetlights, and lifting regulations that required façade lighting. Additionally, energy-saving measures included limiting heating temperatures and reducing heating hours in public buildings, as well as regulating temperatures in residential buildings connected to the city's district heating network. As a result, the city reduced its heating energy consumption by 15 to 18%. The estimated savings from these efforts amounted to about 4 million euros for the year. This fund, accessible to various municipal infrastructures and departments, facilitated the installation of solar panels, replacement of gas boilers and inefficient lighting systems, and the implementation of greening initiatives such as tree planting to absorb emissions. These efforts aimed to enhance energy efficiency across approximately 60 municipal buildings, including schools and kindergartens[122].

The REA's initiatives were instrumental in advancing Riga's goal of achieving climate neutrality by 2030. By reinvesting energy savings into sustainable projects, the city not only reduced its carbon footprint but also fostered a culture of environmental responsibility among its residents. The success of these programs underscored the importance of strategic planning and community involvement in the pursuit of long-term sustainability objectives[123].

Overall, Riga's continued dedication to energy efficiency and the proactive measures implemented in 2024 exemplify the city's leadership in urban sustainability and its commitment to creating a greener future for its citizens.

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[119] https://zrea.lv/en/?utm_source=chatgpt.com
[120] https://www.zalabriviba.lv/projekti/startsun/?utm_source=chatgpt.com
[121] https://www.jelgava.lv/dokumenti/projekti/jaunuznemumi-start-up-saules-energokopienam-startsun/?utm_source=chatgpt.com
[122] https://eu-mayors.ec.europa.eu/sites/default/files/2023-12/2023_CoMo_CaseStudy_Riga_EN.pdf?utm_source=chatgpt.com
[123] https://eu-mayors.ec.europa.eu/en/Reinvesting-energy-savings-for-a-climate-neutral-future-Riga-Case-Study?utm_source=chatgpt.com

Smart metering and billing infrastructures

AS Sadales tīkls, the electricity distribution company, has completed its smart electricity metering programme in 2023, providing more than one million customers in Latvia with remote and automated electricity metering, data services and other benefits. Introducing these innovative technologies has led to an increase in customer satisfaction and digital transformation that leads to operational efficiency. Smart metres lead to electricity market and energy industry development, including distributed generation and the achievement of national energy and carbon neutrality goals. The financial investment for this project totaled €44.5 million, averaging €40 per connection point. This cost-efficiency positions Latvia as a leading nation in Europe concerning the cost-benefit ratio of smart metering implementations[124].

The smart electricity meter data is available at any time and free of charge via e-st.lv or the electricity trader. The data can be sorted by months, days or hours. More than 50% of customers use the data, which can help to improve energy efficiency by ~20%. Free-of-charge data encourages the customer to analyse consumption patterns and become more energy efficient, raises interest about energy market developments and increases the public's energy literacy. [125]

In terms of billing infrastructure, Latvia has embraced advanced systems that complement the smart metering framework. Companies like Complete Payment Systems (CPS) offer comprehensive billing solutions, including recurring payments, smart invoicing, and intelligent routing. These services are designed to integrate seamlessly with modern metering systems, ensuring accurate and timely billing for consumers[126].

Collectively, the deployment of smart metering and the advancement of billing infrastructures signify a substantial progression in Latvia's energy sector.

Green Mobility Solutions within PEDs

Latvian smart mobility initiatives are transforming cities through the integration of electric transportation solutions (**Electrify**, **GetUgo**, **Transport and Telecommunication Institute**), advanced public transit systems (**Rīgas Satiksme**, **Riga Technical University**), bike lanes and ride-sharing services (**Fiqsy**). These efforts are all part of a broader strategy to develop a comprehensive ecosystem aimed at reducing congestion and minimizing CO2 emissions. Additionally, Latvia is pioneering aviation technologies with hydrogen engines that emit no harmful elements into the atmosphere (**Fokker Next Gen**), along with other innovative and eco-friendly transportation options.

Incorporation of Electricity Storage

To encourage the adoption of energy storage at the consumer level, the Latvian

[124] https://www.baltictimes.com/latvia_s_smart_electricity_meter_roll-out_completed__metering_of_more_than_1_million_connection_points_happens_remotely/?utm_source=chatgpt.com
[125] https://labsoflatvia.com/en/news/latvias-smart-electricity-meter-roll-out-completed
[126] https://www.cps.lv/?utm_source=chatgpt.com

government introduced a support program in February 2024[127]. This initiative offers financial aid for the installation of electricity storage facilities, with a minimum capacity requirement of 5 kW and a maximum support amount of €2,500 per unit. The program aims to empower consumers to store self-generated renewable energy, such as solar or wind, for use during periods when generation is low, thereby promoting energy self-sufficiency and easing demand on the national grid.

Portugal

Legislative framework, regulations and standards for PEDs

Portugal has adopted legislation for Renewable Energy Communities (RECs) and Citizen Energy Communities (CECs). The legislation does include measures for building an enabling framework for RECs, however none of these requirements go beyond what is covered in the EU Directives. The government has yet to conduct an examination of the drivers and impediments to the establishment of RECs, even though it is legally required to. The government has also launched an investment support plan as part of its Recovery and Resilience Plan.

There are also tools in place to provide information to prospective community initiatives, as well as an online e-Portal to assist in the registration of energy community self-consumption projects and to facilitate information transfer between the DSO, the energy community, and the appropriate supplier(s). There are also certain eased administrative procedures for approving smaller projects, but no regulations have been developed specifically for RECs. There is no separate subsidy mechanism for REC initiatives. Overall, while Portugal has adopted definitions for RECs and CECs, it has yet to construct a comprehensive or coherent enabling structure to allow energy communities to grow. While legislation governing community self-consumption have been enacted, several gaps remain that will prohibit energy communities from fully exercising their rights under EU directives.[128]

Energy communities with potential evolution to PEDs

Portugal is making significant progress in the development of energy communities and renewable energy initiatives, and there are emerging projects that could evolve into PEDs. While the country does not yet have fully established PEDs at a national level, several regions are exploring innovative energy solutions that align with the principles of PEDs, such as local energy production, energy efficiency and community involvement. As Portugal continues to implement its energy transition strategies, these initiatives, along with others in development, position the country as a potential leader in the creation of PEDs in the future.

