Positive Energy Districts (PEDs)

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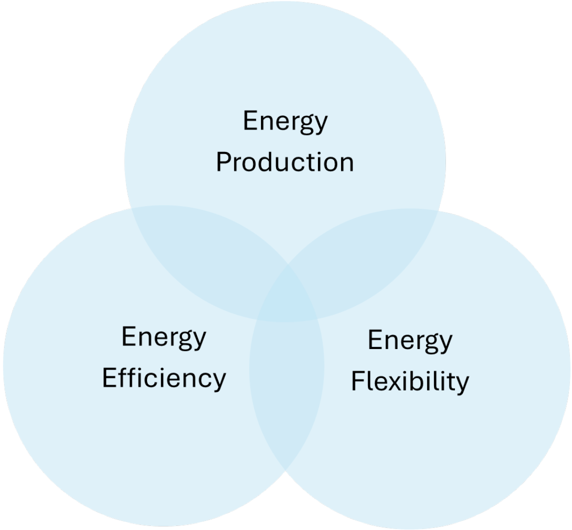
Energy policies and the European framework to address the energy transition of urban areas

The urgent need to address climate change and reduce dependency on fossil fuels has accelerated the global energy transition towards renewables. As cities account for a significant portion of global energy use and CO_2 emissions, the focus on urban areas for clean energy solutions has intensified (IEA, 2021). As densely populated areas are characterised by the concentration of energy consumption, urban energy landscapes can be designed to create sustainable energy systems aiming at self-sufficiency, while concurrently addressing the challenges of a "just" energy transition. This involves the necessity for new social business models to engage different stakeholders on an equal basis, and significantly influence sustainable human lifestyle.

Several approaches have been proposed over time to address these challenges and provide cities with the enabling tools to ensure the achievement of decarbonisation and energy security goals, including Positive Energy Districts (PEDs) currently considered the main European framework for energy transition. PEDs has been set as an emerging concept as part of a broader shift to create renewable energy landscapes to prioritise local energy production, efficient district energy systems, and energy flexibility (European Commission, 2022).

PEDs 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 (see figure below). 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 (JPI Urban Europe, 2020).



Positive Energy Districts Framework

The European Union's Strategic Energy Technology Plan (SET-Plan) has set an ambitious objective of implementing at least 100 PEDs in Europe by 2025. This has resulted in an initiative by a group of stakeholders, including researchers, practitioners and municipalities, to define operational methods for implementing and replicating virtuous models that can direct decarbonisation strategies in urban areas while ensuring the achievement of the target of energy surplus from renewable energy sources.

Several international working groups were formed, the most prominent of which are the COST Action Positive Energy Districts European Network CA19126 and the IEA Annex 83 Positive Energy Districts. These groups comprise various stakeholders who have collaborated to define and propose to different stakeholders innovative methodologies and effective solutions for determining the achievement of the set targets. The research and case studies conducted in Europe revealed several distinctive features, which collectively constituted a set of shared best practices aiming at replication in a variety of urban contexts.

PEDs as a Model for Renewable Energy Multiscale Integration

In contrast to conventional urban energy models that depend on centralised grids and fossil fuels, PEDs employ renewable energy sources such as solar, wind, and geothermal power, enabling them to be self-sufficient and frequently net-energy positive. The decentralised and interconnected design of PEDs is meant to facilitate the integration of distributed renewable energy systems, thereby accelerating the transition away from centralised fossil fuel-based grids. Furthermore, PEDs underscore the role of distributed energy resources as foundational elements in reshaping energy landscapes. PEDs function as microgrids where highly efficient energy systems generate and distribute renewable energy at the local level, thereby enhancing energy flexibility and security. They contribute to the stabilisation of national energy grids by reducing demand peaks and allowing surplus energy to flow into surrounding areas. The active generation and distribution of renewable energy by PEDs serves to reduce grid dependency and minimise transmission losses, thereby supporting the development of a more resilient and adaptable energy system.

Making the case for a positive transition pathway: Energy transition and the decentralisation of power generation

Decentralisation is a key principle of the energy transition, facilitating the development of renewable energy landscapes that prioritise local, renewable resources over fossil fuels. PEDs embody this shift, creating urban areas where energy is generated, consumed, and managed on a community level, often involving citizens as "prosumers" who both produce and consume energy (Derkenbaeva et al., 2022). This model transforms urban energy dynamics and accelerates renewable adoption by empowering communities to take ownership of their energy use.

Decentralised PEDs also mitigate challenges associated with renewable intermittency by integrating energy storage systems, such as batteries and thermal storage, and advanced demand-response solutions. These technologies enable PEDs to store surplus energy and deliver it during periods of high demand, supporting a more flexible, resilient, and renewable-dominant grid (Anastasovski et al., 2024). As a result, PEDs help create renewable energy landscapes that are less reliant on centralised energy production and more adaptable to fluctuations in energy demand and supply.

Technological and social innovations in PEDs to support the energy transition

The effectiveness of PEDs in the energy transition relies on both technological advancements and community engagement. Technologically, PEDs integrate renewable energy generation, storage, and smart grid technology, allowing for dynamic management of local energy flows (Haase et al., 2024). These technologies enable PEDs to provide energy services that are flexible and responsive to real-time energy demands, enhancing grid stability and supporting the transition to renewables.

