RES PED

Enabling Energy Resilience through new energy flexible and affordable PED concepts

DELIVERABLE 1.1: STOCKTAKING OF ENERGY RESILIENCE AND ENERGY POVERTY VIA PEDS

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Abstract
This document presents the work undertaken in RESPED project related to new concepts for energy resilience of PEDs, and how energy poverty could be mitigated and how affordability could be improved via PEDs. The same elements of PEDs that may alleviate energy poverty (e.g. improved energy efficiency, local energy production, smart energy management) could also improve the energy resilience of the district. That is why these subjects are highly interrelated, and it is worth studying their prerequisites and effects in the same context. This report provides a conceptual foundation for understanding the energy resilience of Positive Energy Districts (PEDs) in relation to current and future challenges, as well as their role in alleviating energy poverty.

Keywords
Energy resilient districts, resilience, energy poverty

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EXECUTIVE SUMMARY

This document presents the work undertaken in RESPED project related to new concepts for energy resilience of PEDs, and how energy poverty could be mitigated and how affordability could be improved via PEDs. The same elements of PEDs that may alleviate energy poverty (e.g. improved energy efficiency, local energy production, smart energy management) could also improve the energy resilience of the district. That is why these subjects are highly interrelated, and it is worth studying their prerequisites and effects in the same context. This report provides a conceptual foundation for understanding the energy resilience of Positive Energy Districts (PEDs) in relation to current and future challenges, as well as their role in alleviating energy poverty.

To fully understand and assess resilience, it is relevant to break it down to key components. Therefore, an analysis on close concepts including stability, reliability, redundancy, flexibility, robustness, recoverability, transformability, and antifragility was conducted. It was concluded that these terms operate at different timelines, however, resilience is a broader concept that spans across all these dimensions. By analyzing these different terms together, a more holistic understanding of energy resilience was gained. The next step was to discuss these aspects in expert workshops to formulate a working definition of an energy-resilient district:

"An energy resilient district is a geographically defined and interconnected cluster of buildings, energy infrastructure, and local resources that can anticipate, withstand, adapt to, and recover from energy-related stressors and disruptions, whether physical, operational, or economic, while ensuring continuity of critical services, particularly thermal and electrical supply, and supporting the health and well-being of end users and communities".

Next, the stressors and challenges against which the PEDs have to be resilient were studied. These stressors reveal the context where the different aspects of resilience become meaningful. This makes resilience not just a theoretical construct, but a context-dependent property of the district. The stressors were grouped into six categories including Climate & Environmental, Market & Economic, Infrastructure & Technical, Geopolitical & Security, Policy & Governance, and Social, Behavioral & Cyber each representing possible sources of disruption. To contextualize these categories, an expert workshop was conducted, complemented by an analysis of past disruptions. This approach enabled the identification of country-specific stressors across four European contexts:

- Finland: cold climate, geopolitical challenges, cybersecurity threats, and peak demand gaps
- Czechia: grid instability, cyber threats, price volatility, and geopolitical tensions
- Austria: gas dependency, cyber threats, energy price volatility, and the rapid expansion of photovoltaics
- Italy: heatwaves, institutional challenges, price volatility, and aging infrastructure

Building-level characteristics were further analyzed to understand how they contribute to or constrain resilience. Four key dimensions were considered:

- Age & Composition: Older buildings with weaker standards reduce energy efficiency and passive survivability, while the residential vs. non-residential mix influences demand profiles and the continuity of critical services.
- Thermal Efficiency: Stronger building envelopes reduce overall energy demand and improve thermal reliability during supply disruptions.
- Fuel Dependence: A diversified energy mix enhances system flexibility and reduces vulnerability to single-source failures.

- Policy Mechanisms: Renovation programs, subsidies, and financial instruments support large-scale upgrades and decarbonization, strengthening the long-term resilience of the building stock.

Resilience must also be understood in a social context, particularly in relation to energy poverty. As districts face increasing pressures the ability of households to access affordable, reliable and sufficient energy becomes a critical dimension of resilience.

In addition to the resilience analysis, this report presents the current status of energy poverty in the pilot countries of RESPED and elaborates the impact and interdependencies of PEDs on energy poverty, assessing both the potential benefits and risks that PED development can generate for vulnerable households. The analysis examines these effects from two directions — the positive (PEDs decreasing energy poverty) and the negative (PEDs increasing energy poverty) — and across four key dimensions (impact mechanism): income, energy costs, building energy efficiency, and energy-saving behaviour. The investigation of positive impact mechanisms shows that PEDs can have a strong alleviating effect on energy poverty, primarily by reducing household energy costs through local renewable generation and highest building efficiency. Conversely, the analysis of negative mechanisms highlights that PEDs may inadvertently intensify affordability challenges, particularly through the energy efficiency dimension, where renovation and modernization can lead to higher rents or property values that displace low-income residents. To mitigate these risks, the deliverable outlines policy and design recommendations aimed at strengthening affordability, ensuring social inclusion in PED implementation, and maximizing their positive contribution to a just and equitable energy transition.

Overall, this deliverable establishes a shared understanding of energy resilience in PEDs in relation to current and future challenges, as well as their role in alleviating energy poverty, and provides the conceptual and analytical basis for subsequent work in RESPED project.

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ACRONYMS AND TERMS

Acronym	Full name
EC	European Commission
EENS	Expected Energy Not Served
EOD	Expected Outage Duration
EU	European Union
HI	Heat Index
IOD	Indoor Overheating Degree
KPI	Key Performance Indicator
PC	Project Coordinator
PED	Positive Energy District
PEB	Positive Energy Building
PSI	Passive Survivability Index
PV	Photovoltaic
WP	Work Package
ZEC	Zero Energy Community

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1 Introduction

1.1 Purpose of the document

Energy resilience is a crucial, multi-layered concept for tackling today's interconnected challenges of climate change, geopolitics, and rapid digitalization, with relevance across buildings, electric systems, urban infrastructure, and beyond. While there exist definitions for energy resilience and other related concepts, there is no clear definition for energy resilient districts. Also, more understanding is needed of the challenges and stressors demanding resilience, and how the different elements of PEDs could contribute to energy resilience. This deliverable aims to establish a shared understanding of energy resilience in PEDs, its relation to energy poverty alleviation, and provide the conceptual and analytical basis for subsequent work packages.

Buildings account for approximately 40% of total energy demand in the European Union (EU) and contribute to 36% of energy-related CO_2 emissions. A significant portion of the EU's building stock, nearly 75%, is considered inefficient, with around one-third of buildings being over 50 years old (Bruck et al., 2022). As a result, many households face high energy consumption and costs, increasing the risk of energy poverty. Despite these challenges, the current renovation rate remains low, at around 1% per year (European Parliament, 2025; European Parliament, 2018). To address this issue, the European Commission (EC) has introduced policy measures such as the revised Energy Performance of Buildings Directive (European Parliament, 2024) and the Energy Efficiency Directive (European Parliament, 2023), as well as the "Renovation Wave" strategy (European Commission, 2020) under the European Green Deal (European Commission, 2021).

In this context, Positive Energy Districts (PEDs) have emerged as an important strategy for transforming urban energy systems (European Commission, 2020). By integrating energy-efficient buildings, renewable energy generation, and smart energy management at the district level, PEDs offer the potential to reduce energy poverty through, for example, lower energy costs, increased energy self-sufficiency, and improved housing conditions. However, their implementation also presents challenges, such as high initial investment costs, the risk of social exclusion in urban redevelopment, and the need for coordinated governance. This report explores how PEDs can contribute to alleviating energy poverty, the opportunities they provide, and the challenges that should be addressed to ensure an inclusive and effective transition and to avoid a (further) increase in energy poverty rates.

The same elements of PEDs that may alleviate energy poverty (e.g. improved energy efficiency, local energy production, smart energy management) could also improve the energy resilience of the district. That is why these subjects are highly interrelated, and it is worth studying their prerequisites and effects in the same context.

1.2 Scope and structure of the document

This document presents the work undertaken in RESPED project (WP1) related to new concepts for energy resilience of PEDs (T1.1), and how energy poverty could be mitigated and how affordability could be improved via PEDs (T1.2). The deliverable provides a conceptual foundation for understanding the energy resilience of Positive Energy Districts (PEDs) in relation to current and future challenges, as well as their role in alleviating energy poverty.

After the introduction (in Section 1), the methodologies used for achieving the results are presented in Section 2. Section 3 introduces the key concepts of the document: Positive Energy Districts (PEDs), energy resilience and energy poverty. Section 4 starts with a review of concepts closely related to resilience (such as flexibility, robustness, reliability, and stability) and continues with formulating a working definition of an energy-resilient district. The challenges and stressors to which PEDs must be resilient are analysed in Section 5. In Section 6 it is discussed how different scales (from individual buildings to districts) and different configurations (new construction, renovations, and mixed districts) influence resilience, as well as the role of building stock and building heating energy use in resilience. Section 7 moves to energy poverty, and presents the current status of energy poverty in the pilot countries of RESPED. The ways the PEDs can increase (Section 8) or decrease (Section 9) the energy poverty are investigated next. The recommendations driven from this analysis are presented in Section 10, and the conclusions of the work are collected to Section 11.

2 Methodology

This study employs a mixed-methods approach combining an extensive literature review with a series of stakeholder workshops to explore the intersection of energy resilience and energy poverty within the framework of Positive Energy Districts (PEDs). The literature review serves as the initial stage, aiming to identify, differentiate, and critically assess the key conceptual synergies and distinctions between energy resilience and related constructs such as flexibility, robustness, reliability, and stability. Furthermore, this phase investigates the emerging stressors and vulnerabilities faced by buildings, districts, and decentralized energy systems in PED contexts. Special emphasis is placed on the evolving role of building stock, both in terms of new construction and renovation, as well as advanced technologies, including seasonal storage, control strategies, and grid interaction mechanisms. The implications of mixed urban typologies, particularly the co-existence of old and new constructions within districts, are also examined in terms of their positive impacts on or detriments from systemic energy resilience and security.

Building upon insights from the literature, two participatory workshops were conducted to further develop and validate the theoretical framework. These workshops brought together stakeholders and experts from the four European pilot countries of RESPED representing diverse climatic zones: Finland, Czechia, Austria, and Italy. The workshops were structured thematically, with the first session involving unpacking energy resilience–related concepts and collaboratively drafting a preliminary working definition of what constitutes an energy resilient district. The second workshop focused on identifying concrete challenges and stressors faced by current buildings, districts, and decentralized systems, thereby contextualizing the theoretical insights in real-world scenarios.

The workshops used a combination of semi-structured interviews, expert validation, and thematic clustering techniques to unify diverse perspectives into a coherent analytical framework. This iterative process of stakeholder engagement enabled both validation and refinement of concepts, particularly concerning the stressors and challenges faced in each participating country in urban and peri-urban settings. The insights generated from the workshops were triangulated with literature findings to develop a multidimensional understanding of resilience within PEDs.

For the energy poverty part, the methodological approach combined a targeted literature review with stakeholder-driven discussions to identify and structure the key impact mechanisms linking PEDs and energy poverty. First, an extensive literature research was conducted to map existing knowledge on how PEDs influence affordability, energy consumption, and social inclusion. Building on these insights, a first internal RESPED workshop was organized to analyse the positive and negative impacts of PEDs on energy poverty across four defined mechanisms: income, energy costs, building energy efficiency, and energy-saving behaviour. The developed framework and preliminary findings were then further discussed and validated during an external session at the national conference “Forum Sustainable Spotlights” in Austria, allowing broader expert feedback and refinement of the conceptual approach.