Table 23. POCITYF – A Positive Energy City Transformation Framework

Name: POCITYF – A Positive Energy City Transformation Framework[129]

[127] https://eng.lsm.lv/article/economy/economy/23.02.2024-aid-to-be-available-for-energy-storage-equipment-in-latvia.a544132/?utm_source=chatgpt.com
[128] https://www.rescoop.eu/policy/transposition-tracker/enabling-frameworks-support-schemes/portugal
[129] https://jpi-urbaneurope.eu/wp-content/uploads/2020/06/PED-Booklet-Update-Feb-2020_2.pdf

Location: Évora, Portugal	**Type of district**: Residential
Number of members: 6.11 hectares, divided into 3 PEDs	**Established**: 2019-2024
Description: POCITYF is a collaborative effort aimed at transforming Évora into a sustainable and energy-positive city. The project brings together stakeholders from public and private sectors, leveraging innovative solutions to promote energy self-consumption, efficiency and local renewable energy production in urban and heritage areas.	
Funding: *Private:* 64.6% | *Public:* 13.5% | *Research Funding:* 21.9%	
Governance structure: No specific governance structure is detailed.	
Challenges: • Historic area restrictions: Limited ability to install PV systems on roofs and facades in protected heritage zones. • Complex licensing requirements for PV systems exceeding contractual capacity. • Absence of frameworks for ancillary services, local peer-to-peer energy trading and aggregation of consumer flexibility. • Industrial buildings aim to grow energy use for economic reasons, while old building retrofits face strict aesthetic preservation requirements. • Difficulty in maintaining citizen engagement and long-term use of energy monitoring tools. • POCITYF demonstrates the challenges and potential of energy transition in heritage areas while showcasing innovative, scalable solutions for creating energy-positive cities.	***Successes:*** • Developed energy-positive districts that integrate solutions for energy self-consumption and local renewable energy production. • Established a peer-to-peer energy platform, enabling residents to create virtual energy wallets. • Enhanced grid flexibility by integrating electro-mobility solutions. • Incorporated advanced ICT solutions into city platforms through open and standardized interfaces, enabling innovative services. • Engaged citizens in co-creation and decision-making processes, fostering participation. • Developed bankable business models and fostered cooperation with other smart city projects across EU member states. • Completed a two-year evaluation of demonstration results, validating the project's effectiveness.

Table 24. Coopérnico

Name: Coopérnico[130]	
Location: Lisbon, Portugal	**Type of district**: Energy Cooperative
Number of members: 4,353	**Established**: 2013
Description: Coopérnico is Portugal's only national renewable energy cooperative, operating through regional groups. Established in 2013, the cooperative has over **4,250 members** and provides energy retail services to more than **3,500 customers**. Coopérnico has invested approximately **€2 million** in decentralized solar PV installations, primarily supporting the **social sector**. The cooperative encourages local citizen initiatives for collective self-consumption of electricity produced by PV panels, aligning with Portugal's **Renewable Energy Communities scheme** introduced in 2022.	
Technology & Infrastructure: Energy production is **100% green**, sourced entirely from renewable energy systems.	
Funding: **€2 million** invested in solar PV systems and related initiatives.	
Governance structure: No specific governance structure is detailed.	

[130] https://www.coopernico.org/

Challenges: • Although not explicitly mentioned, the cooperative likely faces common challenges such as navigating regulatory frameworks, scaling local initiatives, and maintaining long-term member engagement. • Coopérnico exemplifies a successful citizen-led initiative for renewable energy transition, showcasing the potential of cooperative models in promoting sustainability and energy autonomy.	***Successes:*** • Recognized as a top project (2019) within the Social Innovation to Tackle Fuel Poverty programme, supported by the Schneider Electric Foundation and Ashoka Foundation. • Successfully mobilized collective investments in solar PV projects, strengthening the community's transition to sustainable energy practices. • Pioneered energy retail services and renewable energy production within the social sector.

Table 25. Solar Energy Community in Miranda do Douro

Name: Solar Energy Community in Miranda do Douro [131]	
Location: Miranda do Douro, Portugal	**Type of district**: Residential
Number of members: Estimated 25,000 families (once Cleanwatts' project is fully implemented)	**Established**: 2021
Description: This solar energy community is part of Cleanwatts' **"100 Aldeias"** (100 Villages) initiative, aimed at combating energy poverty in rural and isolated villages across Portugal. The project focuses on creating energy communities that provide affordable, clean energy to over **25,000 families**. Members benefit from significantly lower energy costs by purchasing locally sourced clean energy from **prosumers** (energy producers within the community). Prosumers, in turn, increase their returns by trading surplus energy within the community.	
Technology & Infrastructure: Installed **73.3 kW** production capacity using solar panels.	
Funding: Financed as part of Cleanwatts' **"100 Villages"** project.	
Governance structure: No specific governance structure is detailed.	
Challenges: • Bureaucratic delays in licensing renewable energy projects have slowed progress. • The paper-based permitting process for energy communities has created a backlog, prompting calls for faster approvals to enable the establishment of more energy communities. • This initiative highlights how solar energy communities can drive rural energy transformation, reduce energy costs, and promote sustainable practices, all while fostering energy independence in isolated areas.	***Successes:*** • In its first year, the community saved approximately €31,500 in electricity costs. • Demonstrates the potential of community-based renewable energy initiatives to reduce energy poverty and promote sustainability.

Table 26. Solar Energy Community in Castelões

Name: Solar Energy Community in Castelões [132]	
Location: Castelões, Parish of Calvão, Municipality of Chaves, Portugal	**Type of district**: Residential
Number of members: 200 people	**Established**: 2019

[131] https://www.solarpowereurope.org/advocacy/solar-saves/stories/solar-energy-community-in-portugal
[132] https://goparity.com/project/energy-communities-201

Description: This renewable energy community, part of Cleanwatts' **"100 Villages"** initiative, aims to promote clean energy access in rural areas of Portugal. Located in Castelões, the project includes the installation of an **86.2 KWp** solar plant, expected to generate approximately **140.8 MWh** of renewable energy annually. The project is one of three solar plants planned for the parish of Calvão, contributing to the larger vision of energy self-sufficiency and poverty reduction across the region.

Technology & Infrastructure: Annual clean energy production of approximately **140 MWh** through solar power.

Funding: Funded with **€67,400** raised from 560 private investors.

Governance structure: No specific governance structure is detailed.

Challenges:

- Bureaucratic delays in licensing renewable energy projects have impeded progress.
- A paper-based permitting process for energy communities has created significant backlogs, prompting companies like Cleanwatts to advocate for more efficient approval processes to facilitate the expansion of similar initiatives.
- This project exemplifies how community-driven renewable energy systems can accelerate the energy transition, foster sustainability, and improve energy affordability in rural areas.

Successes:

- Demonstrates the potential of small-scale renewable energy projects to foster local energy independence and reduce costs for community members.

Current technological status

Smart metering and billing infrastructures

In mainland Portugal and the Madeira region, DSOs are actively installing electricity smart meters, supported by Decree-Law no. 15/2022, which mandates that all BTN customers in mainland Portugal be integrated into a smart grid by 2024. This integration enables access to advanced services designed to enhance consumer engagement and energy management.

The smart grid infrastructure includes not only smart meters but also essential ICT and data management systems that facilitate a range of new services, such as remote daily meter readings, availability of 15-minute demand and generation data on digital platforms, real-time consumption data, remote power adjustments and consumption alerts.