Socially, PEDs encourage community engagement by involving citizens in the planning and management of local energy resources, fostering energy literacy, and building a shared commitment to sustainability. This participatory approach transforms citizens from passive consumers to active energy stakeholders, promoting a culture of sustainability within PEDs. By increasing local buy-in and engagement, PEDs not only contribute to the success of renewable energy projects but also enhance long-term community resilience.

PEDs and energy security in the context of geopolitical instability

In light of recent geopolitical tensions and energy market volatility, energy security has become a priority in the energy transition. PEDs offer a localised approach to energy generation that enhances energy resilience and reduces dependency on imported fossil fuels (IRENA, 2023). By leveraging local renewable resources, PEDs contribute to energy independence, which is particularly valuable during times of supply chain disruptions and fluctuating energy prices. The energy autonomy that PEDs provide strengthens urban resilience, ensuring that communities have reliable access to clean energy regardless of global energy market conditions.

PEDs can play a crucial role in national energy strategies by reducing urban demand on centralised energy grids, which are vulnerable to geopolitical disruptions. This localised energy model diversifies the energy landscape and promotes energy sovereignty, an increasingly important consideration for nations facing energy security challenges.

Policy implications and strategic recommendations

The integration of PEDs into urban planning requires supportive policies and strategic investments to overcome financial and regulatory challenges. Policymakers play a key role in facilitating PED adoption by offering incentives for renewable energy installations, subsidies for smart grid infrastructure, and streamlined permitting for PED projects (Kuzov et al., 2023). Additionally, harmonised standards for PED technologies and practices can enhance inter-operability and scalability across different urban areas, supporting widespread PED deployment. The success of PEDs also depends on robust partnerships between governments, private companies, and local communities. Collaborative approaches can secure the financial and technical resources necessary for PED projects, especially in cities with limited budgets. Public-private partnerships can further help deploy smart grid and storage solutions that are essential for PED functionality.

Positive Energy Districts Case studies: La Fleuriaye West, Carquefou, France

The La Fleuriaye district in Carquefou, which forms part of the Nantes metropolitan area in France, is a forward-thinking, sustainable neighbourhood that has been designed to become a Positive Energy District (PED).

The objective of this project is to achieve a positive energy balance, whereby the generated energy exceeds the consumed energy, through the utilisation of renewable resources, innovative technology and natural solutions. By prioritising environmental objectives and improving the quality of life for residents, La Fleuriaye provides an exemplar for future urban developments.

District of La Fleuriaye, Carquefou in France
image source: Construction 21

Goals

- *Achieve positive energy status*: The primary objective is for the district to produce more energy than it consumes, focusing on renewable sources and highly efficient building design.
  Enhance environmental quality: The project aims to create a low-carbon, energy-efficient district with minimal environmental impact, aligning with France's national goals for reducing carbon emissions.
- *Promote slow mobility*: With integrated green spaces, pedestrian-friendly areas, and low-emission transport, La Fleuriaye supports an eco-friendly lifestyle.
- *Foster social and community engagement:* The district encourages a sense of community and aims to promote a lifestyle that prioritizes sustainability and environmental awareness.

Strategies for positive energy achievement

- *Energy-efficient building design and construction*: The district's buildings are designed to high energy performance standards, minimizing the need for heating, cooling, and other energy-intensive systems.
- *Local renewable energy generation*: Solar panels and geothermal energy are the main sources of renewable energy, designed to exceed the neighbourhood's consumption needs.
- *Smart energy management and storage:* A microgrid system with battery storage enables energy sharing among buildings, optimizing the use of locally generated energy.
- *Nature-based solutions*: Integrated green spaces, green roofs, and water management systems support biodiversity, reduce urban heat, and enhance overall environmental quality.

Adopted Solutions

Energy Production

Solar Photovoltaic (PV) Panels:

- Capacity: La Fleuriaye has around 10,000 m² of rooftop and facade-mounted solar PV panels, generating approximately 1.5-2 MW of installed solar capacity.
- Energy output: The PV panels produce around 2,000-2,500 MWh of electricity annually, enough to cover a significant portion of the district's electricity demand, particularly during daylight hours.
- Self-consumption strategy: Most of the energy produced is consumed on-site. Excess energy is stored in local battery systems or fed back to the regional grid, supporting Nantes' wider renewable energy goals.

Geothermal Energy:

- Ground-Source Heat Pumps: The district is equipped with a network of ground-source heat pumps, which provide low-carbon heating and cooling by harnessing underground thermal energy.

- Energy output: The geothermal system provides around 1,200-1,500 MWh of heating energy annually, covering the bulk of the heating and hot water needs for the district's residential and commercial buildings.
- Efficiency: The heat pumps operate with a high Coefficient of Performance of around 4, meaning that one unit of electricity generates four units of heat, making it highly efficient.