3 Introduction to the key concepts

In this section, the report introduces the three key concepts that frame the analysis: Positive Energy Districts, energy resilience, and energy poverty. These concepts constitute the foundation of the discussion, and providing clear definitions at the outset helps to avoid ambiguity and ensure consistency throughout. Taken together, they also lay the groundwork for addressing the central question of what an energy resilient district could mean in practice.

3.1 Positive Energy Districts

The reference framework for PEDs (based on national consultation within the EU) outlines three functions of urban areas in the context of energy systems: (1) renewable energy production, (2) energy efficiency to make the best use of the energy generated, and (3) energy flexibility for optimality in the urban energy system, given the non-schedulable nature of renewable energy sources (JPI Urban Europe, 2020). These three functions also constitute guiding principles for PEDs (Derkenbaeva et al., 2022). Positive energy districts (PED) are defined as energy-efficient and energy-flexible urban areas with net-zero energy import and greenhouse gas emissions and interact with the urban and regional energy grid (Bossi et al., 2020; JPI Urban Europe, 2020). The key to a PED is to keep annual local energy use below the amount of locally produced renewable energy through highly energy efficient buildings keeping the energy consumption within the district low (Hearn et al., 2021). The energy demand of a district includes the energy demand of buildings and other infrastructures such as waste and water management, public infrastructure like parks and public lighting, as well as the energy demand for transport (Ala-Juusela et al., 2016). Given the complexity of the energy system, flexibility options are another key focus. Thus, through energy-balance, demand-side management, storing energy and sector coupling PEDs support energy flexibility and grid stability to manage the non-schedulable yield of renewable energy sources (SET Plan Working Group, 2018; Monti et al., 2016; Derkenbaeva et al., 2022). Besides technical aspects, PEDs also include social and economic aspects and thereby should address all three pillars of sustainability in a comprehensive approach toward sustainable urbanization (Alpagut et al., 2019; JPI Urban Europe, 2020; Brozovski et al., 2021). With regards to inclusiveness the white paper framework for PEDs specifically asks for a “special focus on affordability and prevention of energy poverty” (JPI Urban Europe, 2020)

A review article by Casamassima et al. (2022) provides a comparison between the concept of PEDs and other related concepts to determine connections and outline how PEDs differ from these other concepts. Based on the sustainability triangle made up of the pillars of environmental, social and economic the authors compare the concepts of PED, Positive Energy Communities, Net Zero Energy Neighborhood, Positive Energy Blocks as well as others along the dimensions of (1) spatial resolution, (2) energy balance, (3) energy efficiency, (4) considerations of potential trade-offs in land use (e.g. between use for renewable energy generation or for social activities), (5) emissions (e.g. focus on GHG reduction or inclusion of local pollutants such as particulate matter), and (6) considerations of energy justice by shifting the attention to those whose livelihoods rely on the fossil fuels industry and to the more vulnerable people. The analysis by Casamassima et al. (2022) shows that there are strong correlations between the concepts analyzed. The major distinction lies in the energy balance and the consideration of land use as well as energy justice. The concept of Positive Energy Blocks differs from PED due to the smaller spatial resolution and because they do not deal with land use considerations. Zero Energy Communities (ZEC) differ from PED because of their zero energy balance and the absence of energy justice aspects. Other concepts only consider emissions and overall efficiency neglecting land use and energy justice (e.g. Net Zero Energy Neighborhoods).

3.2 Energy resilience

Energy resilience is a crucial, multi-layered concept for tackling today's interconnected challenges of climate change, geopolitics, and rapid digitalization, with relevance across buildings, electric systems, urban infrastructure, and beyond.

In buildings, energy resilience often refers to 'passive survivability', the ability of structures to maintain safe, habitable conditions without reliance on active energy systems during disruptions (U.S. Department of Energy, 2024). This can be achieved through features like insulation, ventilation, and daylighting, providing autonomy and safeguarding occupants when grid power is lost. For electric systems, resilience means the capability of the grid to absorb, withstand, and quickly recover from shocks such as extreme weather, cyber threats, or equipment failure (Zitelman, 2024). Distributed energy resources, like microgrids and local renewables, support these goals by reducing reliance on centralized grids and enabling independent operation when necessary (Energy Sustainability Directory, 2025).

At the urban systems level, energy resilience involves ensuring that interconnected digital, physical, and market subsystems can collectively respond, adapt, and learn from disruptions, be they internal or external, predictable or unexpected, and of varying durations and severities. Sharifi and Yamagata (2015) similarly define urban energy resilience as "a range of preparation, absorption, recovery, and adaptation measures that ensure availability, accessibility, affordability, and acceptability of energy supply, transmission and distribution over time". Cities face high and growing demand, grid congestion, aging infrastructure, and socio-economic vulnerabilities, while also concentrating critical infrastructure and populations that make them particularly susceptible to cascading failures (Buldyrev et.al, 2010). Resilient urban energy systems - enabled by sector coupling, smart grids, and risk-aware planning - are vital for reducing blackouts, safeguarding vulnerable populations, and supporting economic stability in the face of disasters or cyber-attacks. The diversity of threats requires systems that can preserve essential services, restore operations swiftly, and evolve to meet new risks.

For industrial districts and other specialized applications, energy resilience directly impacts reliability for critical operations and the economic fallout of power disruptions. Rose (2007) defines resilience in this context as "the ability of an entity or system to maintain function when shocked," emphasizing that "power outages can result in direct losses and indirect costs". Outages can impede continuity, safety, and profitability, making solutions like backup systems, hardened infrastructure, and redundant supply chains essential for maintaining production and supporting broader economic resilience (Stark, 2025). Martin and Sunley (2015) suggest that resilience in economic systems involves the capacity for "bounce back, absorptive capacity, positive adaptability, and system transformation," depending on the nature and scale of disruptions.

Across all these domains, the lack of a unified definition or framework for energy resilient districts complicates the landscape, leading to inconsistent practices but also driving innovation as stakeholders seek region-specific tailored solutions.

To translate these multi-layered concepts into actionable insights, Key Performance Indicators (KPIs) are increasingly used to quantify energy resilience across buildings, grids, and urban systems. According to Wei et al. (2023), selecting the right KPIs for assessing energy resilience at the district level requires a thorough understanding of the local context. This involves examining the potential types of disruptions the locality/district might encounter, the existing energy systems, and the priorities of the local population. The initial step involves defining the primary objective: whether it is to ensure energy continuity during outages, reduce emissions, or safeguard vulnerable populations. Subsequently, it is essential to identify the types of disruptions that may affect the district. These can be natural hazards like floods, heatwaves, and storms, or anthropogenic threats such as cyberattacks, equipment failures, or fuel shortages. The district's local conditions also play a pivotal role, including the climate, the building typologies and their usage pattern, the energy infrastructure, and social aspects such as the population density and the prevalence of energy poverty. KPIs should be tailored to reflect these specific conditions. For example, the most appropriate measure of resilience for flooding may differ significantly from that of heat waves.

At the occupant level, one of the most relevant metrics is the Passive Survivability Index (PSI), which quantifies the duration a building can passively maintain habitable indoor temperatures during a blackout (Homaei and Hamdy, 2021; Lopez-Cabeza and Agarwal, 2022). Additional occupant-centered metrics include the Indoor Overheating Degree (IOD), which quantifies the severity and duration of overheating (Hamdy and Hensen, 2021; Rahif, Amaripadath, and Attia, 2021) and Heat Index (HI), which reflects the perceived heat stress (Anderson, Bell, and Peng, 2013; Rothfusz, 1990). Beyond indoor thermal conditions, grid- and infrastructure-level KPIs provide insight into broader energy system resilience. These include the Expected Energy Not Served (EENS), which estimates the energy demand that cannot be met (Igbogidi, Dike and Idoniboyeobu, 2023), Expected Outage Duration (EOD), which measures the time one is without power (Jaech et al., 2019), Functionality Loss, which refers to the reduction in a system's ability to deliver its intended services (Moslehi and Reddy, 2018), and Rate of Resilience, which represents the speed at which a system regains its functional performance after a disruption (Charani Shandiz et al., 2020). While these KPIs are not exhaustive, they give an initial understanding of the subject.

3.3 Energy poverty

The Social Climate Fund regulation defines energy poverty as 'a situation in which households are unable to access essential energy services that underpin a decent standard of living and health, such as adequate warmth through heating, cooling, lighting, and energy to power appliances' (European Parliament, 2023). Affordability of housing and energy poverty has become a widely recognised challenge in the EU. Across the EU member states there is, however, no unified legal definition for energy poverty, leading to fragmented policies and responses. The main causes of energy poverty include energy-inefficient buildings, high energy prices, and low incomes, with behavioral factors playing a minor role (Wegschneider-Pichler et al., 2024, Hearn et al., 2022). Because vulnerable groups often do not have the means to renovate and retrofit their apartments, they are usually more prone to live in lower efficiency buildings (Hearn et al., 2022). Rising energy prices further sharpen their financial burden.

PEDs explicitly state the need for a just energy transition. This includes citizen participation and engagement, prevention of energy poverty and other social aspects (SET Plan Working Group, 2018; Paci et al., 2020; Saheb et al. 2019). Similar to PEDs, publications regarding Zero Energy Communities highlight their potential for alleviating energy poverty (Becchio et al., 2018; Gonzales et al., 2012) as ZEC both lower energy demand through efficiency gains and reduce energy prices due to increased self-production. The main difference here is the explicit inclusion of practices that could improve inclusiveness, fairness and justice in the transition process within the PED definition (Casamassima et al., 2022).

Typically, the transformation of urban areas to PEDs includes conventional thermal renovation by retrofitting the building envelope to increase energy efficiency and thereby reduce the energy consumption of the district. However, in warm climates and districts with low population density, this approach may not be economically efficient for PEDs. Thermal insulation might not be necessary to achieve energy balance; instead, measures for energy production like the installation of PV panels might be more economical (Bruck et al., 2022). This may also contribute to social justice aspects, as lower investment costs allow for easier cost amortization for tenants. Still, building renovation remains valuable in PEDs with higher energy tariffs, colder climate and denser urban environments as higher energy demand needs to be aligned with lower capacities for on-site renewable energy production. Questions regarding the tradeoff between retrofitting and new installations extend to the balance in carbon emissions. While retrofitted PEDs need less energy infrastructure which saves internalized emissions, retrofit materials must also be produced and installed (Bruck et al., 2022).

The topic of energy poverty in the EU is extensively studied in the work by Maier and Dreoni (2024). This research focuses on understanding who is "energy poor" in the EU by using four key indicators. These indicators help to identify households experiencing energy-related deprivations due to various factors such as high energy costs, low income, and poor energy efficiency. Indicators Studied included the following (Maier and Dreoni, 2024):

- Low Absolute Energy Expenditure (M2): Households are classified as M2-poor if their equivalized energy expenditure on residential energy is below half the national median.
- High Income Share of Energy Expenditure (2M): Households are considered 2M-poor if their income share of residential energy expenditure is above twice the national median.
- Inability to Keep Home Adequately Warm (AW): This indicator aims to find the share of the population who are not able to keep their home adequately warm. It is based on the question "Can your household afford to keep its home adequately warm?"
- Arrears on Utility Bills (UB): Households are classified as UB-poor if they answer "yes, once or twice" to the following question: "In the past twelve months, has the household been in arrears, i.e., has been unable to pay the utility bills (heating, electricity, gas, water, etc.) of the main dwelling on time due to financial difficulties?"