The Smart Grid Services Code (RSRI), approved by ERSE under Regulation no. 817/2023, defines these services and incentivizes DSOs who offer them by sharing costs and benefits based on actual service availability. By the end of 2023, 86% of low-voltage installations in mainland Portugal had smart meters, with approximately 4.7 million already integrated into the smart grid. This progress aligns with the government's timeline, aiming for full smart meter access by 2024 in mainland.

Norway

Legislative framework, regulations and standards for PEDs

The climate targets with the EU for emission cuts, are integrated into Norwegian policy and legislation. **The Climate Act** (2017) constitutes the legal framework for Norwegian climate policy and consolidates commitment in the Paris Agreement. **Climate plan for 2021-2030** explains how Norway will reduce greenhouse gas emissions until 2030 in line with the climate goals and in cooperation with the EU[133].

Additionally, through the work on Climate cure 2030, various measures and tools have been studied that can provide at least a 50 percent reduction in no quota- obligatory emissions in 2030 compared to 2005. Also, the most central measures in the report are climate gas taxes, regulations, emission quotas, climate requirements in public procurement and support for innovation, research and technology development.

The main emphasis is on reductions in emissions not subject to quotas[133]. Furthermore, implementation of the measures in **Klimakur 2030** will require around 6 TWh more electricity than what the Norwegian Environment Agency has set as a basis in the reference path for power use towards 2030 [133].

To investigate which options Norway faces to become a low-emission society by 2050, the **Climate Committee 2050** was appointed by Royal Decree on 13 August 2021. The committee will submit its report by 1 November 2023. In preliminary assessments from the summer of 2022, the committee emphasizes that good decision-making systems ensure stability, transparency and predictable conditions, while at the same time providing flexibility to handle unforeseen events and adapt to new developments.

The Committee's primary responsibilities are to conduct a comprehensive review of Norway's strategies for meeting its 2050 climate target and to outline a cost-effective pathway for transitioning to a low-emission society by 2050. This transition should promote efficient resource use while maintaining competitiveness in business and industry. The process must also ensure that development supports biodiversity and upholds a welfare-oriented society. Additionally, the Committee will assess progress towards the targets and evaluate the benefits in relation to economic costs[133].

Energy communities with potential evolution to PEDs

Since 2017, *Research Center for Zero-Emission Areas in smart cities (FME ZEN)* has developed methodology, analysis tools and guides for use in the planning, development and operation of zero-emission areas, in parallel with testing **in 9 pilot projects** around Norway. Such knowledge is important for Norway to be able to reach the target of a 55 percent reduction in emissions of greenhouse gases in 2030, for the transition towards a low-emission society in 2050, and to meet the EU's revised building energy directive.

[133] https://www.regjeringen.no/contentassets/5f15fcecae3143d1bf9cade7da6afe6e/no/pdfs/nou202320230003000dddpdfs.pdf

Table 27. Campus Evenstad

Name: Campus Evenstad[134]	
Location: StorElvdal Municipality, Norway	**Type of district**: Residential
Number of members: 20 buildings	**Established**: 2017
Description: Campus Evenstad is a rural university campus comprises approximately 20 buildings, including offices, lecture rooms, student housing, and a cantina. The construction of a new administration building in early 2017 brought the campus closer to achieving its ZEN goals by integrating energy-efficient and sustainable technologies. It serves as a model for sustainable development in rural areas, showcasing the integration of innovative energy systems and the potential for achieving zero-emission goals in operation.	
Technology & Infrastructure: **Local Renewable Energy Sources:** The campus partially meets its electricity demand using **on-site solar cells** and a **combined heat-and-power (CHP) plant**, with additional electricity sourced from the grid. **Heat Supply:** Heat demand is primarily fulfilled by the CHP plant, a **bio boiler**, and **solar collectors**, supplemented by electric units like boilers and heaters. **Energy Management System:** The system optimizes the use of local energy resources. **Electrification:** Includes an **electric vehicle (EV) charger** and a **stationary electric battery** to support transport and energy storage.	
Funding: Most of the campus is owned and operated by Statsbygg, a publicly financed building agency in Norway.	
Governance structure: Not explicitly detailed.	
Challenges: • Achieving zero-emission operations for its buildings depends on the emission factor of grid electricity, emphasizing the need for continued reliance on low-emission energy sources.	***Successes:*** • **Emission Reduction Potential:** Campus Evenstad integrates energy-efficient buildings and local low-carbon energy generation, advancing its Zero Emission Neighbourhood goals. • **Electrification and Waste Handling:** Incorporation of electrification and waste handling processes highlights its comprehensive approach to emission reductions.

Table 28. Fornebu

Name: Fornebu [135]	
Location: Bærum municipality, Norway	**Type of district**: Residential and commercial
Number of members: approx. 1,250 citizens, 36 060 m2	**Established**: 2018–2025 (Under construction)
Description: The town planning initiative outlines the layout of streets, parks, and urban spaces, while also establishing a clear framework for new buildings within a defined quarter structure. All existing buildings are preserved and key facilities such as schools and libraries are centrally located within the urban plan. The area features urban structures designed for low- and zero-carbon mobility, including pedestrian and bicycle pathways and fossil-free public transport. In the spring of 2018, the Fornebu development area was designated as a test area for reducing GHG emissions. The “ClimateStrategy 2030”, describes Fornebu as a zero-emission area by 2027. In the years until then, climate-friendly construction is to be carried out both under public and private procurement.	
Funding: Not explicitly detailed.	
Governance structure: Key stakeholders include Bærum Municipality and other stakeholders collaborating to implement the ZEN vision: Future Built and Skanska.	

[134] https://fmezen.no/wp-content/uploads/2020/05/ZEN-Report-no-22_Zero-emissionneighbourhoods-Drivers-and-barriers-towards-future-development.pdf
[135] https://fmezen.com/fornebu-baerum/

Challenges:	Successes:
• Communication between the municipality's entities and ZEN researchers is not established on all levels or in all areas. • A ready-made recipe is often sought by developers to achieve ZEN. • Making the right decisions today is challenging when planning for a long-term horizon.	• Plans for all buildings to be certified as BREEAM-NOR Excellent. • Near zero-energy buildings and integrated energy strategies, including smart solutions for power management and renewable energy production. • Commitment to fossil-free construction sites and the use of long-lasting, low-maintenance materials. • The planned Fornebu Metroline contributes to making Fornebu an excellent area for zeroemission mobility solutions.