Battery energy storage:
- Capacity: The neighbourhood includes a central battery storage system with a total capacity of around 500-700 kWh. Additionally, individual buildings are equipped with smaller battery systems to store locally generated solar energy.
- Energy Flow Optimization: The storage system helps balance supply and demand, ensuring a consistent energy supply even during peak demand or periods of low solar production.

Energy consumption

Energy-Efficient Building Envelope:
- Passive Design Standards: The buildings in La Fleuriaye meet France's stringent RT 2012 and RT 2020 energy regulations, featuring high-performance insulation, double or triple-glazed windows, and energy-efficient construction materials.
- Reduced Heating and Cooling Demand: Passive solar design and insulation reduce heating and cooling energy needs by around 40-50% compared to conventional construction.

Energy-Efficient Appliances and LED Lighting:
- Low-Energy Appliances: The buildings are equipped with energy-efficient appliances, which reduce electricity consumption in residences and commercial spaces.
- LED Lighting Systems: LED lighting is installed throughout the district, consuming up to 75% less electricity than traditional lighting and reducing lighting-related energy demand.

Smart Energy Management and Automation:
- Smart Meters and IoT Sensors: Smart meters and IoT sensors allow real-time monitoring of energy use, providing data to optimize consumption and adjust energy flow based on demand.
- Home Automation: Automated systems for heating, cooling, and lighting are standard, ensuring that energy is used only when and where it's needed.

District Heating and Cooling Network:
- Efficient Distribution: The geothermal system is integrated into a district heating network, which efficiently distributes heat to all buildings in the district.
- Lower Carbon Emissions: Centralized heating and cooling reduce the need for individual systems, cutting overall emissions by approximately 20-30% compared to standalone systems.

Open space in the district of La Fleuriaye, *Source: Construction 21*

Mobility and Transportation:

- Electric Vehicle (EV) Charging Stations: The district is equipped with EV charging points to encourage the use of electric vehicles, reducing transport emissions.
- Bike and Pedestrian Infrastructure: Extensive bike lanes, pedestrian-friendly pathways, and connections to public transport encourage sustainable travel within and around the district.

Nature-Based Solutions

Green Roofs and Green Walls:

- Vegetated Roofs: Many of the buildings are topped with green roofs, which provide natural insulation, reduce rainwater runoff, and support local biodiversity by creating habitats for insects and birds.
- Green Walls: Green facades are used on several buildings, improving air quality, insulating the buildings, and enhancing aesthetic appeal

Rainwater Harvesting and Water Management:

- Rainwater Collection: Rainwater is collected from rooftops and stored in tanks, used for landscape irrigation, and, in some cases, for non-potable applications like toilet flushing.
- Bioswales and Permeable Surfaces: To manage stormwater runoff, permeable surfaces and bioswales are incorporated in public spaces, allowing rainwater to percolate naturally into the soil. This helps prevent flooding and improves groundwater recharge.

Community Green Spaces and Biodiversity Enhancements:

- Native planting design: Public spaces are planted with native and drought-resistant vegetation, reducing water requirements and creating habitats for local wildlife.
- Biodiversity Corridors: Green corridors connect different parts of the neighbourhood, allowing flora and fauna to thrive in an urban environment.
- Urban Cooling: Green spaces help reduce the urban heat island effect, providing shaded, cool areas for residents to relax and enhancing overall liveability.

The La Fleuriaye district in Carquefou represents a model of sustainable and resilient urban development. By attaining Positive Energy District (PED) status through the generation of renewable energy, the utilisation of energy-efficient building design, and the incorporation of nature-based solutions, it exemplifies the potential for urban areas to minimise environmental impact while simultaneously enhancing quality of life. The district's green infrastructure, water management, and emphasis on sustainable mobility contribute to its status as an eco-friendly, vibrant community. The district is designed to produce renewable energy on annual basis approximately around 3,200 to 4,000 MWh, while the energy surplus is in the range of 10-15% of more energy than the district's annual consumption. By employing smart energy solutions, fostering community engagement, and pursuing ecological design, La Fleuriaye serves as a replicable model for future PEDs across Europe and beyond.

Schoonship, Amsterdam

The Schoonschip project in Amsterdam represents a pioneering floating neighbourhood and is regarded as one of the most ambitious and sustainable Positive Energy Districts (PEDs) in Europe. Situated on a canal in Amsterdam's northern district, the Schoonschip project is designed to generate more energy than it consumes on an annual basis, while exemplifying pioneering and community-driven methodologies for sustainable living.

Goals

1. *Achieve positive energy balance:* The primary objective is for the neighbourhood to produce more energy than it consumes through renewable energy sources and energy-efficient design.
2. *Create a circular, self-sufficient community:* Schoonschip seeks to implement circular

Schoonship overview, *source: Archivibe*

economy principles, with minimal waste production, efficient water use, and sustainable resource management.
3. *Emphasize community and social cohesion:* Designed as a cooperative, the community has been actively involved in the development and management of the district. The neighborhood promotes communal responsibility, sustainability, and energy sharing.
4. *Increase the biodiversity of the area:* Schoonschip is committed to enhancing biodiversity and implementing nature-based solutions to support local ecosystems and water quality.