In addition to the above, a range of indicators is used to monitor and assess energy poverty across Europe. Additional indicators capture fuel prices, housing conditions, and access to heating or cooling systems (Energy Poverty Advisory Hub, 2022).

4 Definition of an Energy Resilient District

Having outlined the key concepts of PEDs, resilience, and energy poverty, the next step is to move closer to a working definition of an energy resilient district. The first steppingstone towards a definition is a review of the related concepts in literature (Section 4.1). Building on this foundation, expert workshops help to develop a shared understanding of how resilience should be interpreted in the district context (Section 4.2). Together, these inputs make it possible to propose a definition of an energy resilient district (Section 4.3).

4.1 Conceptual perspectives from literature

Resilience has been researched from multiple theoretical standpoints, among which the equilibrium and evolutionary perspectives are particularly well-known (Ministry of Business, Innovation & Employment, 2023). The equilibrium perspective tends to view shock in a negative way (disruption) and emphasizes the importance of returning to a prior stable state (equilibrium). This view aligns with characteristics such as robustness, stability, reliability, redundancy, and recoverability, all of which support the system's ability to "bounce back" after a disturbance (World Economic Forum, 2013; Ministry of Business, Innovation & Employment, 2023, ICLEI, 2009)).

In contrast, the evolutionary perspective tends to view shock as a learning opportunity. Rather than restoring the system to the previous state, this perspective emphasizes the capacity of a system to adapt, evolve, and fundamentally improve in the face of numerous shocks and disturbances, essentially "bouncing forward" (Rockström et.al.,2023, Kresge, 2015). Key attributes associated with this perspective include flexibility, antifragility, and transformability, reflecting a dynamic and adaptive response to ongoing change and uncertainty (Folke et.al., 2010, Taleb, 2014).

Both the equilibrium and evolutionary perspectives offer insights into the multifaceted nature of resilience, and their integration is particularly critical when aiming to develop energy resilient PEDs (RISE, 2024). While the equilibrium view ensures continuity, reliability, and immediate recovery in the face of disruptions, the evolutionary perspective equips the buildings and the energy systems with the capacity to adapt and thrive amidst long-term uncertainties and systemic shifts. In the context of PEDs, which are envisioned as future-proof, decentralized, and low-carbon urban systems (Ntafalias et.al., 2024), balancing these two perspectives is essential to withstand both short-term as well as long-term shocks. This dual approach is increasingly relevant today as climate change, energy crises, and socio-economic inequalities intensify the urgency for resilient energy infrastructures. By incorporating these aspects, PEDs can serve as future-ready models for urban energy resilience.

4.2 Unpacking concepts related to resilience

In times of disruption, the resilience of a system is put to the test. But resilience doesn't stand alone. It exists alongside several related concepts. Robustness comes into play before the crisis even begins (World Economic Forum, 2013). Hardened power lines and reinforced substations, for instance, are designed to resist damage and delay failure when exposed to extreme conditions like storms (Karagiannis et.al., 2019). A robust system experiences less impact from disruptions, especially predictable ones, which reinforces overall resilience.

Meanwhile, reliability ensures consistency in the system's performance over time (Gholami et.al., 2018 , Hossain et.al, 2021) Regular pre-storm maintenance, for instance, helps minimize points of failure. In engineered systems such as nuclear power plants, reliability is a critical attribute that helps the system to resist disruption (Hosseini et.al, 2016). But reliability typically addresses the expected conditions, where, when a storm exceeds those expectations, even a well-maintained system can be overwhelmed.

When systems do falter, redundancy becomes a key aspect (Bruneau et.al, 2003). In technical terms, redundancy is the intentional duplication of critical system functions or components, ensuring that if one element fails, another can seamlessly maintain operational capacity (Al-Humaiqani and Al-Ghamdi, 2024). Backup generators in hospitals and emergency centres keep vital operations running even as the larger grid fails. However, while redundancy contributes to resilience, its primary focus is on mitigating risk and maintaining static preparedness.

Flexibility enables adaptive responses to evolving crises. In the context of building energy systems, it refers to the ability of the building to adapt its energy demand and generation in real time to varying operational requirements by utilising controllable loads, storage, and system reconfiguration. According to the IEA Annex 67 (2018), energy flexibility in buildings is defined as "the ability to manage its demand and generation according to local climate conditions, user needs and grid requirements," enabling demand-side management or load control responsive to the grid's requirement. When a sudden outage disrupts communications, authorities might reroute emergency response teams using satellite phones. However, resilience extends beyond these initial reactions.

At the same time, stability attempts to get the system to maintain or return to equilibrium, as voltage regulators kick in to balance surges and prevent cascading blackouts (Arghandeh et.al, 2016). However, stability often implies a lack of change despite disturbances, with a narrow focus on continuity. Conversely, resilience involves broader processes of recovery and adaptation that may require temporary deviation from the original state (Rockström et.al, 2023).

Recoverability, in the context of energy systems and critical infrastructure, refers to the capacity of system elements to restore performance to original or desired levels following a disruption, encompassing both the speed and efficiency of recovery. It is the ability of infrastructure to return to normal operations after a disturbance, with the pace of recovery determined by available resources and recovery operations (Rehak et.al., 2022, Afrin and Yodo, 2019). The rapid deployment of mobile substations, for example, can restore power to a majority of households within days.

But some crises signal a deeper need, not just to recover, but to reinvent the system. This is where transformability enters. Walker et al. (2004) describe transformability as "the capacity to create a fundamentally new system when ecological, economic, or social (including political) conditions make the existing system untenable". In response to recurring failures, communities might shift toward decentralized, renewable energy networks, reducing reliance on vulnerable centralized grids (Sustainability Directory, 2025a). While resilience often aims to restore a system to its previous state following disruption, transformability involves creating new systems better suited to emerging conditions.

Some systems go even further. They aim to improve because of the disruption. This is the domain of **antifragility** (Taleb, 2014). It refers to the capacity of a system not merely to withstand shocks, but to improve its structure and performance because of them. Unlike resilience, which emphasizes bouncing back to a prior state, antifragility denotes systems that evolve and strengthen through exposure to volatility, stressors, and disruption. In context of energy systems, this translates into upgrades including weather-resistant components and solar microgrids after a crisis. Each of these qualities operates on a different timeline. Figure 1 illustrates how their relevance shifts across the pre-crisis, crisis, and post-crisis phases. Reliability, stability, and redundancy are most relevant before a crisis. Robustness and flexibility span the moments during it. Recoverability dominates the post-crisis phase. Transformability and antifragility are relevant on an even longer timescale. Resilience, however, starts from anticipation and spans all the way to recovery and reinvention.

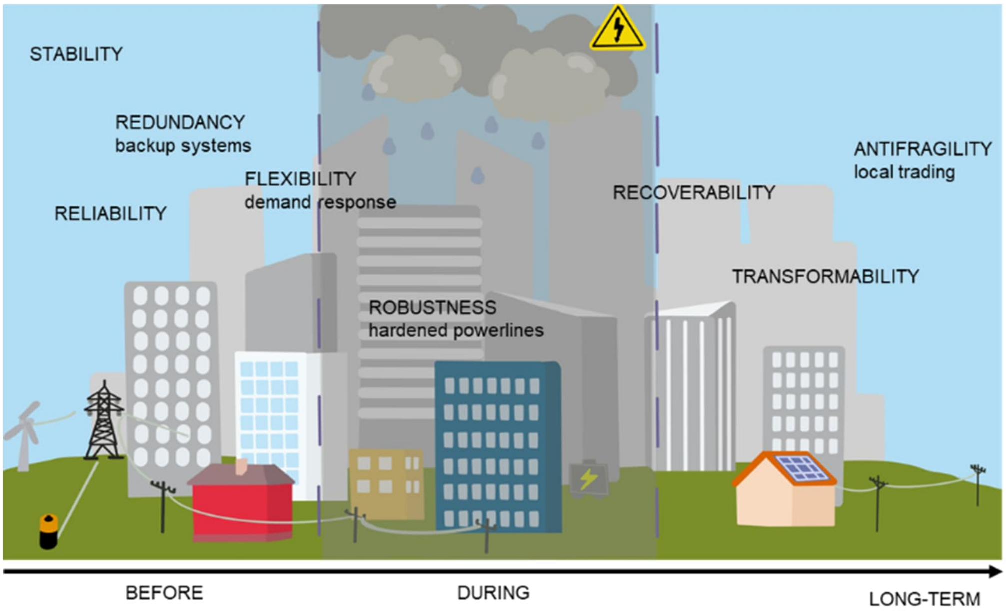

Figure 1: Key resilience-related concepts across a disruption timeline, from stability to antifragility, showing how each supports system performance before, during, and after disruptions.

4.3 Towards a definition of Energy Resilient Districts

Academic literature presents a scattered picture of energy resilience definitions (Pimm, 1984; Roege et.al., 2014, IEA, 2015; Arghandeh et al., 2016), with researchers offering a range of different perspectives. Current studies highlight several approaches: system-based definitions that focus on returning to a stable state after a disruption; adaptive approaches that look at how systems can change and settle into new forms; and process-based definitions that emphasize the ability to keep adapting over time. The technical side of energy resilience often focuses on strong infrastructure, backup systems, and fast recovery. Social aspects include community participation, fair access to reliable energy supply, and how the costs of resilience are shared. Institutional factors cover the policies, rules, and governance systems that manage how disruptions are handled. However, the complex nature of energy resilience creates some practical issues. Many resilience studies rely on subjective judgments, largely because there is no universal definition or agreed metric. Without consensus on whether resilience should emphasize robustness, recovery speed, adaptability, or a combination, researchers often focus on a single dimension or threat, shaped by available data and perceived priorities. Hence, in this work, we try to define what an energy resilient district is, aiming to bring clarity to the concept amid this diversity of perspectives and challenges.

The first phase of this research focused on defining and scoping energy resilience at the district level (Section 4.2). This involved not only describing key terminology but also distinguishing resilience from closely related concepts such as robustness, flexibility, reliability, and stability. The aim was to co-create a working definition of an energy resilient district that is grounded in both theoretical understanding and stakeholder-driven insights. For this purpose, a two-pronged approach was adopted: an extensive literature review followed by two participatory workshops engaging stakeholders and experts from the four European pilot countries with diverse climatic conditions: Finland, Czechia, Austria, and Italy.

The first workshop, conducted virtually and facilitated by VTT, served as an exploratory platform to initiate discussion and build conceptual consensus. Using tools such as Miro boards for collaborative online brainstorming and structured templates, participants were encouraged to think from a neutral standpoint before engaging in national-level group discussions. A snapshot of the working Miro Board from the first workshop is shown in Figure 2.