Table 29. Furuset

Name: Furuset[136]	
Location: Furuset, Oslo, Norway	**Type of district**: Residential and commercial
Number of members: 9 500 inhabitants	**Established**: Completion planned by 2030
Description: Furuset is a sub-urban area in Groruddalen in the east part of Oslo. There is around 323,000 m² of built-up area with 1,400 homes, 3,800 inhabitants and 1,500 jobs. There is a multicultural population in the area. Furuset has living condition challenges and physical improvements must be seen in the context of social measures. The area has good public transport coverage through bus and subway, and significant development potential at the hub. Furuset seeks to combine environmental renewal with urban development, creating a vibrant urban centre with upgraded infrastructure, residential units, workplaces and urban green spaces.	
Technology & Infrastructure: **Local Renewable Energy Sources:** The project integrates: PV on new buildings, seasonal storage of heat in energy wells, low temperature district heating network, local flexibility market for electricity. **Mobility Infrastructure:** The neighbourhood is designed to leverage existing metro and bus networks while improving pedestrian and cycling pathways. Plans also include reducing vehicle emissions through strategic traffic management and enhancing the urban landscape with green and blue infrastructure.	
Funding: The project is funded through public investments, emphasizing the municipality's commitment to urban renewal and sustainability.	
Governance structure: Oslo Municipality leads the project in collaboration with other stakeholders collaborating to implement the ZEN vision FutureBuilt, OBOS, Norsk fjernvarme (Celsio).	
Challenges: • This includes contact between local stakeholders and ZEN researchers • No clear plan for building upgrades, particularly for residential buildings. • Disagreement on the methodology for calculating district heating at the individual building level. • Lack of broad understanding of ZEN measures among residents and users. • Residents in the neighbourhood show insufficient interest in adopting ZEN measures.	***Successes:*** • The Furuset Project has established a comprehensive planning framework, incorporating input from local stakeholders to balance sustainability goals with community needs. The area regulation adopted in 2016 facilitates the development of key infrastructure and public spaces.

[136] https://jpi-urbaneurope.eu/wp-content/uploads/2020/06/PED-Booklet-Update-Feb-2020_2.pdf

Table 30. Ydalir Project

<table>
<tr><th colspan="2">**Name**: Ydalir Project [137]</th></tr>
<tr><td>**Location**: Elverum, Norway</td><td>**Type of district**: Residential</td></tr>
<tr><td>**Number of members**: 800 residential units</td><td>**Established**: Planned 2019-2035</td></tr>
<tr><td colspan="2">**Description:** Ydalir is the name of a new development area located 1.5-2 km to the northeast of the centre of Elverum, Innlandet. At the end of the construction period the area will have a new school (sized 6,000 m2 for 350 pupils), a kindergarten (sized 1700 m2 for 120 children), and about 800 residential units. The development of Ydalir will take place over a period of 10-15 years and is scheduled to be completed between 2035-2040. Ydalir is being developed with the goal of creating a zero-emission area, emphasizing both technical and physical solutions for a socially sustainable residential environment. Social spaces and meeting areas are being created to encourage positive relationships among residents and with the community.</td></tr>
<tr><td colspan="2">**Technology & Infrastructure:**
Local Renewable Energy Sources: Planned energy sources include solar power, groundwater heating, biofuels, and district heating. Energy storage options, such as batteries or bedrock, are being explored to enhance sustainability.
Mobility Infrastructure: A robust public transport network will feature frequent bus services and safe, well-designed walking and cycling paths. Parking spaces will be centralized and shared, minimizing car dependency and encouraging low-emission mobility.</td></tr>
<tr><td colspan="2">**Funding:** Supported through a mix of public and private funding, including contributions from local developers and the municipality.</td></tr>
<tr><td colspan="2">**Governance structure:** Project is managed by Elverum Tomteselskap, a semi-public organization owning 80% of the development area. Additional stakeholders include two private landowners, seven private developers, consultant agencies, a transportation agency and local energy and waste management companies.</td></tr>
<tr><td>***Challenges:***
• Laws and regulations: initially, all buildings in Ydalir were supposed to be passive houses, but current laws don't allow buildings to be required to meet stricter standards than the minimum building code (TEK 17).
• Restrictions on sharing locally produced energy between buildings.
• Communicating the right message has been a challenge.</td><td>***Successes:***
• There was a demand for a new school, kindergarten, and additional residential units near the city centre of Elverum at the start of 2014.
• There was a desire to create a showcase for sustainable construction, low energy use, and the use of wood.
• Ambitious politicians and the municipality played a role.</td></tr>
</table>

Current technological status

Collective electricity generation and distribution practices

Power consumption in Norway is currently around 138 TWh. According to NVE's and Statnett's projections, there will be an increase in power use of 21-30 TWh towards 2030, and 36-45 TWh towards 2040, among other things because of measures to reduce GHG emissions and the establishment of new industry[138]. Norwegian power production is mainly renewable. The share of renewable power production will vary with energy prices and the weather but is around 98 per cent in a normal year. Very few countries in the world have a higher share of renewables in power production. Hydropower accounts for 88 per cent of power production in a normal year, while wind power accounts for ten per cent. The rest consists of some solar power and thermal power production based on fossil fuels, mainly gas power at Mongstad and Melkøya.

[137] https://jpi-urbaneurope.eu/wp-content/uploads/2020/06/PED-Booklet-Update-Feb-2020_2.pdf
[138]https://www.regjeringen.no/contentassets/5f15fcecae3143d1bf9cade7da6afe6e/no/pdfs/nou202320230003000dddpdfs.pdf

Norwegian power production is also characterized by the fact that it is largely flexible, due to the large proportion of adjustable hydropower[138].

Smart metering and billing infrastructures

All electricity consumers in Norway have a smart meter installed. With Advanced Metering System, consumers receive advanced information about their electricity consumption, a more accurate meter reading and better opportunities to engage in demand response[139]. Norway implements the development of a smart energy management system to reduce the peaks in energy consumption and thereby the load on the electricity grid. The aim is to increase the amount of self-produced and self-consumed energy**Error! Bookmark not defined.**.

Demand side management strategies

The primary stakeholders in the development of a ZEN are the building owners and end-users on the demand side, as well as the material and energy suppliers on the supply side. A key motivator for stakeholders on the demand side is to connect the energy needs of end-users with decisions regarding materials, design, and technologies made by building owners, with the aim of reducing costs and emissions[140].

Green Mobility Solutions within PEDs

Currently, the ZEN Centre has chosen to base its mobility criteria mainly on communities, focusing on low-emission transport solutions and access to public transport. Also, is in progress the development of a transport infrastructure based on a broad network of walking and bicycle paths, charging stations for electrical bikes, a car-pool for electric cars, and an electric bus that connects the neighbourhood to the nearby train station.

Incorporation of Electricity Storage

Today, most opt for battery energy storage in a network of buildings with varying energy needs during the day, week and year but nevertheless, energy storage within the bedrock is a possibility in Norway.

Level of Digitalisation

Application of the living lab methodology to engage campus users in activities which minimize energy consumption and greenhouse gas emissions.