Strategies for Positive Energy Achievement

1. *Community-driven energy production and consumption*: Schoonschip has established a neighbourhood-owned energy cooperative to manage and distribute energy within the community. This cooperative also educates residents on energy-saving practices, fostering a culture of conscious energy use.
2. *100% Renewable Energy Integration*: The district uses only renewable energy sources to meet all energy needs, focusing on solar energy and efficient energy storage.
3. *Smart energy management and sharing:* A smart microgrid allows homes to share energy, ensuring efficient distribution and maximizing the use of locally produced energy. Surplus energy is fed back to the grid, supporting the broader Amsterdam power network.
4. *Water-based infrastructure and low-impact design*: Built on water, the district uses floating foundations for all homes, reducing land footprint and allowing buildings to adapt to rising sea levels.

Adopted Solutions

Energy Production

Solar Photovoltaic (PV) Panels:

- Capacity: Each of the 46 floating homes is equipped with rooftop solar panels, collectively producing around 150 kW of solar capacity across the neighbourhood.
- Energy output: The PV panels generate approximately 280,000 kWh of electricity annually, exceeding the neighbourhood's total energy needs. Each home is designed to be self-sufficient in terms of energy production, though energy sharing ensures efficient distribution across the district.

Heat Pump Systems:

- Water-Source Heat Pumps: Schoonschip utilizes water-source heat pumps that extract thermal energy from the canal water to heat and cool the homes. These systems are particularly efficient in water-based environments and reduce reliance on conventional electric heating.

- Efficiency: Each pump can achieve a Coefficient of Performance (COP) of around 4, meaning it generates four units of heat energy for every unit of electricity used, significantly reducing the total energy required for heating.

Energy Storage:

- Battery Storage: Homes are equipped with batteries (around 10 kWh per household) to store excess solar energy generated during the day. This storage capacity allows for a stable energy supply, even during non-peak generation hours.
- Energy Flow Optimization: The battery storage is coordinated through the smart grid to balance supply and demand efficiently, reducing the need for grid energy during peak times.

Smart Microgrid System:

- Schoonschip's energy distribution is managed through a microgrid, allowing residents to share energy efficiently. Surplus energy from one home can be used by others in the community, maximizing the efficiency of energy usage.
- Blockchain Technology: A blockchain-based platform facilitates peer-to-peer energy exchange, enabling residents to trade excess energy with each other in a transparent and efficient way. This blockchain system enhances autonomy, accountability, and community-based energy management.

Energy Consumption

High-Performance Building Envelope:

- Thermal insulation and Triple-Glazed Windows: Each floating home is built with high-performance insulation and triple-glazed windows, reducing heat loss and minimize energy requirements for heating and cooling.
- Energy Savings: Well-insulated building envelopes reduce heating and cooling energy demand by approximately 40-50% compared to typical standards.

Efficient Appliances and LED Lighting:

- All appliances are energy-efficient models, reducing the energy demand for domestic tasks. LED lighting systems are used throughout the homes and public areas, which consume up to 75% less electricity than traditional lighting.
- Energy Impact: The use of efficient appliances and lighting cuts overall energy consumption by an estimated 15-20%.

Smart Energy Management Systems:

- Home Automation and Monitoring: Each household is equipped with a smart energy management system, which allows residents to monitor and adjust their energy consumption in real time.
- Reduced Consumption: Automated systems lower unnecessary energy use, helping the district achieve overall energy savings of 10-15%.

Nature-Based Solutions

Floating Gardens and Green Roofs:

- Floating Gardens: Floating planters are used to introduce green spaces on the water surface, promoting biodiversity by creating habitats for fish, birds, and insects.
- Green Roofs: Many homes have green roofs planted with native vegetation, providing natural insulation, reducing rainwater runoff, and supporting local wildlife.
- Environmental Impact: These green elements improve water quality by absorbing pollutants, enhance local biodiversity, and reduce urban heat island effects.

Sustainable Water Management:

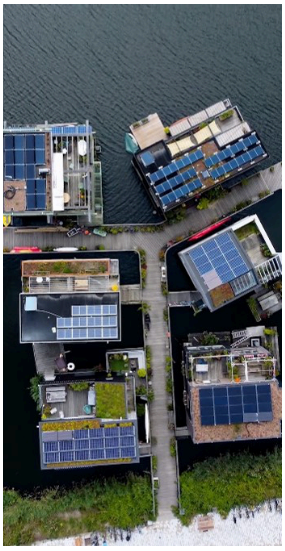
- Rainwater Harvesting: Rainwater is collected and filtered for use in non-potable applications, such as irrigation, reducing the neighborhood's reliance on municipal water supply.
- Wastewater Treatment: An innovative system treats and reuses graywater (non-potable water from sinks, showers, etc.) within the community, supporting circular water use.

Passive Cooling Techniques:

- Natural ventilation and shading techniques reduce the need for air conditioning during warmer months. By maximizing passive cooling, Schoonschip minimizes its cooling energy requirements.

Schoonschip represents a prototypical instance of sustainable urban living. The generation of surplus renewable energy and the efficient management of consumption enable the achievement of the Positive Energy District (PED) target. The project is designed to produce renewable energy on annual basis of approximately 600 MWh from solar PV, with additional heating provided by heat pumps.