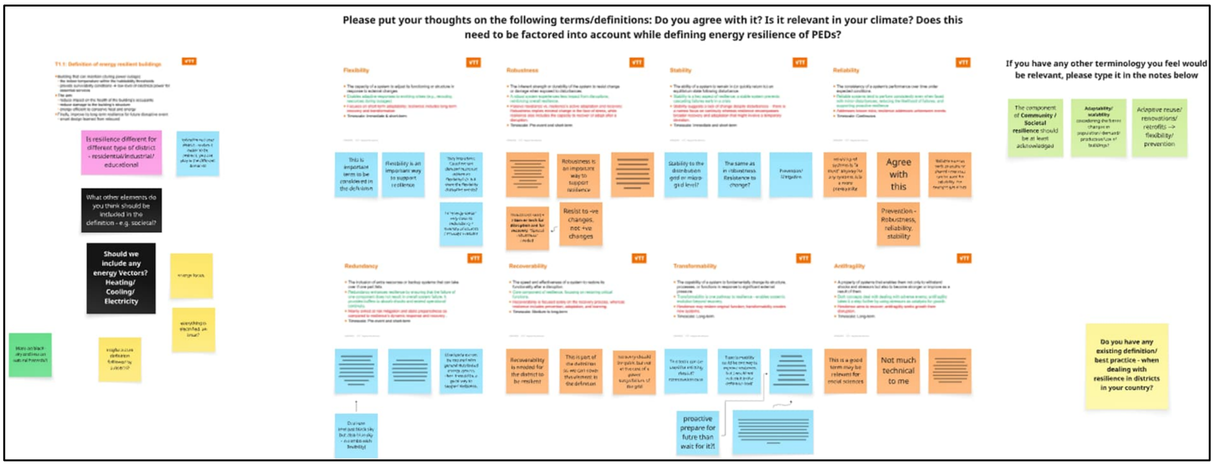

Figure 2: Snapshot of the Miro board from the first workshop, used to support collaborative discussion on energy resilience concepts

Key outputs from this workshop included several fundamental insights:

- Participants emphasized the importance of incorporating energy vectors (e.g., electricity, heating) within the definition.
- Closely related resilience-enabling attributes, such as flexibility, robustness, and redundancy, were not to be included within the core definition, but rather elaborated in a secondary, supportive layer (a "sub-definition").
- A recurring theme was the need for dual-use capability, i.e., systems and components that function not only during black-sky events but also enhance performance under normal conditions.
- Recoverability was seen as crucial but needed to be managed carefully to avoid unintended consequences, such as power surges or grid instability upon rapid restoration.
- Transformability was broadly recognized as important, especially for future-readiness, though it was not prioritized within the working definition itself.
- Additionally, antifragility was seen as conceptually relevant in social sciences, but less applicable to the built environment, which tends to behave passively rather than actively benefiting from disruption.

Building upon the insights from Workshop 1, the research team refined the working definition and proposed a more structured framing of energy resilient districts. This was further discussed during the second workshop, held in person as part of the first General Assembly of the RESPED project. Key questions emerged, including:

- Should the definition incorporate psychological and social dimensions of resilience, particularly in terms of user well-being and behavioural responses?
- Can the definition be partially quantified, at least in terms of measurable attributes or indicators?
- How should stressors and disruptions be framed in the definition: should the focus be solely on energy system disruptions or include broader socio-technical risks?

Taking all feedback into account, a working definition and an accompanying sub-definition were consolidated as follows:

"An energy resilient district is a geographically defined and interconnected cluster of buildings, energy infrastructure, and local resources that can anticipate, withstand, adapt to, and recover from energy-related stressors and disruptions, whether physical, operational, or economic, while ensuring continuity of critical services, particularly thermal and electrical supply, and supporting the health and well-being of end users and communities".

Energy resilience at the district level is supported by a set of interrelated capabilities:

- Energy flexibility, which enables dynamic demand-side responses and distributed energy resource coordination under normal and disrupted conditions.
- Robustness and stability of control systems and supply-demand balance mechanisms, which must preserve operational integrity without becoming rigid barriers to adaptive or emergency responses.
- Reliability, reflecting the district's ability to sustain continuous operation with minimal service interruptions under typical conditions.
- Redundancy and diversity, not necessarily through duplicative systems - which may be economically unfeasible - but through multi-vector energy systems (e.g., electricity, district heating, thermal storage), allowing dual-use infrastructure to serve both routine and emergency conditions.
- Recoverability, where system restoration following disruption is rapid, coordinated, and staged to avoid cascading failures—such as load spikes or equipment stress caused by uncontrolled simultaneous reactivation.
- Adaptability, ensuring that the district evolves its technical, operational, and organizational structures in response to new stressors, climate variability, or socio-technical shifts.
- Habitability and user well-being, maintaining acceptable indoor environmental conditions and access to critical energy services to support the safety, comfort, and functionality of end users during both blue-sky and crisis conditions.

This methodology of combining stakeholder engagement with analytical and conceptual depth offers a balanced perspective on what energy resilience is in the context of PEDs. It highlights the necessity for an integrated framework that addresses technical infrastructure, community values, and coordinated system-level planning to meet both present and future urban energy challenges.

5 Challenges and stressors facing PEDs

Once resilience is defined in theoretical terms, it becomes important to consider the factors that challenge it in practice. By mapping stressors across different categories, this analysis seeks to identify the pressures to which PEDs are exposed and, in turn, what they must be resilient against. This way, the concept of resilience is directly connected to the real-world challenges faced by European PEDs.

5.1 Mapping the landscape of stressors

Within the framework of energy resilience, stressors are commonly classified as either acute or chronic, highlighting differences in their temporal characteristics and impacts (Collier et.al., 2018). Acute stressors are defined as sudden, short-duration events that deliver immediate shocks to the energy system; they are typically high in intensity and may cause rapid service disruptions. Examples of acute stressors include severe weather phenomena, deliberate cyberattacks targeting the grid or telecommunication networks, and large-scale power outages triggered by technical failures or cascading grid collapses (Sustainability Directory, 2025b). On the other hand, chronic stressors are characterized by long-term, persistent pressures that gradually erode system reliability and resilience over extended periods. For instance, chronic stressors in energy systems include aging infrastructure, the slow but steady impacts of climate change, and regulatory fragmentation (Sustainability Directory, 2025b). While acute stressors require rapid mitigation and response efforts, chronic stressors demand long-range planning, continuous maintenance, and adaptive strategies to strengthen the system over time. Recognizing the distinction between these categories is crucial for developing comprehensive resilience strategies that can both absorb immediate shocks and address enduring vulnerabilities. While the acute-chronic distinction highlights important temporal differences, stressors can also be further differentiated according to their origin and mode of impact on energy systems. In the context of European PEDs, these stressors are commonly grouped into the following categories: climate and environmental, economic and market, technological and infrastructural, geopolitical and security, policy and governance, and social, behavioural, and cyber. This classification provides a more systematic basis for analysing the diverse stressors that shape energy resilience.

Climate and Environmental Stressors: Climate and environmental factors increasingly stress energy systems through both acute and chronic effects. Extreme temperatures, such as heat waves or cold spells, alter energy demand for cooling and heating, while storms, flooding, and heavy snowfall can damage infrastructure, disrupt operations, and delay fuel deliveries. Hurricanes and windstorms may knock down transmission towers, while sea-level rise or heavy rainfall can inundate power plants and substations. Prolonged heat can reduce generation efficiency and strain both grid capacity and fuel supply. Regions relying on hydropower face additional risks from droughts or changing precipitation patterns, limiting reservoir levels and cooling water availability. Longer-term environmental impacts, such as water stress or coastal erosion, threaten the sitting and operation of energy assets. Moreover, periods of low solar irradiance or wind can suppress renewable output and cause operational balance problems (Cronin et.al, 2018, Yalew et.al, 2020). The above-mentioned climate and environmental stressors not only impact infrastructure but also ripple into economic, social, and policy domains.

Economic and Market Stressors: Economic and market-based stressors also exert extensive influence on energy resilience. Volatile fuel and commodity prices often affect both short-term affordability and long-term planning. High fuel prices can strain utility budgets, inflate consumer costs, and disincentivise investment in grid upgrades or redundancy. Conversely, economic recessions reduce energy demand but also diminish revenues, delaying infrastructure modernization. High upfront costs for reserve capacity or resilience measures often deter investment. Regulatory mechanisms such as carbon pricing can introduce additional financial pressure if not paired with support mechanisms.

Market structures themselves may exacerbate vulnerabilities, such as when price signals fail to reflect resilience needs or demand response is underdeveloped. Limited capital availability, credit constraints, or competing priorities further delay resilience-enhancing investments. (Panarello et.al, 2024; Wang et.al, 2020) Together, these stressors skew incentives away from reliability, leaving systems more exposed during crises.

Technological and Infrastructural Stressors: The condition and design of physical infrastructure, along with the maturity of supporting technologies, heavily influence energy system resilience. Many existing energy systems rely on aging, centralized architectures with outdated components such as old transformers, generation units, and analog control systems. These components are more prone to failure and harder to maintain reliably. Limited real-time monitoring, control capabilities, and predictive maintenance tools further degrade responsiveness. Grid interdependence introduces additional layers of complexity, increasing systemic risk, especially without sufficient storage, demand response, or smart grid technologies. As energy systems become more interconnected, the failure or instability of one component can cascade into wider disruptions. Integration challenges also emerge as variable renewables are added without adequate grid flexibility or forecasting improvements. Infrastructure upgrades are often delayed by high costs, regulatory hurdles, or skilled workforce shortages, further magnifying the vulnerabilities. In this context, technology lags can amplify other stressors, including climate impacts, market instability, or security threats. (ARUP, 2021; Hammad & Haddad, 2021)

Geopolitical and Security Stressors: Geopolitical instability and security threats are growing sources of risk for energy systems, particularly in an increasingly interconnected global energy system. Global energy flows, particularly for oil and natural gas, often pass through politically unstable regions or contested trade routes. Conflicts, sanctions, or diplomatic rifts can abruptly sever these supply chains, causing fuel shortages or market volatility. For countries dependent on centralized or imported energy, these disruptions threaten both energy security and economic stability. Geopolitical tensions can also hinder cross-border infrastructure cooperation or reserve sharing. On the security front, physical attacks, sabotage, or terrorism targeting pipelines, substations, or power plants can lead to widespread and prolonged outages. Cyber threats are equally potent: grid management systems and energy control networks are increasingly digitized and vulnerable to malware, ransomware, or espionage. Attacks targeting operational technology can disable critical infrastructure, while human factors, like poor cybersecurity practices, can exacerbate the threat. The globalized nature of these risks underscores the importance of international coordination and resilient infrastructure planning. (Wang et.al., 2024; Chen et.al., 2025)

Policy and Governance related stressors: Policy frameworks and institutional governance play a pivotal role in energy resilience, but often fall short in practice. Fragmented authority across multiple agencies or jurisdictions can lead to inconsistent or delayed responses during crises. Regulations that focus narrowly on short-term costs without valuing reliability may deter investment in hardening infrastructure or maintaining backup capacity. Policy volatility, such as shifting subsidies, tax regimes, or mandates, introduces uncertainty and discourages long-term planning. Institutional inertia, lock-ins, and slow technology adoption further constrain system modernization. Additionally, the lack of comprehensive emergency response strategies and integrated risk assessments weakens system preparedness. Information asymmetry and poor communication between stakeholders (regulators, operators, and the public) can erode trust and impede coordination during emergencies. To enhance resilience, governance must integrate climate, economic, and technological perspectives while ensuring coherence across all levels of decision-making. (Sourgens, 2025; Butler et.al; 2018)

Social, Behavioural, and Cyber Risks: Social behaviours, public perception, and cyber vulnerabilities represent emerging and increasingly complex stressors. On the social front, limited public awareness and preparedness for energy disruptions can result in unmanaged demand spikes during critical periods. Public awareness of energy system vulnerabilities remains low, and preparedness for disruptions is often inadequate (Dabbous et.al., 2025). Resistance to new technologies, including smart meters and demand response tools, can limit the effectiveness of flexibility measures. Disparities in access to efficient energy systems can exacerbate vulnerability among low-income households. Rapid shifts in behaviour, such as mass adoption of electric vehicles or distributed energy systems, can stress grids if not coordinated with infrastructure upgrades (Qadir et.al., 2024). At the same time, digitalization introduces significant cyber risks (Saeed et.al., 2023). As control systems become interconnected and remotely accessible, they face greater exposure to cyberattacks. Malware, phishing, and insider threats can compromise grid stability and sensitive data. Effective resilience strategies must combine technical cybersecurity measures with social outreach, behavioural adaptation, and equitable access to protective technologies.