To achieve its high ambitions, the ZEN Centre will, together with its partners create cost effective, resource and energy efficient buildings by developing low carbon technologies and construction systems based on lifecycle design strategies. The ZEN

[139] https://www.nve.no/norwegian-energy-regulatory-authority/retail-market/smart-metering-ams/#:~:text=All%20electricity%20consumers%20in%20Norway,to%20engage%20in%20demand%20response.
[140] https://fmezen.no/wp-content/uploads/2019/01/ZEN-Report-no-10.pdf

Research Centre has eight pilot projects spread over Norway. Table 2 gives a short overview of the projects and their main characteristics[104].

Table 31. Eight pilot projects at a glance, ZEN Centre, Norway

	City population (1.1.2017)	Project owner	Area size in m^2	Planned/Existing function	Construction	Status/Phase
Elverum - Ydalir	14 877	Public (Municipality)	430 000	Residential area with a school and kindergarten (planned)	New construction: 1 000 dwellings (ca. 100 000 m^2), a school and a kindergarten	Implementation
Oslo - Furuset	666 759	Public (Municipality)	870 000	Multifunctional local centre with 1 400 dwellings and 3 800 inhabitants, 213 100 m^2 (existing)	Retro-fitting/upgrading and new construction: 1 700 – 2 300 dwellings and 2 000 – 3 400 work places (up to 160000 m^2)	Implementation and Operation
Bergen - ZVB	278 556	Private (Developer)	378 000	Residential area with a kindergarten and additional services (planned)	New construction, 720 dwellings (92 000 m^2), a kindergarten and additional service functions	Planning
Trondheim – NTNU Campus	190 464	Public (NTNU/ Municipality)	339 031	University Campus (existing)	Retro-fitting and new construction (ca. 136 000 m^2)	Planning and Operation
Trondheim -Sluppen	190 464	Public / Private	275 000	Multifunctional local centre with a mobility hub (planned)	Retro-fitting and new construction	Planning and Operation
Steinkjer – Former NRK site	12 744	Public (Municipality)	11 113	Kindergarten and dwellings (planned)	Re-use and new construction of 10-12 dwellings	Planning
Evenstad - Campus	2 530 (Municipality)	Public (University)	61 000	University campus (existing)	Building stock in use: 10 000 $m^{2,}$ no further construction planned	Operation
Bodø – New City – New Airport	51 002	Public (Municipality)	3 400 000	Multifunctional city centre extension with residential and business areas (planned)	Re-use and new construction: 2 800 dwellings in the first construction stage	Planning

3. Energy Transition Action Plan for PEDs

Based on the research conducted in the above sections, to achieve a green transition and ensure that Positive Energy Districts are sustainable and replicable, a structured Transition Action Plan is proposed based of previous conducted research and must guide the development, deployment, and replication of PEDs across various European cities. This plan emphasizes six essential action areas designed to integrate PEDs within urban environments while maximizing their energy efficiency, economic viability and capacity for scale.

The transition towards climate neutrality brings forth a series of challenges and opportunities for local communities in the context of PEDs, both urban and rural. The goal is not only to reach the destination of achieving climate neutrality, but also to drive societal transformations, technological advancements and enhancements in the built environment, all aimed at improving the quality of life for people.

Figure 7. Energy Transition Action Plan for PEDs

From an energy perspective, addressing these decarbonization challenges must start with defining the energy boundary of cities to clearly define the PED - how the energy perimeter is effectively delineated in relation to the built environment on one hand and defining urban energy systems on the other.

This definition, in practice, breaks down energy systems into two main categories:

- **Large urban energy systems** (electric grids, natural gas networks, district heating systems, potable water supply networks, sewage systems, public street lighting, telecommunications systems, local public transportation, waste collection systems and others) that provide essential public utilities for cities.

- **Small-scale domestic systems and technologies**, which include all functional and energy-consuming equipment within residential buildings and other categories of structures, including HVAC systems, lighting and more recently, local energy generation systems from renewable sources.

From the perspective of urban energy management and the ambition for decarbonization, the focus on technical solutions, technology adoption, and modernization must therefore occur at both levels of urban energy systems. This requires different resources, distinct approaches, policies and local governance models.

In this context, both technical and societal modelling of cities is essential. This begins with defining their boundaries, including energy and emission contours, and continues with established models in specialized literature: cities as thermodynamic systems, cities as metabolic systems and cities as complex systems. Additionally, socio-technical models that differentiate the two main categories of urban energy systems - large systems and small-scale domestic systems - are also necessary[141]. A data-driven action plan ensures effective development, implementation, and monitoring of strategies aimed at achieving PED. Unlike approaches that rely solely on forecasts, data-driven plans provide concrete insights into current energy consumption patterns, system performance and potential areas for improvement.

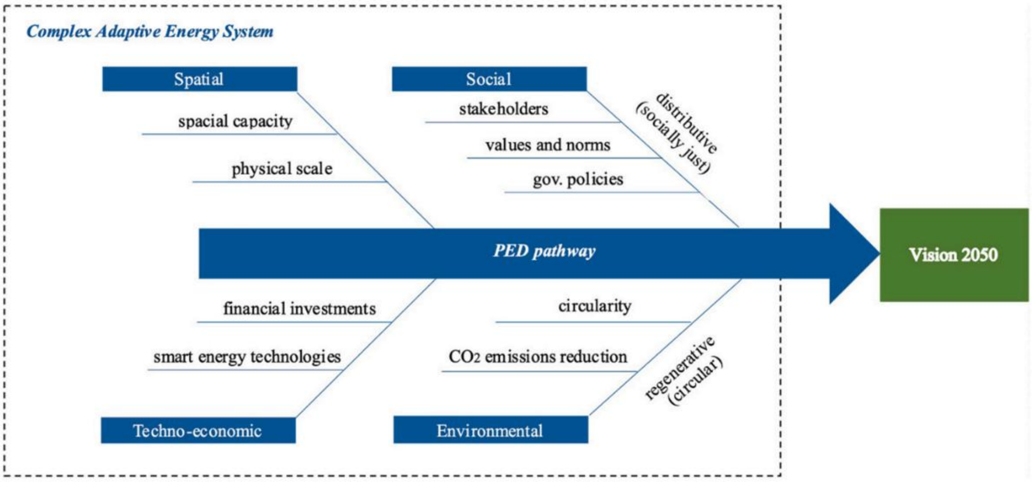

Figure 8. Doughnut pathway toward the vision[142].

By leveraging real-time data and comprehensive analytics, stakeholders can make informed decisions that adapt to evolving conditions, optimize resource allocation, and swiftly respond to emerging challenges. This approach enhances accountability, promotes continuous refinement of strategies and ensures that decarbonization efforts remain aligned with actual urban energy dynamics.