Schoonship is designed to be energy self-sufficient, producing enough to meet or exceed its collective demand. This floating district exemplifies how urban development can be energy-positive, environmentally responsible, and community-driven, thereby establishing a new standard for sustainable neighborhoods in urban areas worldwide. Furthermore, the integration of nature-based solutions serves to reinforce the neighbourhood's resilience, biodiversity, and environmental benefits. The utilisation of blockchain-based energy sharing establishes Schoonschip as a paradigm for community-centric, pioneering energy solutions.



Solar PV rooftops on the houseboats,
Source: Space&Matter

Hunziker Areal, Zurich

The Hunziker Areal project in Zürich, Switzerland, represents an innovative, community-centred approach to urban development that is grounded in sustainable principles.

The project has been designed with the objective of meeting ambitious environmental goals, with the intention of becoming a Positive Energy District (PED) through the reduction of energy consumption and the maximisation of renewable energy production. The cooperative-led project incorporates energy efficiency, community engagement, and nature-based solutions with the objective of creating a liveable, energy-positive environment.

Goals

1. *Achieve Positive Energy*: Hunziker Areal aims to generate more energy than it consumes annually, with a focus on renewable energy sources and efficiency in building design.
2. *Promote Sustainable Living and Social Cohesion*: Developed by the cooperative Mehr als Wohnen ("More than Housing"), the project aims to foster community spirit and cooperative living while prioritizing sustainability.
3. *Implement Circular Economy and Low-Carbon Solutions:* The district is designed with a focus on minimizing waste, reusing resources, and reducing carbon emissions.
4. *Enhance Biodiversity and Environmental Quality*: Nature-based solutions and green spaces are integrated to improve local biodiversity and well-being, creating a resilient urban ecosystem.

Haus E at Hunziker Square by Müller Sigrist Architects
Source: buildingsocialecology.org

Strategies for Positive Energy Achievement

1. *Energy-Efficient Building Design*: The project focuses on passive building design, insulation, and high-efficiency construction materials to reduce heating and cooling demands.
2. *Integrated Renewable Energy Systems*: Solar photovoltaic (PV) panels and ground-source heat pumps provide clean, locally-produced energy to meet the district's power and heating needs.
3. *Smart Energy Management:* Hunziker Areal utilizes a neighborhood-wide energy management system to optimize energy use and monitor consumption in real time.
4. *Mobility Solutions*: Car-sharing, cycling, and public transportation infrastructure encourage low-emission transport options within and beyond the district.

Adopted Solutions

Energy Production

Solar Photovoltaic (PV) Panels:

- Capacity: Hunziker Areal has installed approximately 1,200 square meters of solar PV panels across rooftops, which collectively generate around 180,000 kWh annually.
- Energy Output: Solar PV provides about 20% of the district's total energy needs, covering a substantial portion of electricity demand for communal spaces and individual apartments.
- Self-Consumption Strategy: The energy produced is primarily used within the district, with surplus energy fed back into the local grid when demand is low.

Ground-Source Heat Pumps:

- Heat Production: The district employs ground-source heat pumps that draw energy from geothermal wells, providing renewable heating and hot water for the buildings.
- Capacity: The ground-source system covers nearly 80% of the district's heating demand, reducing reliance on conventional heating and achieving significant energy savings.
- Efficiency: With a Coefficient of Performance (COP) of around 4, the heat pumps efficiently convert each unit of electricity into four units of heat, significantly lowering heating energy requirements.

District Heating Network:

- Renewable Heat Sources: Hunziker Areal is connected to Zürich's district heating network, which supplies any additional heating required during peak demands.
- Heat Source Mix: The city's district heating network uses a mix of waste heat, biomass, and other renewable sources, further enhancing the area's sustainability profile.

Energy Consumption

High-Performance Building Envelope:

- Passive Design Standards: The buildings meet the Minergie-P standard, a Swiss energy label similar to the Passivhaus standard, ensuring high insulation and minimal thermal bridging.
- Energy Savings: This design reduces heating demand by approximately 40-60% compared to conventional construction, minimizing energy consumption while enhancing comfort.

Energy-Efficient Appliances and LED Lighting:

- Low-Energy Appliances: All apartments and communal spaces are equipped with energy-efficient appliances that consume significantly less electricity.
- LED Lighting Systems: LED lighting is installed throughout the district, reducing lighting energy use by up to 75% and extending bulb life.

Smart Metering and Home Automation:

- Real-Time Monitoring: Residents have access to smart meters that display real-time data on energy usage, helping them track and reduce their consumption.
- Automated Systems: Automated heating, ventilation, and lighting systems ensure energy is only used when needed, reducing waste and optimizing comfort.

Sustainable Mobility and Transportation:

- Car Sharing and E-Mobility: The district provides car-sharing services and EV charging stations, reducing private car ownership and promoting low-emission transport.
- Bicycle Infrastructure: Hunziker Areal is bike-friendly, with dedicated bike lanes and ample parking to encourage cycling. Additionally, public transit connections reduce the need for personal vehicles.