The categories of stressors discussed above, along with representative examples, are summarised in Table 1. Taken together, these categories illustrate the extent and complexity of the pressures confronting PEDs, ranging from immediate shocks to long-term systemic risks. Classifying stressors in this way ensures that resilience is not treated as an abstract notion, but as a capacity to anticipate, withstand, and adapt to diverse challenges. The following section builds on this framework by examining how such stressors have materialized in practice through disruptions experienced in the pilot countries.

Table 1: Stressor categories and representative stressors affecting energy resilience

Stressor Category	Representative Stressors
Climate & Environmental	Extreme temperatures (heatwaves, cold spells), storms, flooding, snowfall, low renewable generation periods
Market & Economic	Energy price volatility, fuel and component supply chain disruptions, carbon pricing pressures
Infrastructure & Technical	Aging or fragile infrastructure, lack of interoperability, limited monitoring and control systems, shortage of skilled workforce
Geopolitical & Security	Attacks on infrastructure, political tension, conflicts, dependency on imported components
Policy & Governance	Fragmented governance, institutional inertia, lack of emergency planning, stakeholder information asymmetry
Social, Behavioural & Cyber	Low awareness and preparedness, resistance to automation and flexibility, equity and accessibility gaps, cybersecurity vulnerabilities

5.2 Revisiting past disruptions

Importantly, the relevance and intensity of each stressor can vary significantly between, for instance, different climate zones and areas. For example, extreme heat may pose the greatest threat to southern European cities, while grid fragility may be more prominent in rural regions. Therefore, further study is needed to characterize and prioritize these stressors at the national level. The case-specific examples for Finland, Czechia, Austria, and Italy (pilot countries), and their collective implications for user comfort, energy security, and public health are presented below.

Finland

Finland's energy system faces extreme cold-weather stresses alongside significant technical infrastructure challenges. Climate impacts include severe winter storms causing up to 100 000 household power outages, with winds reaching 31 meters per second and generating 7-meter waves (Teivainen, 2024). The January 2024 extreme cold surge pushed electricity consumption to extraordinary levels, with prices reaching €1 900/MWh during peak demand periods (Fingrid, 2024). Winter storms create widespread damage through fallen trees and ice loads on power lines, with Windstorm Aila in September 2020 affecting 160 000 households (Láng et al., 2021).

Technical infrastructure failures create acute vulnerabilities in Finland's nuclear-dependent energy system. Olkiluoto-3, Europe's largest nuclear facility producing 14% of national electricity, underwent a 74-day maintenance outage in 2024, twice the planned duration, due to technical complications (Dalton, 2024). Spot prices for electricity exceeded 60 cents per kWh during the reactor shutdowns (Yle News, 2024b). The technical snags with the reactors create persistent maintenance challenges, while the loss of Russian energy imports has intensified system vulnerabilities by reducing redundancy. Finland also faces escalating cyber-physical threats targeting critical infrastructure like power grids and communication cables. Notable incidents include the suspected sabotage of the Estlink-2 undersea cable and daily cyberattacks on energy utility Fortum (Yle News, 2024a; EnergyNews.pro, 2024). These threats highlight the growing intersection of digital warfare and physical disruption amid heightened geopolitical tensions.

Czechia

Czechia faces both severe weather impacts and critical infrastructure reliability challenges (IEA, 2022a). Climate-related stressors include powerful windstorms causing widespread damage, with winds reaching 180 km/h during the February 2020 storms that left 300 000 people without power. Heavy rainfall and flooding regularly disrupt power systems, with the 2021 South Moravia tornado leaving 70 000 households powerless and destroying 1 600 homes. The September 2024 storms affected over 260 000 households, with primary causes being fallen trees and branches on power lines due to strong winds that also toppled utility poles (Expats.cz, 2024).

Technical infrastructure failures reveal systemic vulnerabilities in Czechia's aging energy network (Dębiec, 2025). The July 2025 blackout affecting 1 million customers demonstrated critical weaknesses when the transmission line failure triggered cascading effects throughout the system. The incident affected 1 500 MW of production and 2 700 MW of consumption, disrupting transportation networks and trapping hundreds in elevators. Investigation revealed that the affected grid section had been overloaded for years, with transmission capacity doubling plans delayed from 2016 to 2026-2028 due to legal challenges and bureaucratic delays. Slow renewable energy deployment and inefficient building heating systems contribute to ongoing vulnerabilities, with energy use per square meter among the highest in the EU (Eurostat, 2025a). Persistent underinvestment, high fossil dependency, and slow renewable deployment have left Czechia's grid old and inflexible. Czechia is also highly prone to price shocks in energy fuels. Gas prices spiked already before the Russian invasion of Ukraine in 2/2022. The increase was threefold (2021-2023), requiring state intervention and capping of household energy prices (Eurostat, 2025b).

Austria

Austria experiences severe flooding events alongside complex grid infrastructure vulnerabilities. The September 2024 floods resulted in €1.3 billion in damages for Austria, and 27 fatalities across Central Europe, with Lower Austria receiving five times normal monthly rainfall in four days (ASCII et al., 2024; Blöschl, 2024). These floods knocked out the electricity infrastructure, leaving residents without power and heating systems. Climate change is causing seasonal shifts in hydropower patterns, with earlier spring runoff reducing summer generation while increasing winter production (Ekkelboom-White, 2024). Projections of an additional 1-2°C warming by 2050 are predicted to create demand pattern shifts, with heating demand potentially decreasing while cooling demand could increase by 350% (Suna et al., 2024).

Technical infrastructure challenges create cascading failure risks throughout Austria's transmission network. The country's risk assessment identifies serial equipment failures due to systematic defects that can trigger cascade effects across interconnected systems (Federal Ministry Republic of Austria, 2020). Austria experienced significant transformer failures during the 2020 storms, with over 230 units failing in Styria alone, affecting 16 000 households (IEA, 2021). Austria's energy system is under stress from the volatility of rapid PV expansion, requiring redispatch interventions on 18 days in November 2024 to manage congestion and secure supply (APG, 2025). In that same month, 4 863 MWh of renewable generation was curtailed to prevent overloads, highlighting the need for increased storage and grid reinforcement. Grid modernization faces delays and complexity challenges during the energy transition, with changing system architecture creating new cascading risks from renewable energy integration.

Italy

Italy faces a complex array of both climate and infrastructure-driven energy stressors. Climate-related challenges include intense heatwaves reaching 47-48°C that trigger widespread blackouts across major cities, including Rome, Milan, Florence, and Bergamo (Salame, 2025). These extreme temperatures overwhelm power lines through overheating while simultaneously creating massive air conditioning demand spikes. The July 2025 heatwave led to 25% increases in emergency room admissions and demonstrated how underground cables become particularly vulnerable to heat damage (Giuffrida, 2023). Beyond temperature extremes, prolonged droughts have devastated hydropower output (Webuild, 2024).

Non-climate stressors compound these vulnerabilities significantly. Italy experienced a surge in cyberattacks on critical infrastructure, with major incidents affecting oil and energy companies, including 700GB of data stolen, which compromised energy market operations and forced system shutdowns (Lanzavecchia, 2024). These attacks exploit Italy's aging electrical infrastructure, with 40% of European grid infrastructure over 40 years old (Kardaś, 2023). The 2003 Italy blackout, which affected 56 million people for 12 hours, demonstrated systemic cascade vulnerabilities when a single tree flashover in Switzerland disconnected Italy from the European grid (Lirosi, 2024). Current grid saturation challenges include massive data centre electricity demand in Milan, potentially requiring several hundred MW of additional power by 2030 (Advant Nctm, 2025). Italy has been a prime target for hybrid warfare, while insufficient cybersecurity investment creates persistent vulnerabilities in critical energy infrastructure (Carrer, 2025).

5.3 Main stressors in pilot countries

Following an extensive literature review on acute and chronic energy stressors, including their classification and impacts across buildings and districts in the European Union, with a specific focus on Finland, Czechia, Austria, and Italy, a second workshop was convened as part of Task 1.1. This workshop was held in person as part of the first General Assembly of the RESPED project, bringing together a diverse group of experts and key stakeholders from each of the four pilot countries under study.

Participants were organized into country-specific groups (Finland, Czechia, Austria, and Italy). Each group was instructed to systematically identify all potential stressors to energy resilience relevant to that nation, using the comprehensive list of stressor types previously discussed (climatic, technological, socio-economic, and other domains). Within their groups, participants engaged in discussions to reach consensus on what they collectively considered to be the three most critical energy resilience stressors facing their subject country. These discussions were grounded in considerations of local relevance (e.g., like snowstorms in Finland and heatwaves in Italy), emerging and cross-cutting risks (such as digitalization and the energy transition), and system interdependencies (e.g., the linkages between fuel supply and district heating systems). Upon conclusion of the group work, a spokesperson from each national team was tasked with presenting their prioritized top stressors to the other participants. In addition to stating their selections, each spokesperson provided a brief rationale for the choices, referencing country-specific context, anticipated (Figure 3).