[141] Urban Energy Systems: An Integrated Approach. by James Keirstead and Nilay Shah. 2013. New York: Routledge, 2013, 336 pp., ISBN 978-0-415-52902-0

[142] Derkenbaeva, Erkinai & Vega, Solmaria & Hofstede, Gert Jan & Leeuwen, Eveline. (2022). Positive energy districts: Mainstreaming energy transition in urban areas. Renewable and Sustainable Energy Reviews. 153. 111782. 10.1016/j.rser.2021.111782.

The transition to climate neutrality demands a robust action plan that fosters inclusivity and addresses the unique challenges and opportunities associated with PEDs. The following strategic action plan is structured around key pillars essential for effective implementation. The shift towards climate neutrality necessitates a tailored action plan that supports inclusivity and navigates the unique challenges and potential of PEDs.

Table 31 highlights **strategic action** plan outlines key pillars for successful PED implementation.

Table 32. Key pillars for successful PED implementation

Pillar	Strategic actions
Development planning and strategies	• Craft localized energy policies and urban planning regulations to direct the development of PEDs. • Create comprehensive concepts and strategies, including municipal climate strategies and energy transition roadmaps. • Deploy robust indicator systems and balance sheets to assess and track the climate impact and progress of PEDs. • Establish waste management strategies that align with the sustainability goals of PEDs.
Municipal buildings and facilities	• Integrate energy efficiency solutions and renewables into public buildings within PEDs. • Conduct detailed evaluations of existing municipal buildings and develop stringent energy standards for future public constructions. • Set clear and measurable goals for energy use, efficiency and carbon impact to guide and monitor PED progress.
Energy supply and resource management	• Design strategies for the delivery and distribution of clean energy within PEDs, ensuring funding for energy efficiency and renewable projects. • Drive the use of renewable energy, foster sustainable products and practices, and encourage eco-conscious consumer behaviour. • Implement waste-to-energy systems and improve water and wastewater management for resource efficiency.
Sustainable mobility	• Support sustainable mobility options within PEDs and enhance public transportation networks. • Develop safe bicycle lanes and pedestrian pathways to promote active transport. • Revise public spaces to encourage pedestrian and public transport use, reduce traffic speeds and improve overall urban accessibility.
Internal governance and organization	• Define clear policies, roles, and oversight protocols to facilitate efficient execution of PED initiatives. • Form internal energy-focused committees and allocate dedicated human resources. • Implement staff training, performance evaluations and continuous improvement processes to align internal operations with PED objectives.
Community engagement and cooperation	• Promote energy efficiency measures through community partnerships and incentive programs. • Engage residents, schools, NGOs and businesses to participate in PED activities. • Offer resources for private-sector involvement through pilot projects, informational hubs and financial aid programs.

Value of an integrated approach

The synergy between these pillars ensures that PEDs function effectively as cohesive, sustainable energy ecosystems. Development planning lays the groundwork for policy and strategy, influencing the deployment of energy solutions and infrastructure. Municipal buildings serve as prototypes for best practices, leading community-wide adoption. A robust energy supply strategy supports the optimization of resources, while sustainable mobility reduces emissions and integrates seamlessly with urban design.

Internal governance structures are crucial for coordinating these efforts, ensuring accountability, and maintaining momentum across different sectors. Lastly, communication and active cooperation foster trust, inspire collective action and facilitate knowledge-sharing within the community.

Adopting a holistic approach ensures these components reinforce one another, creating adaptive and resilient PEDs that respond to community needs and contribute to long-term environmental, social, and economic sustainability.

Evaluation of Key Sub-Pillars for PEDs Energy Transition

Based on the conducted research, when proposing and forming PEDs, certain sub-pillars must be carefully considered and evaluated to ensure successful implementation and sustainable outcomes.

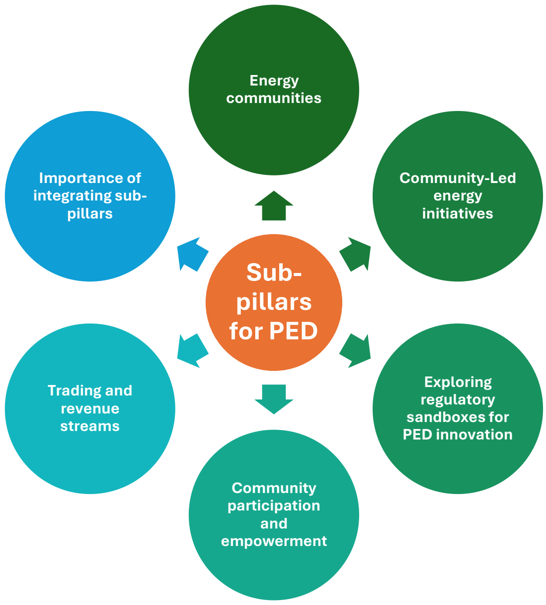

Figure 9. PED sub-pillars

The critical sub-pillars for PED (Figure 9) development are outlined:

Energy communities. At present, the formation of PEDs is most feasible through the establishment of energy communities and cooperatives. These structures play an important role in pooling resources, enabling shared ownership and fostering collaboration among stakeholders. Energy communities facilitate collective investment in renewable energy projects, local energy generation and shared consumption, creating a supportive ecosystem for PEDs.

Community-Led energy initiatives. Community-led energy initiatives are essential for empowering local stakeholders and ensuring that PEDs align with the needs and goals of the community. Such initiatives foster local engagement, build trust, and encourage participation, which are crucial for long-term sustainability. PEDs should prioritize mechanisms for involving residents in decision-making and project planning to enhance the sense of ownership and commitment.

Exploring regulatory sandboxes for PED innovation. The concept of regulatory sandboxes allows for the controlled testing of new energy technologies and business models within a PED framework. In the EU, these sandboxes are crucial for fostering innovation by providing a regulatory environment where new ideas can be trailed with limited risk. By incorporating regulatory sandboxes, PEDs can experiment with emerging solutions, improve regulatory flexibility and adapt to evolving energy landscapes.

Community participation and empowerment from a trading perspective. Community participation should not only focus on energy consumption and generation but also on active involvement in energy trading. PEDs should facilitate frameworks that allow community members to participate in local energy markets, promoting peer-to-peer energy trading and enhancing economic benefits. Empowering communities through trading mechanisms can create new revenue streams and reinforce the financial sustainability of PEDs.

Trading and revenue streams at PED level. Developing robust trading and revenue models is essential for the financial viability of PEDs. These models should consider mechanisms such as net metering, feed-in tariffs and dynamic pricing. Additionally, PEDs should explore innovative revenue-generating activities, including demand response programs and the sale of excess energy back to the grid, to ensure economic resilience.

Importance of integrating sub-pillars. The integration of these sub-pillars ensures that PEDs are not only technically sound but also socially inclusive and economically sustainable. Energy communities and community-led initiatives provide the foundation for active participation and shared responsibility, while regulatory sandboxes support innovation and adaptability. Community empowerment in trading enhances local engagement and creates economic opportunities and robust revenue streams underpin the long-term success of PEDs.