Nature-Based Solutions

Green Roofs and Façades:

- Green Roofs: Many buildings feature green roofs planted with native vegetation, enhancing insulation and supporting local biodiversity by creating habitats for insects, birds, and small mammals.
- Green Façades: Green walls and façades contribute to natural cooling, reducing building temperatures in summer and improving air quality.
- Impact: These green elements act as natural insulators, reducing the district's overall heating and cooling demand by approximately 10-15%.

Rainwater Harvesting and Greywater Recycling:

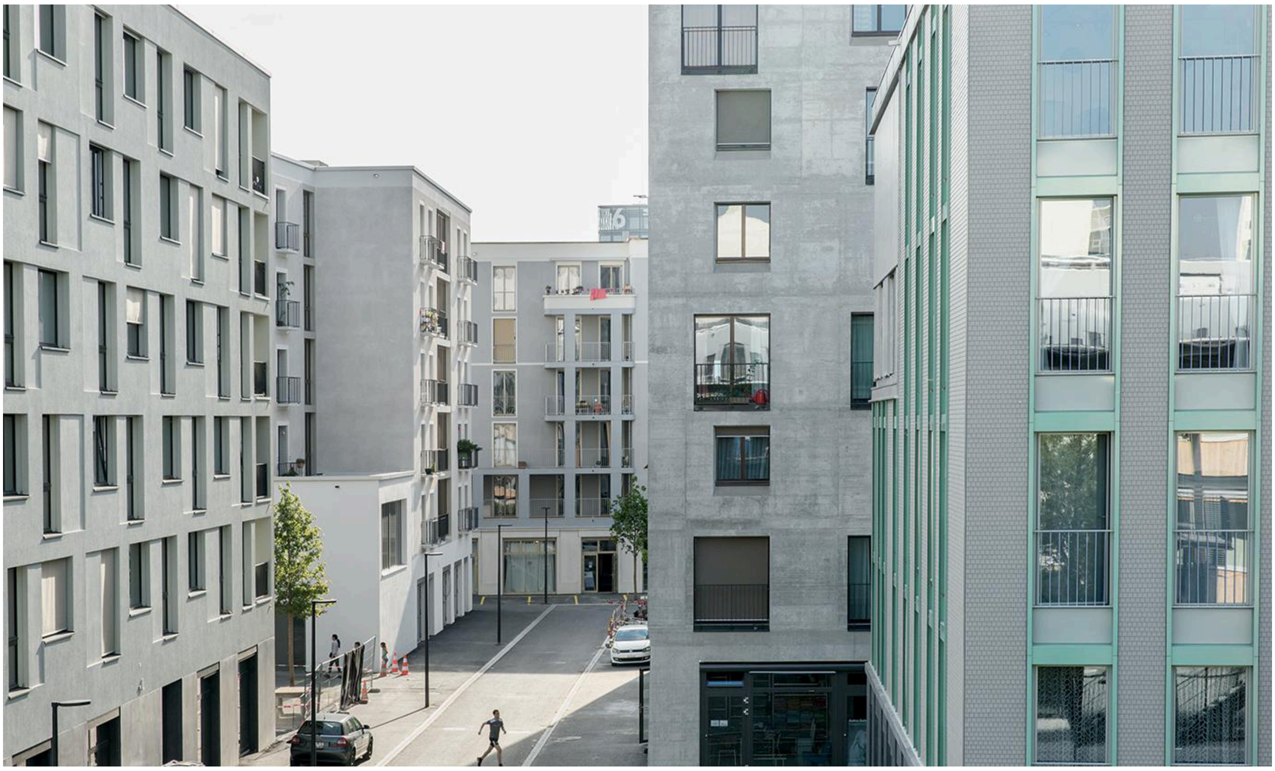
- Rainwater Collection: Rainwater is collected for irrigation and toilet flushing, reducing dependency on potable water and relieving strain on municipal water infrastructure.
- Greywater Recycling: Greywater from showers and sinks is treated and reused for non-potable

purposes, supporting a circular water system within the district.

Community Green Spaces and Biodiversity enhancing:

- Native Vegetation: Public spaces are planted with native species, which require less water and provide food and habitat for local wildlife.
- Ecological Corridors: Connected green spaces form corridors that allow wildlife to move through the district, enhancing local biodiversity.
- Cooling and Quality of Life: Green spaces provide shade, reduce the urban heat island effect, and create recreational areas for residents, enhancing well-being and fostering community interaction.

The Hunziker Areal project exemplifies the integration of energy-efficient design, renewable energy production, and nature-based solutions into a dense urban environment, thereby achieving Positive Energy District (PED) status. The project is designed to produce renewable energy on annual basis of about 1,180 to 1,680 MWh (solar PV and heat pump production combined). By generating surplus energy through renewable sources, Hunziker Areal not only meets its energy demands but also contributes to Zürich's objective of reducing city-wide carbon emissions. The cooperative model encourages community engagement, while the integration of nature-based solutions enhances biodiversity and environmental resilience, thereby establishing Hunziker Areal as a model for future sustainable urban developments.