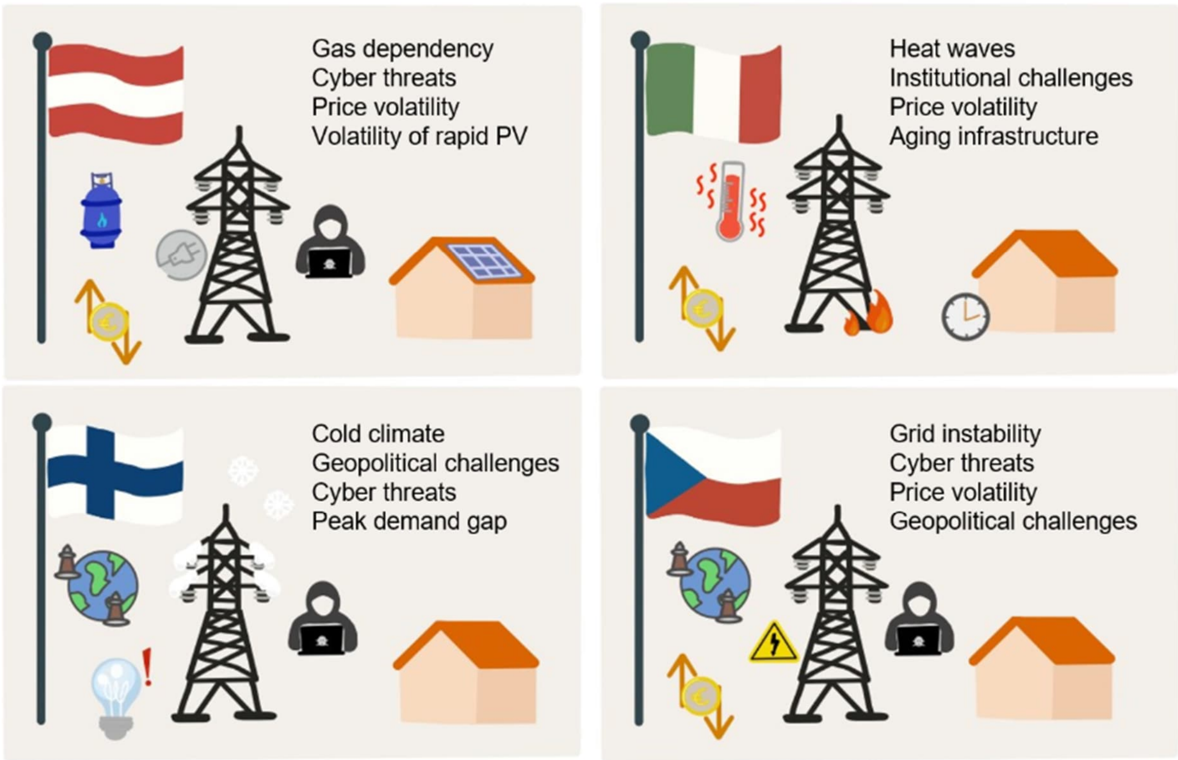

Figure 3: Energy resilience stressors in pilot countries: Finland, Czechia, Austria, and Italy highlighting challenges such as energy supply security, infrastructure vulnerability, rising energy costs, and renewable integration.

Finland

- Cold Climate: Cited the unique challenges of maintaining reliable energy services and user comfort during extended and severe winter periods, and a perceived undervaluation of resilience measures during planning stages for these conditions.
- Geopolitical issues: Underlined risks arising from cross-border dependencies and regional political tensions, which can threaten energy supply security and influence pricing.
- Cyber-Physical threats: Pointed to the growing vulnerability of the Finnish energy system to both digital attacks and physical outages, especially in relation to the increasing digitalization.
- Peak demand gap and flexibility limits: Expressed concern that the current power system lacks sufficient flexibility and storage capacity to reliably meet peak demand, especially during extreme cold events. This increases the risk of local blackouts and grid stress.

Additional mentions include concern over high electricity prices and the population's relatively low preparedness for managing emergent risks such as heatwaves.

Czechia

- Grid instability and infrastructure constraints: Noted that ageing grid assets, limited interconnection capacity, and insufficient investment have led to concerns about reliability and operational resilience. Rapid renewable integration without adequate grid reinforcement was also viewed as a source of instability.
- Cybersecurity threats: Raised alarm over vulnerabilities from increasingly sophisticated cyberattacks targeting energy sector data and infrastructure assets.
- Price Volatility and affordability pressures: Identified as the most urgent risk, this encompasses sudden price increases driven by external geopolitical developments, with direct impacts on affordability and energy security.
- Geopolitical challenges: Highlighted the country's exposure to regional supply dynamics and external geopolitical tensions, particularly concerning fuel and electricity imports. These dependencies increase vulnerability to disruptions and market instability.

Austria

- Energy dependency: Cited the experiences from 2022 onwards, with gas price increases and supply uncertainties highlighting Austria's structural vulnerabilities and long-term reliance on Russian gas.
- Cyber threats: Acknowledged growing cybersecurity risks to Austria's electricity and gas networks, particularly as digitalization increases grid interconnectivity. Emphasis was placed on the need for robust response mechanisms and cross-border coordination to mitigate disruptions.
- Price volatility and rising electricity demand: Signalled major challenges from industrial decarbonization and electrification trends (particularly in the steel industry, heating, and transport) which are driving up electricity demand and contributing to market volatility. Higher grid fees and price swings have increased concerns about energy affordability and competitiveness.
- Volatility from rapid PV expansion: Highlighted risks to stability from the accelerated integration of solar PV, leading to possible blackouts and curtailment, particularly in local grid segments.

Additional concerns were voiced about seasonal hydropower volatility due to decreased precipitation, increasing grid fees contributing to energy poverty, and the slow pace of building stock renovation.

Italy

- Heatwaves and extreme weather impacts: Recognized as a growing threat due to their increasing frequency and severity, with direct consequences for national infrastructure, energy demand patterns, and public health, amplified by ongoing climate change.
- Institutional challenges: Identified persistent institutional inertia, lack of responsibilities, and underfunded resilience investments as major barriers to modernization. Delays in implementing regulatory reforms and streamlining permitting processes hinder proactive adaptation measures.
- Price volatility: Highlighted concerns about sustained energy price instability, which risks of rendering energy unaffordable for vulnerable populations, as well as creating uncertainty for end users.

- Ageing infrastructure: Stressed the urgent need to modernize Italy's ageing electricity and gas networks. Outdated infrastructure limits system efficiency and reliability, while limiting grid regulations further constrain the establishment of additional reserve capacity and storage solutions.

This structured workshop methodology facilitated the identification, not only of the stressors most salient within each national context, but also of global and emergent risks common to energy transitions in the EU. The expert rationales highlight the importance of accounting for local climatic, infrastructural, technological, and socio-economic conditions when designing actionable, tailored strategies for energy resilience.

6 Buildings and technologies shaping PED resilience

Identifying external stressors highlights the threats to energy systems, but resilience is also shaped from within. The condition of the building stock, the energy system and the technologies embedded in them determine how districts respond when disruptions occur. By moving from stressors to vulnerabilities, the analysis bridges the gap between "outside pressures" and "inside capacities." This shift highlights why some communities are more exposed than others, setting up the discussion of resilience concerning energy poverty.

6.1 Resilience from individual buildings to mixed districts

Resilience to energy disruptions varies significantly across the building stock, particularly between older and newer constructions. This distinction is critical when evaluating energy resilience at both the building and district levels. A study by Rehman and Hasan (2023) compared a 1970s-1980s house and a 2000s building in Finland during winter blackouts. The older house could maintain habitable indoor temperatures for about 17 hours, while the newer building sustained them for the whole 30-hour blackout. With the addition of rooftop photovoltaic systems and battery storage, resilience was found to improve. These findings highlight how modern buildings are inherently more robust against energy disruptions, whereas older buildings are often more vulnerable.

At the district scale, the composition of building stock becomes even more important. Districts dominated by older buildings may face higher risks during energy disruptions and should prioritize retrofitting, thermal envelope upgrades, and decentralized backup systems. Mirzabeigi et al. (2022) found that retrofitting older homes can enhance thermal resilience by 10–62%, depending on the strategies employed. Newer districts benefit from advanced materials, improved insulation, and smart technologies. However, these buildings may also introduce new vulnerabilities, such as cybersecurity risks and technical failures due to increased reliance on interconnected systems (RICS, 2025).

Districts with a mix of old and new buildings might have different characteristics. Disparities in energy performance can lead to unequal access to safe indoor conditions during a crisis. On the other hand, the diversity of building types can be leveraged. For example, newer buildings with PV systems and storage capacity can serve as local energy hubs, supporting the district through energy sharing.

Another aspect of mixed districts is the use of buildings. Zhou et al. (2016) found that although commercial and office buildings consume significantly more energy than residential ones, a balanced mix can reduce fluctuations in energy demand. The most stable energy profile was observed with a ratio of 0.84 residential to 0.08 commercial and 0.08 office. This configuration reduced energy fluctuation by up to 60% compared to other scenarios. However, the relationship was non-linear, as higher proportions of non-residential functions eventually increased the fluctuations.

A study by Hachem-Vermette et al. (2015) modeled a mixed-use neighborhood in Calgary with more than 1,000 residential units and various commercial, office, and institutional buildings. Simulations showed that single-family and townhomes could reach net-positive energy status, while larger buildings that are limited by roof space and higher demand could not. The findings reveal a key challenge in mixed-use districts. There is uneven self-sufficiency across building types.

Climate also plays a crucial role in shaping resilience strategies. Rehman and Hasan's (2023) study in Finland emphasizes resilience in cold climates, where retaining indoor heat is critical. In contrast, Wijesuriya et al. (2024) examined homes in hot, humid Houston. During heat waves and power outages, indoor temperatures in conventional homes surpassed safe thresholds within 12 hours. Yet, with measures such as passive ventilation, phase-change materials, and improved insulation, thermal survivability (time it takes for indoor air to reach the safety threshold temperature during extreme heat or cold) was extended to 24–37 hours. These findings reinforce that the suitable solutions for resilience differ between climates.

6.2 The state of building stocks in Europe and pilot countries

The EU building stock is notably heterogeneous, shaped by varied construction booms, historical context, and regional climates. The four countries which host the project's PED demonstration sites are considered alongside the EU data. The total building stock comprises approximately 125.9 million buildings in the EU-27, with Finland (1.53 million), Czechia (2.42 million), Austria (2.35 million), and Italy (14.67 million) representing the countries analyzed in this study (BSO, 2020). These are analyzed from different aspects that have an impact on the resilience: age of the stock, envelope performance, composition of the stock, energy mix, and renovation schemes. These and implications considered are presented in Table 2.

Table 2: Dimensions analyzed and resilience implications

Dimension	Key factors	Resilience Implications
Age & Composition	Age of stock, proportion of residential vs. non-residential stock	Older stock with weaker standards reduces efficiency and survivability, residential vs. non-residential composition shapes demand profiles and critical service continuity
Thermal Efficiency	U-value limits, building code requirements	Reduces overall energy demand and enhances system-level thermal reliability
Fuel dependence	Energy mix: electricity, gas, oil, renewables, district heating, storable fuels	Determines energy system flexibility and robustness: diversified, storable sources mitigate shocks and reduce dependency on single carriers
Policy mechanisms	National/regional renovation programmes, subsidies, financial instruments	Supports large-scale upgrades, accelerates decarbonisation, and strengthens systemic resilience of the building stock

Age and composition of the stock – resilience baseline

A significant share of the EU building stock predates modern energy standards. Within the EU, 38% of residential buildings and 42% of non-residential buildings were constructed before the introduction of thermal regulations in the 1970s (RICS, 2020). Among the four pilot countries considered, the share of buildings constructed before 1980 ranges from 48.5% in Finland to 61.8% in Austria, with corresponding floor area shares between 43.3% and 62.4%. The total number of buildings built before and after 1980 and their respective percentage shares of the total building stock for each country and the EU-27 is depicted in Figure 4. These age profiles matter because they largely determine the baseline thermal performance of the building stock and the scale of renovation required over the next decades.