A comprehensive approach that considers these interconnected sub-pillars will result in PEDs that are resilient, adaptable and aligned with the goals of the energy transition, fostering a pathway toward climate-neutral and community-centric energy districts.

An action plan is a detailed document that outlines the steps needed to achieve a specific goal or set of goals. It breaks down the goal into smaller, manageable tasks, assigns responsibilities, establishes a timeline and identifies necessary resources to ensure efficient and organized progress. Action plans are widely used in various fields, such as business, project management, education and personal development, to provide clarity, structure and accountability.

PED Action Plan objectives

The objectives of the PED Action Plan are multifaceted and focus on reducing CO_2 emissions and energy consumption among end-users, covering both public and private sectors. The primary objectives include:

- **Climate change mitigation**: Contribute to the reduction of greenhouse gas emissions and minimize the costs and adverse impacts associated with climate change on society and the environment.

***KPI**: Reduction in CO2 emissions (%). This indicates the percentage decrease in emissions relative to a baseline year.*

- **Sustainable transport**: Develop and maintain a transportation system that meets the economic, social, and environmental needs of the community, while minimizing its negative impact on the economy, society and the environment.

***KPI**: Percentage of public transport usage. This reflects the proportion of trips made using public transportation*.

- **Sustainable production and consumption models**: Promote sustainable production and consumption patterns within public and private buildings and facilities to reduce energy consumption and CO_2 emissions.

***KPI**: Energy consumption reduction (%). This measures the percentage decrease in energy usage over time.*

- **Efficient natural resource management**: Enhance the management of natural resources to prevent overexploitation, recognizing the value of ecosystem services and the importance of their conservation.

***KPI**: Water usage efficiency (litters per capita). It tracks average water consumption per individual to monitor sustainable resource use.*

- **Public health and protection**: Foster public well-being and health by ensuring solidarity and protection against health threats in an equitable and sustainable manner.

***KPI**: Air quality index (AQI). It is a standardized measure that reflects the overall air quality in an area.*

- **Social inclusion and quality of life**: Create a socially inclusive society that promotes intergenerational solidarity, ensures security and improves the quality of life for all citizens.

***KPI**: Social inclusion index. This index can be constructed based on surveys and measures that account for factors such as access to services, income equality and community participation.*

Operationalizing PEDs

Assessment metrics play a significant role in implementing, comparing, and replicating PEDs. Thus, the metrics are expected to reflect the defining elements of the PED concept[143].

Energy performance within a geographical boundary

A geographical boundary is one of the defining elements of PEDs. However, it can only be characterized qualitatively by a unit (a building, a neighbourhood or a district) that gives an idea of the area size. The areas are treated as a single unit while assessing the scale of energy efficient areas. Therefore, it is fundamental to specify these units while addressing the metrics.

[143] Erkinai Derkenbaeva, Solmaria Halleck Vega, Gert Jan Hofstede, Eveline van Leeuwen, “Positive energy districts: Mainstreaming energy transition in urban areas, Renewable and Sustainable Energy Reviews, Volume 153, 2022, 111782, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2021.111782.

The other defining elements of the PEDs and overall, the energy performance is assessed within a geographical boundary. Ala-Juusela[144] propose a general set of indicators to assess energy efficiency. More specifically, these indicators relate to energy (energy consumption, generation, efficiency label), economic (energy cost, energy sold to the grid, energy cost savings) and environmental (CO_2 emissions, energy savings) aspects. While these indicators provide a broad scope of energy efficiency, indicators related to contextual and individual factors are still required to contribute to a clearer indication of the PEDs' energy performance.

Interaction with an energy grid

To optimize energy use, two-way communication between buildings and energy grids (smart grids) has become an important element. Different indicators and approaches have been proposed to analyse the building-to-grid interaction[145]. The grid interaction index represents the variability of the energy flow within a year, where the energy flow is a net export that is defined as a difference between exported and delivered energy within a given time interval.

From the viewpoint of a grid, the authors highlight an important characteristic: grid interaction flexibility, which allows response to signals from the smart grid such as price signals, and therefore, adjusts load, generation, and storage control. For this purpose, it is meaningful to assess grid interaction flexibility hourly or even with a higher time resolution.

Assessing grid interaction flexibility with such a high time resolution is a focus of import/export energy balance calculation and contributes to providing more complete information on the interaction with the smart grid[146].

Energy supply method

As one of the defining elements, energy supply gained significant attention in the literature on PEDs and similar concepts. While the on-site supply is distinguished between supply within the building footprint (located on the building) and the building site (located on-site but not on the building), the off-site supply indicates that the building either uses renewable energy sources available off-site to produce energy on-site or purchases off-site renewable energy sources. However, there is ambiguity in renewable energy supply that in some cases is seen as on-site when focusing on the actual location of the energy generation, while in other cases as off-site when focusing on the fuel's origin. Therefore, clear distinctions and definitions of energy supply methods need to be outlined for a common understanding of PEDs[147].

[144] Ala-Juusela, Mia & Crosbie, Tracey & Hukkalainen, Mari. (2016). Defining and operationalising the concept of an energy positive neighbourhood. Energy Conversion and Management. 125. 10.1016/j.enconman.2016.05.052.
[145] Marszal AJ, Heiselberg P, Bourrelle JS, Musall E, Voss K, Sartori I, et al. Zero Energy Building - a review of definitions and calculation methodologies. Energy Build 2011;43:971–9. https://doi.org/10.1016/j.enbuild.2010.12.022.
[146] Sartori I, Napolitano A, Voss K. Net zero energy buildings: a consistent definition framework. Energy Build 2012;48:220–32. https://doi.org/10.1016/j. enbuild.2012.01.032.

[147] Erkinai Derkenbaeva, Solmaria Halleck Vega, Gert Jan Hofstede, Eveline van Leeuwen,
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Renewable and Sustainable Energy Reviews, Volume 153, 2022, 111782, ISSN 1364-0321,
https://doi.org/10.1016/j.rser.2021.111782.

Balancing period

A balancing period has been heavily discussed in the literature on PEDs and similar concepts, where the annual energy balance is the most accepted one for calculating the energy balance. To measure the annual balance between local energy supply and demand, in a set of KPIs are designed.

The foremost KPI, "On-site Energy Ratio (OER)" measures the balance between energy demand and supply from the local renewable energy sources. However, because the OER is generic as it does not consider the time of energy demand and supply (e.g. peak energy demand time) and different types of energy, and could be included. Another option is the sub-yearly balance such as seasonal or monthly. These balancing periods allow energy supply systems to better match the actual energy demand. Nevertheless, it is more challenging to achieve zero balance than in the case of annual balance because of the seasonal differences between energy demand and renewable energy generation.