Hunzikerareal, from left to right, buildings by: Müller Sigrist, Duplex Architekten, Miroslav Šik, Pool Architekten (last two buildings on the right).
Source: www.espazium.ch

Under the bottom line

In order to evaluate the performance of PEDs, KPIs were selected for the purpose of understanding their impact on the renewable energy landscape and their potential contribution to the energy transition of urban areas.

PEDs embody the principles of self-sufficiency, highly efficient-urban energy system implementation and energy flexibility. Their effectiveness in renewable energy landscapes can be attributed to the following key factors:

1. *Local energy production and reduced transmission losses*: PEDs prioritize localized renewable energy sources, such as solar, wind, and geothermal energy. This reduces energy losses associated with long-distance transmission, resulting in higher efficiency and reduced environmental impact.
2. *Energy storage and demand response technologies:* PEDs integrate advanced energy storage solutions, such as batteries and thermal storage, alongside demand response mechanisms. These technologies facilitate the balancing of energy supply and demand within the district, improving reliability and resilience.
3. *Enhanced energy efficiency and building standards*: PEDs incorporate energy-efficient building designs, smart grids, and intelligent control systems. Energy-saving measures and optimized consumption reduce overall demand, enabling districts to maintain positive energy balances.
4. *Social and economic benefits*: PEDs create energy-secure communities, often at lower costs, and promote local economic growth. With residents and local businesses benefitting from reduced energy costs and potential revenue from energy exports, PEDs foster community engagement and acceptance.
5. *Contribution to climate goals and policy alignment*: Many cities and regions have ambitious climate targets that require substantial reductions in emissions. PEDs directly contribute to these goals by providing measurable reductions in carbon emissions, aligning well with government policies and international climate agreements.

To assess the performance of PEDs, several approaches and methods can be used, including:

1. *Energy balance calculations:* A PED's net energy balance is calculated by comparing total energy production with total energy consumption within the district over a defined period (e.g., annually). This balance should be positive to classify the district as a PED.
2. *Life Cycle Assessment (LCA):* LCA methodologies are employed to assess the environmental impact of PEDs, considering the entire lifecycle of energy systems, materials, and resources used.

This can reveal the long-term sustainability of the district's energy solutions.

3. *Simulation and Modeling Tools:* Digital twins and simulation software (e.g., EnergyPlus, OpenStudio) are used to model PED's energy flows and predict their performance. These tools allow for testing various scenarios, such as fluctuating energy demand, weather conditions, and technology upgrades.
4. *Energy Monitoring Systems*: Real-time energy monitoring systems track PED performance by capturing data on energy production, storage, and consumption. Smart meters and IoT devices provide a comprehensive view of energy use patterns and potential areas for optimization.
5. *Economic and Social Impact Studies:* PEDs influence local economies and social structures. Surveys and econometric analyses can measure the financial benefits, job creation, and social acceptance of PEDs within communities.

Key Performance Indicators (KPIs) for Renewable Energy Landscape Economy in PEDs

The evolving connotation of the PED concept has prompted international research initiatives to define methodologies and key performance indicators that can effectively and efficiently assess the performance of PED in diverse urban contexts. Nevertheless, there is currently no established evaluation system in place, as international implementation experiences are required to test strategies and solutions that are still in the validation phase.

Notwithstanding the aforementioned limitations, the most frequently occurring indicators in the extant scientific literature are presented. These indicators have been previously elaborated upon the basis of prior experiences in the field of decarbonisation of urban areas and district and city transformation processes. This elaboration has been conducted through an examination of the existing certification protocols of strategies and solutions at the neighbourhood and district scale. The aforementioned strategies and solutions include LEED-Neighbourhood and Districts, BREEAM Communities, and WELL.

Through an examination of the scientific literature and existing certification systems, as well as an assessment of their recurrence, relevance to the scale of intervention, and alignment with European and international decarbonisation and renewable energy objectives, specific KPIs were selected and classified. This approach provides evidence that the implementation of PEDs requires an integrated, hence systemic, approach to enable the virtuous process of urban transformation in the context of energy transition.

Several categories of KPIs fundamental to the assessment of the efficacy of PED in the renewable energy landscape are presented below and only the most representative key performance indicators are presented to provide a valid although synthetic reference for the implementation of Positive Energy Districts in urban settings.

Environmental KPIs

- *Carbon Emissions Reduction* (tCO2eq): Tracks the reduction in carbon emissions achieved by PEDs compared to conventional urban areas.
- *Energy Autonomy* (%): Measures the proportion of locally sourced renewable energy in meeting the district's total energy demand.
- *Resource Efficiency* (kWh/m²): Assesses the energy efficiency of buildings and infrastructure within the district.

Energy and Technical KPIs

- *Net Energy Balance* (kWh): The difference between energy produced and consumed, confirming the district's positive energy status.
- *Renewable Energy Utilization* (%): Indicates the percentage of energy derived from renewable sources.
- *Grid Resilience and Stability Index*: Evaluates the district's ability to maintain stable energy supplies, even under external stressors.

Economic KPIs

- *Cost Savings* (%): The reduction in energy costs for residents and businesses due to the use of renewable energy sources.
- *Return on Investment (*ROI): Evaluates the financial feasibility of PED projects over time, taking into account both initial investments and ongoing savings.
- *Local Job Creation* (number of jobs): Measures the number of jobs generated directly and indirectly by PED implementation, contributing to the local economy.