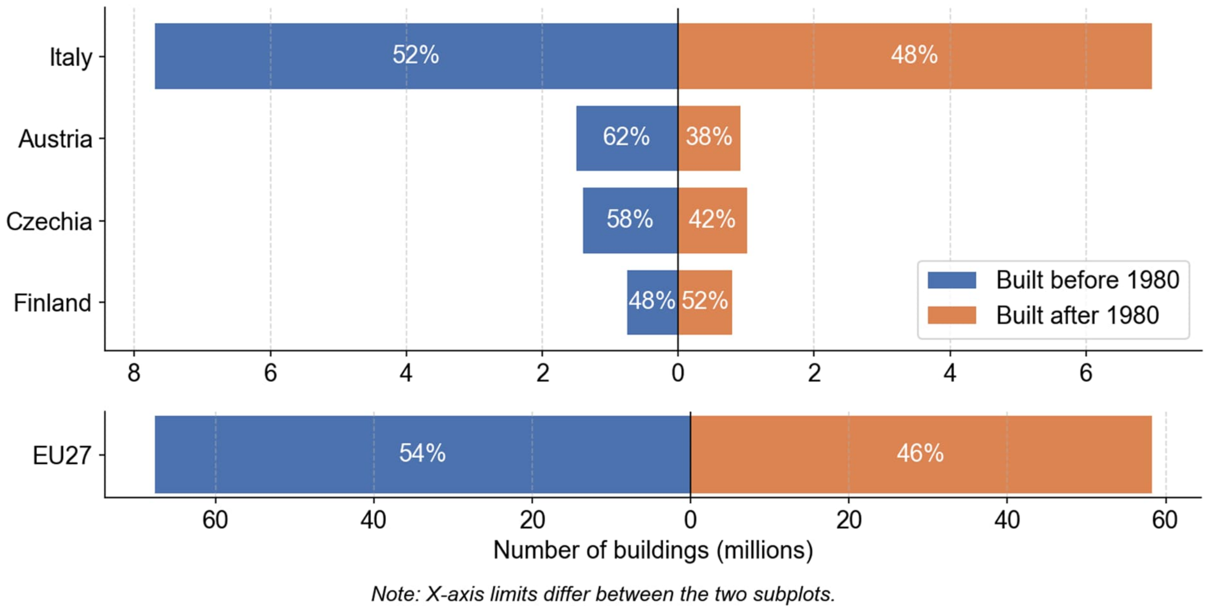

Figure 4: Number of buildings and share of those built before and after 1980 (Year of Data: Finland 2024 (Statistics Finland, 2024), Czechia 2024 (CZCO, 2024), Austria 2021 (Statistics Austria, 2021), Italy 2023 (Estrada Poggio, 2025)

A defining characteristic of these pre-1980 buildings is their poor thermal performance. Constructed before the introduction of modern insulation standards, they typically exhibit high U-values, minimal insulation, and significant air leakage, resulting in elevated heating and cooling loads. From a resilience perspective, this means they have low thermal autonomy: during winter outages, indoor temperatures drop rapidly, reducing the time occupants can remain safe without active heating. In summer, the lack of shading and ventilation exacerbates overheating during heatwaves, which are becoming more frequent across Europe. These buildings, therefore, represent a dual challenge: they are a major source of emissions and a weak link in resilience planning.

Existing building stock dominates future resilience: about 85-95% of today's EU buildings is estimated to still be in use in 2050 (Regan, 2023). Therefore, new construction contributes mainly to the long term, and renovation holds greater potential in perspective of resilience. This indicates that system-wide resilience increase ultimately depends on renovation rates, which however are currently still very low (only around 1% in EU) (European Parliament, 2025). At the same time, new construction activity has been slightly increasing and a recovery in building production can be seen in early 2025 (Eurostat, 2025c). Monitoring both renovation and construction rates is essential for understanding where resilience impacts are currently concentrated and how the built environment is changing.

In addition to the age of the stock, understanding resilience at the district scale requires recognising that the residential buildings coexist with non-residential building stock that demonstrate different load profiles and criticality levels. Mixed-use districts, comprising residential, commercial, and institutional buildings, present diverse occupancy patterns and thermal requirements. While residential buildings demand uninterrupted heating to maintain habitable conditions, non-residential spaces such as offices or retail premises can often tolerate short-term curtailments without severe consequences. This asymmetry implies that during an electrical blackout or supply disruption, prioritisation strategies become essential: maintaining heat in dwellings and critical facilities such as hospitals and care homes, while allowing controlled load shedding in less critical spaces. As shown in

Figure 5, residential shares are 95% in Finland, 94% in Czechia, 97% in Austria, and 96% in Italy, with the EU27 benchmark near 91%. These shares present the number of buildings rather than the floor area. If the floor area was analysed the residential share would most likely decrease a bit, as the service buildings are usually larger in size.

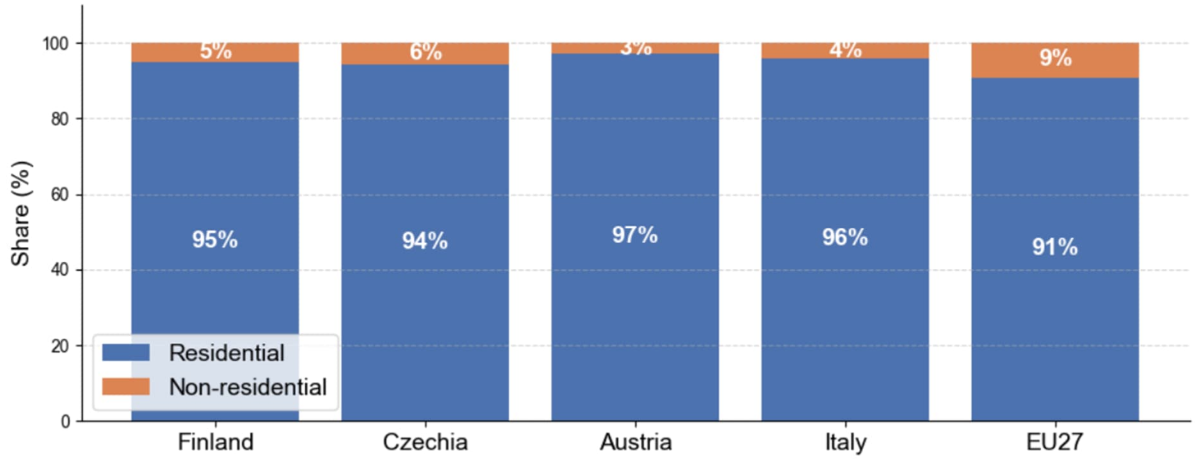

Figure 5: Share of residential and non-residential buildings in the pilot countries vs EU27 (Data from DSO, 2020)

U-values and envelope performance – thermal resilience

A comprehensive stocktaking of buildings reveals notable variations in regulatory standards for thermal transmittance (U-values) and broader building code frameworks among the pilot countries (Table 3) (Congedo et.al, 2024). Among the pilot countries, Finland enforces the most stringent U-value limits, reflecting its cold climate. Czechia and Austria also apply relatively low thresholds, while Italy adopts a zonal system, with stricter standards in colder regions. Across all cases, requirements for existing buildings are more lenient, but the overall trajectory aligns with the EU trend toward stronger thermal performance.

Table 3: National regulatory limits for thermal transmittance (U-values) in new buildings across Finland, Czechia, Austria, and Italy for key envelope components (roofs, external walls, floors, and windows)

Country	**National** climate zone	New building U [W/m2K]			
		Roof	External Walls	Floor	Windows
		Max/Min	Max/Min	Max/Min	Max/Min
Finland		0.09	0.204 / 0.170	0.17 / 0.09	1.00
Czechia		0.24 / 0.16	0.30 / 0.20	0.60 / 0.40	1.50 / 1.20
Austria		0.20	0.35	0.40	1.70 / 1.40
Italy	A	0.35	0.43	0.40	3.00
	B	0.35	0.43	0.40	3.00
	C	0.33	0.34	0.38	2.20
	D	0.26	0.29	0.29	1.80
	E	0.22	0.26	0.26	1.40
	F	0.20	0.24	0.24	1.10

These envelope standards translate directly into seasonal resilience. In Finland, these very low U-values translate into robust winter resilience by retaining heat, reducing heating loads, and buffering against supply or price shocks. However, the same airtightness and insulation that safeguard against heat loss can amplify vulnerability to summer heat stress, as internal gains and solar loads are less easily dissipated. Czechia and Austria share similar regulatory and climatic profiles, with requirements that reduce heating demand during winters and enhance thermal comfort during cold spells. But with summers getting warmer, there is an overheating risk in schools, offices, and topfloor apartments, particularly in urban areas with limited greenery. Italy's zonal framework matches its climatic diversity: strict limits in Alpine and Northern zones protect against the cold winters, while milder Southern zones prioritize summer comfort. Given intensifying heatwaves, the main challenge is overheating rather than winter heating demand.

Across all pilot countries, regulations improve resilience by lowering heat loss, stabilizing indoor conditions, and cutting fossil fuel reliance. But adaptation now requires strategies like shading, ventilation, glazing choices, reflective or green roofs, and urban greening to offset overheating. In the perspective of resilience, regulation protects well against cold stressors but leaves growing exposure to heat stress, calling for a more seasonally balanced framework. In addition to U-value requirements, building codes may mandate indoor temperature limits, ventilation standards, airtightness, and minimum efficiency for heating and cooling systems (Economidou, 2012), further supporting comfort, energy efficiency, and resilience.

Energy mix – resilience to supply shocks

Household energy mixes vary across the four pilot countries, shaping both decarbonisation pathways and resilience during outages. At EU level, households accounted for 26.2% of total final energy consumption in 2023, and space heating represented 62.5% of final residential consumption: statistics that highlight the importance of residential energy performance and heating technology choices for system level performance (Eurostat, 2025d). In Figure 6 the distribution of energy sources in household space heating are presented. The energy mix does not only affect emission, but also vulnerabilities to price shocks, supply disruptions, and climate related risks. At the EU level, gas, oil and petroleum products account for the largest share, followed by renewables and biofuels. Dependency on fossil limits resilience and exposes households to volatile market and geopolitical risks. Finland's building sector has high shares of biofuels and district heating. These systems can be generally seen as more resilient as there is flexibility in the fuel sources. Czechia, on the other hand, shows highest share of solid fossil fuels of the countries analyzed. This creates both environmental and resilience-related challenges. Austria presents quite similar energy profile as the EU. Italy presents clearly the highest reliance on natural gas. However, in all the countries analyzed the high share of renewables is well in line with the importance of domestic energy sources, which can enhance resilience in contrast to imported fuels.