Recommendations for stakeholders of PEDs

The following recommendations outline actionable steps for stakeholders involved in the development, deployment and replication of PEDs across Europe. Designed to support a green transition, these recommendations emphasize collaborative networks, local innovation hubs, standardized tools, and continuous monitoring. By adopting these strategies, stakeholders can ensure that PEDs are not only sustainable and replicable but also scalable, positioning European cities as leaders in sustainable urban development. These recommendations provide a clear path forward to establishing PEDs as integral components of Europe's energy-efficient, future-ready cities.

Build a European positive energy cities network

Recommendation: Establish a network of "European Positive Energy Cities" comprising cities committed to the development and sustainability of PEDs. This network should facilitate the sharing of best practices, alignment on certification standards and collaboration on innovative solutions.

Cities are encouraged to embed PEDs into their long-term urban strategies in partnership with public utilities, infrastructure operators, construction industries, and research organizations. This approach will support a unified understanding of PED requirements, monitoring frameworks and capacity-building initiatives.

Create PED labs for localized innovation

Recommendation: Establish PED Labs across Europe to act as open innovation environments where cities can pilot and experiment with PED concepts, tailoring them to their unique social, economic, and environmental contexts. PED Labs should provide a space for testing advanced technologies, exploring new business models, and fostering community engagement. These labs will facilitate public-private collaboration, uniting cities, industry, academia and civil society to co-create effective solutions for sustainable urban development.

Develop standardized PED guides and tools

Recommendation: Based on insights from PED Labs, create standardized guides and tools to support cities in planning, financing, deploying and replicating PEDs. These resources should include:

- Establish national or European PED certification schemes to ensure quality assurance for cities and investors.
- Offer guidance on navigating legal and regulatory requirements to streamline PED deployment.
- Provide resources on sustainable financing options, including public-private partnerships and innovative investment mechanisms.
- Develop training programs to build expertise within local governments and communities, ensuring the long-term maintenance and expansion of PEDs.

Promote replication and mainstreaming of PEDs

Recommendation: Encourage cities to integrate PEDs into broader urban strategies, focusing on creating scalable solutions rather than isolated pilot projects. Ensure that cities have the necessary regulatory support, stakeholder engagement and infrastructure readiness to facilitate PED replication. Define criteria to transition from pilot projects to larger-scale implementations, initially targeting medium-sized projects that can expand with further insights. Aim to have 100 PEDs in planning, construction or operation across Europe by 2025.

Implement comprehensive monitoring and evaluation framework

Recommendation: Develop and deploy a robust Monitoring and Evaluation (M&E) system for PEDs to track energy performance, socio-economic impacts and environmental outcomes. Conduct M&E activities locally, with synthesized data contributing to national and European insights. This continuous evaluation process will enable cities to identify best practices and refine PED strategies for enhanced efficiency and impact.

Support innovation actions for PEDs

Recommendation: Secure national and transnational Research and Innovation (R&I) funding to support Innovation Actions that drive the continuous development of PEDs. Innovation Actions should promote knowledge sharing across stakeholders, support scalable solutions, and provide a shared repository of tools and methodologies. Establish innovation pipelines involving both public and private sectors, including R&D institutions, to facilitate the commercialization of PED solutions and bolster Europe's global competitiveness in sustainable urban development.

Promote European leadership in sustainable urban development

Recommendation: By implementing the above recommendations, stakeholders can ensure that PEDs contribute effectively to Europe's green transition while remaining sustainable and replicable. Through a well-structured network, local innovation labs, standardized guides, and rigorous monitoring, PEDs can become central to Europe's urban energy landscape, solidifying the region's leadership in global sustainable development.

Final remarks

Report *"D4.1 Energy Transition Action Plan for Positive Energy Districts (PEDs)"* underscores the transformative potential of PEDs in addressing the global climate crisis, achieving energy security, and fostering inclusive urban sustainability. PEDs exemplify the convergence of technological innovation, policy alignment, and community engagement, some of them serving as living laboratories for a sustainable and equitable energy future.

The findings of this report highlight several critical takeaways:

1. PEDs represent a **pivotal model for decarbonizing urban environments**. Their capacity to generate surplus renewable energy, integrate advanced energy management systems and engage local communities positions them as essential pillars of the Green Transition.
2. PEDs deliver **significant environmental, economic and social benefits**. They reduce GHG emissions, enhance energy efficiency, create green jobs and foster a sense of ownership and participation within local communities. These benefits are not only **vital for achieving EU climate goals,** but also for improving the quality of life in urban areas.
3. Despite their promise, PED implementation faces **regulatory ambiguities**, high initial costs and **technical complexities**. Overcoming these barriers requires harmonized policies, targeted financial mechanisms and robust stakeholder collaboration. Emphasis must also be placed on raising public awareness and fostering a culture of sustainable energy use.
4. The diverse experiences of PED and energy community initiatives across partner countries demonstrate the importance of **adapting strategies to local contexts**. From Romania's emerging energy communities to Norway's advanced renewable integration, these cases provide valuable insights into overcoming challenges and leveraging opportunities.
5. Successful PED implementation demands **active collaboration** among municipal authorities, energy providers, researchers, developers, NGOs and citizens. Stakeholders need to **unite around common objectives**, prioritizing innovation and developing scalable models that can be replicated in other urban areas. To realize the vision of widespread PED adoption, the report advocates for:
    - The development of clear, enabling regulatory frameworks.
    - Strategic investment in renewable energy infrastructure, smart grids and storage solutions.
    - Increased community engagement and participatory planning processes to ensure inclusivity and equity.
    - Continuous research and innovation to address technical challenges and enhance system flexibility.

PEDs are more than a technical solution to the challenges of modern energy demands; they represent a profound shift toward a just and sustainable energy future. They symbolize the potential to harmonize environmental stewardship, economic vitality, and social equity within urban settings. By seamlessly integrating renewable energy technologies, fostering local energy production, and enabling community ownership, PEDs redefine urban living for the 21st century. They transform cities into hubs of innovation, resilience, and inclusivity, embodying the principles of the Green Transition.

As EU asserts its leadership in the global energy transition, PEDs will be indispensable in creating cities that are not only carbon-neutral but also economically thriving and socially inclusive. These districts encapsulate a vision where sustainability is woven into the urban fabric, balancing environmental priorities with the well-being of all citizens. By empowering communities to actively participate in energy decision-making and by prioritizing equitable access to clean energy, PEDs address the multifaceted challenges of modern urbanization.

This report underscores the critical need to accelerate PED initiatives. The strategies outlined provide clear pathways to overcome regulatory, economic, and technical barriers, ensuring the successful deployment of PEDs in diverse contexts.

The call to action is clear: the time to act is now. PEDs are not just an ambitious concept, but a practical and achievable solution that can drive the transition to a sustainable, resilient and climate-positive future.