Social and Community KPIs

- *Social Acceptance Rate* (%): Measures public support for PED initiatives based on surveys and feedback.
- *Quality of Life Index:* Evaluates improvements in community well-being, such as health benefits from reduced pollution and increased access to reliable energy.
- *Energy Equity (%)*: The degree to which affordable and sustainable energy is accessible to all residents within the district.

Policy and Regulatory KPIs

- *Alignment with Climate Goals (%)*: The extent to which PEDs contribute to national or regional climate targets.
- *Regulatory Compliance Rate (%)*: Measures the PED's adherence to local, regional, and international energy standards and regulations.

Some recommended research and analysis tasks for landscape economy learners:

In light of the information currently available, it is evident that a comprehensive and integrated approach to the energy transition of urban areas is imperative. Positive Energy Districts address contemporary challenges through inter-scalar strategies and solutions, encompassing the scale of individual buildings, districts, and cities, and extending to the regional level. They actively involve citizens in order to facilitate an effective and efficient urban transition. Such initiatives demand particular attention, particularly during the initial stages of the design process. However, they are supported by operational frameworks derived from scientific research and a wealth of experience in the field.

In order to facilitate the dissemination of the requisite knowledge for the design and implementation of PEDs, a series of guiding questions have been developed to ensure a comprehensive framework, regardless of the specific contextual factors involved. These questions provide a foundation for learners to analyze the multifaceted aspects of PEDs and to think critically about their potential impact on sustainable energy landscapes and urban environments.

Conceptual Understanding of Positive Energy Districts (PEDs)
- What are Positive Energy Districts (PEDs), and how do they differ from traditional urban energy systems?
- Why are PEDs an important concept in the transition to sustainable and renewable energy landscapes?
- How do PEDs align with broader climate goals, such as the reduction of greenhouse gas emissions?
- PEDs and Renewable Energy Integration
- What types of renewable energy sources are typically used in PEDs, and why?
- How do PEDs address the challenges of intermittent renewable energy sources, like solar and wind?
- What roles do energy storage solutions (e.g., batteries, thermal storage) play in making PEDs viable?

Design of Resilient Infrastructure of PEDs
- How can renewable energy infrastructure in PEDs be designed to withstand extreme weather events, such as high winds, floods, or heat waves?
- What roles do energy storage systems play in making PEDs resilient to climate-related disruptions in energy supply, and how does this contribute to both adaptation and mitigation?
- How can adaptive building materials (e.g., cool roofs, flood-resistant foundations) contribute to both energy efficiency (mitigation) and durability against climate impacts (adaptation)?

Nature-Based Solutions and Green Infrastructure in PEDs
- How can nature-based solutions, such as green roofs, urban forests, and permeable surfaces, be incorporated into PED design to support climate adaptation while also reducing energy demand?
- In what ways can green infrastructure in PEDs reduce urban heat island effects, thereby decreasing cooling energy requirements and emissions?
- How can the integration of green spaces and water management systems in PEDs help

manage stormwater, reduce flooding risks, and contribute to a balanced energy landscape?

Energy Demand Flexibility and Climate-Responsive Design

- How can flexible energy demand management (e.g., demand response, adaptive lighting) in PEDs help balance energy loads during extreme weather events, reducing strain on the grid and emissions?
- In what ways can climate-responsive building designs, such as passive solar heating, natural ventilation, and thermal mass, enhance both energy efficiency and comfort in a changing climate?
- How can district heating and cooling systems be optimized for both climate resilience (adaptation) and emissions reduction (mitigation) within a PED?

Measuring and Monitoring PED Performance

- How do we determine if a district qualifies as a Positive Energy District?
- What measurement tools and methods are used to track the energy balance in PEDs?
- What kinds of data are necessary for evaluating the success of a PED, and how is this data collected?

Key Performance Indicators (KPIs) for PEDs

- Which environmental KPIs are most relevant when evaluating PEDs?
- How do social and economic KPIs contribute to understanding the broader impacts of PEDs on communities?

Social and Economic Impact of PEDs

- How might PEDs benefit local communities economically? Consider factors such as job creation and energy cost savings.
- What are the potential social benefits of living in or near a PED?
- How can PEDs promote energy equity and ensure that renewable energy access is fair and inclusive?

Challenges and Limitations of PED Implementation

- What are some of the main barriers to implementing PEDs in urban settings?
- How might high initial capital costs affect the scalability of PEDs?
- What are some regulatory or policy challenges that could hinder PED adoption?

Future of PEDs in Urban Planning

- How could the PED model influence future urban planning and development?
- In what ways might PEDs evolve with advancements in technology, such as artificial intelligence and IoT?
- What steps could policymakers take to encourage wider adoption of PEDs in cities and regions?

PEDs and Climate Action Goals

- How do PEDs contribute to local, national, and international climate action goals?
- In what ways can PEDs help cities achieve net-zero targets?
- How might the success of PEDs in urban areas inspire similar energy-positive approaches in other sectors, such as industry or agriculture?

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