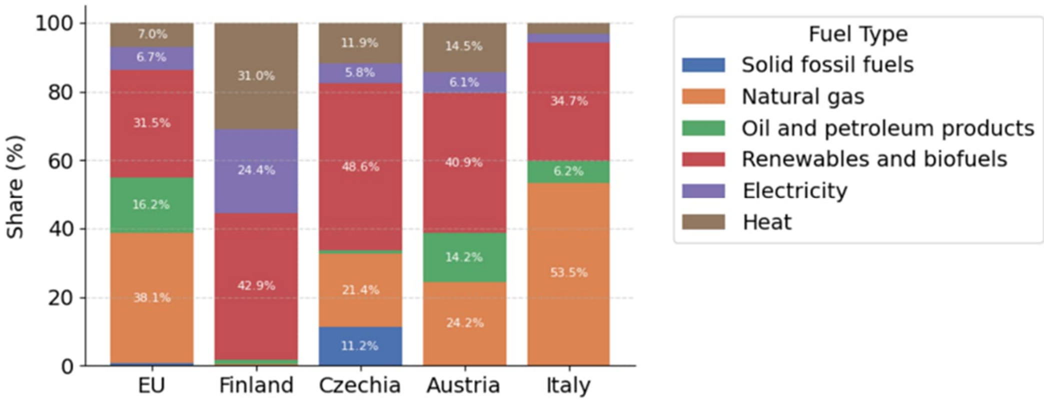

Figure 6: Distribution of energy types in household space heating in 2023 (Data from Eurostat, 2025d)

Interpreted through a resilience lens, the above figures suggest a distinction between decarbonisation effectiveness and tackling disruptions. Greater electrification of heat, whether through individual heat pumps or electrified production, reduces operational emissions where electricity supply is decarbonising, but it also increases the dependence of thermal services on the electricity system's ability to avoid and restore from disruptions. As electrification grows, the consequences of grid stress, extreme weather events, or cyber-physical incidents propagate more directly into residential heating outcomes, a risk emphasised in recent electricity security assessments (IEA, 2022b; IEA, 2020). For district heating, resilience depends on the diversity of heat sources and the availability of backup power for pumping and controls. Where district heating constitutes a substantial share of household energy, as in Finland and, to a lesser extent, Austria and Czechia, district heating can enhance resilience if it incorporates fuel flexibility and contingency measures. In addition, to the heating fuels there are additional aspects that affect the resilience.

Solar power can improve electricity autonomy, especially when paired with storage. By 2030, over 100 million households in the EU are expected to rely on rooftop solar PV (IEA, 2022c). This shows a strong trend towards resilience. At the building scale, resilience depends on both the heating technology and the thermal autonomy of the built environment. Heat pumps paired with thermal storages and predictive controls can charge the thermal mass ahead of predicted events, thereby aiding the survivability of the occupants during short-term outages. Independently of the heating system, improvements in envelope airtightness, insulation, and passive solar control increase the duration over which indoor conditions remain within safe bounds when power is unavailable. These measures are particularly critical in highly electrified contexts, where the absence of alternative carriers leaves buildings fully exposed to grid contingencies. Meanwhile, especially in colder regions, fireplaces offer thermal resilience, ensuring heating during power outages.

Policy mechanisms – resilience trajectory

Renovation schemes are one of the primary levers for aligning the existing stock with resilience goals, targeting older, less efficient buildings and extending thermal autonomy through upgraded envelopes, diversified systems, and low-carbon technologies. Across the EU, the annual energy renovation rate remains low hovering around 1% or less. This pace is insufficient to achieve either EU climate goals or meaningful improvement in resilience over the next two decades. Light renovations outpace deep renovations, which are crucial for transformative gains in efficiency. The European Union's Renovation Wave initiative, launched under the European Green Deal, aims to double the annual rate of energy renovations and renovate 35 million buildings by 2030. This ambitious strategy seeks to reduce greenhouse gas emissions, alleviate energy poverty, and stimulate economic recovery through green jobs and improved building performance.

Renovation in Finland aligns with carbon neutrality goals, focusing on insulation and airtightness. Activity has grown for decades but fell by 4% in 2023 due to rising costs, however recovery is expected from 2025 with economic stabilization and policy support. There are multiple schemes aiming to support the renovation, including KIRAilmasto (Ympäristöministeriö, 2025) and Green Transition Grants (municipalities, research, associations), Motiva's Energy Aid (Motiva, 2025) and OP Bank loans (OP Financial Group, 2025), ARA subsidies (ARA, 2025), and ELY heritage grants (Suomi.fi, 2025), covering both modern retrofits and cultural preservation.

Czechia is a leader in energy retrofits, driven by the New Green Savings Programme, which has supported around 320,000 households, including around 150,000 single-family homes (European Comission, 2024). Subsidy and financial instruments include New Green Savings, IROP, OP EIC, PANEL 2013+, JESSICA II, EFEKT, and ENERG (MEHI, 2025). Current lines are New Green Savings Light (partial, low-income households) and Repair Grandma's House (comprehensive/new builds). Between 2014–2018, renovations were mostly moderate (45%) or shallow (35%), with deep retrofits at 20%, reflecting steady policy-driven improvement in housing energy efficiency.

Austria combines regional and federal support for sustainable renovations. Key programmes include Wohnbauförderung (deep retrofits, renewable heating), Sanierungsscheck (covering up to 30% of costs), klimaaktiv (grants, training, advisory services), and Vienna's THEWOSAN (large-scale housing retrofits) (Economidou et al 2019). These have delivered notable energy savings and emissions cuts, but the overall renovation rate has declined since 2010, highlighting the need for stronger measures to meet climate targets.

Italy distinguishes between major first- and second-level renovations, with deep retrofits linked to nZEB standards. Incentives, particularly the Superbonus, drove renovation investment to €97.7 billion in 2022, more than double projections (Elnagar et al., 2025). However, impacts on renewable shares and CO_2 reductions remain limited: renewables rose by only 1.9 percentage points versus the 9.3 projected. Progress is thus uneven despite substantial financial mobilisation.

In addition to financial incentives, regulatory frameworks also shape the scope of renovation. While subsidies address the physical envelope and heating systems, digitalisation remains only partially integrated. The revised Energy Performance of Buildings Directive (EPBD) requires basic self-regulating devices in new or majorly renovated homes and obliges large non-residential buildings to install Building Automation and Control Systems (BACS) by 2025 (with thresholds tightening in 2029) (Sauter, 2024). From 2026, new and fully renovated dwellings will also need limited automation functions. However, advanced predictive or grid-interactive controls are not mandated, and the Smart Readiness Indicator (SRI) remains voluntary with little uptake (European Commission, 2022; Lițiu et al., 2021). This gap limits the resilience benefits of renovation schemes: without smart controls, buildings cannot pre-heat, optimise thermal storage, or participate effectively in demand-response programmes that could mitigate grid stress or outages.

7 Energy poverty - overview of partner countries

Energy poverty is a multidimensional phenomenon shaped by factors such as income levels, energy costs, housing quality, and climate conditions, which makes direct cross-country comparisons complex. Variations in national definitions, data collection practices, and policy frameworks add to the complexity. Nevertheless, this section explores the state of energy poverty in the pilot countries: Finland, Czechia, Austria and Italy.

Wojewódzka-Wiewiórska et al. (2024) provide a detailed view of household energy poverty across EU countries, analyzing both objective and subjective indicators for 2019 and 2023. Notably, partner countries Finland, Czechia, and Austria consistently perform well. Finland was among the countries with the lowest electricity prices in 2019, excelled in providing warm homes, and had the lowest levels of poor housing conditions. Czechia recorded the lowest poverty rate in both 2019 and 2023. Additionally, in 2019, it was also one of the countries with the lowest utility bill burdens. Similarly, Austria shows strong results in subjective indicators. In 2019, it was among the countries with the lowest rates of households unable to keep their homes adequately warm. Conversely, Italy did not stand out as either a top or bottom performer, indicating a moderate to weaker position compared to the partner countries.

Finland

In Finland, energy poverty is primarily addressed as part of social policy, reflecting the country's northern climate, where maintaining adequate indoor heating is essential for basic living conditions. The concept is closely linked to the status of vulnerable customers. According to Section 19 of the Finnish Constitution, every person unable to secure a decent standard of living has the right to essential subsistence and care, which includes access to necessary energy services such as heating (Ministry of Economic Affairs and Employment, 2024).

Key mitigation measures include a social security system with support for housing and energy costs, as well as targeted subsidies, grants, and loan guarantees (Korvenmaa et al., 2024). Finland also benefits from high standards in energy-efficient construction and advanced heating systems, which reduce energy consumption. Electricity disconnections are prohibited during critical periods, such as winter, for households facing serious financial hardship. A study by Lehtonen et al. (2024) found significant seasonal variation in energy poverty in Finland, with nearly 30% of residents vulnerable in January versus 0.3% in July. The study also highlights a stark urban-rural divide. In winter, 88% of vulnerable individuals lived in rural areas.

According to the Energy Poverty Indicators Dashboard (European Commission, 2024), the following figures have been reported for Finland:

- Inability to keep home adequately warm: 2,7% (2024)
- Households in arrears on utility bills: 8.3% (2024)
- Low absolute energy expenditure: 29% (2020)
- High share of energy expenditure: 24.1 % (2020)

Czechia

In Czechia, energy poverty is defined as a condition where a household cannot afford or access essential energy services, such as heating, hot water, lighting, and power for appliances, due to insufficient income and either high energy costs or low housing energy efficiency (Ministry of Industry and Trade, 2025). Indicators used include households below the third income decile, households spending more than twice the median share of income on energy, and households living with serious dwelling defects (leaks, damp, rotting). To tackle energy poverty, the government offers several support measures. Policy measures include advisory centers, subsidy programs, housing allowance for high-cost households, and emergency benefits. In Czechia, around 1.3 million people are impacted by energy poverty (Rovenský, 2025). The most at-risk groups are found to include elderly individuals, single-parent households, low-income families with children, and those living in poorly insulated or inefficient homes.

According to the Energy Poverty Indicators Dashboard (European Commission, 2024), the following figures have been reported for Czechia:

- Inability to keep home adequately warm: 4.9% (2024)
- Households in arrears on utility bills: 2.6% (2024)
- Low absolute energy expenditure: 20.9% (2020)

Austria

Statistik Austria describes energy poverty as a condition arising from the interplay of low-income, high-energy costs, and low energy efficiency, particularly in the housing sector (STATISTIK AUSTRIA, 2023). Since 2013, Austria has introduced various support measures, including disconnection protection, cost caps, advisory services, and subsidies (ENPOR, 2023). A study by Eisfeld (2023) notes that energy poverty disproportionately affects women, especially single mothers and elderly women. Renters in post-war urban buildings (1945–1980) are particularly vulnerable. Depending on the definition used, between 4% and 12% of Austrian households are found to be affected by energy poverty.

According to the Energy Poverty Indicators Dashboard (European Commission, 2024), the following figures have been reported for Austria:

- Inability to keep home adequately warm: 4% (2024)
- Households in arrears on utility bills: 5.3% (2024)
- Low absolute energy expenditure: 13.6% (2020)
- High share of energy expenditure: 16.7 % (2020)

Italy

In Italy, energy poverty is referred to as the difficulty households face in accessing essential energy services or the need to spend an excessive share of their income to meet basic energy needs (Ministero dello Sviluppo Economico, 2017). To address this, the National Integrated Plan for Energy and Climate outlines a strategy involving cost reduction, energy efficiency improvements, and direct subsidies (Ministero dell'Ambiente e della Sicurezza Energetica, 2024). Policies include electricity/gas bonus schemes, energy efficiency incentives, energy certificates, and advisory services.

According to the ENPOR Policy Fiche (2020), energy poverty rates in Italian regions range from 4.6% in Marche to 16.7% in Calabria. A study by Berti et al. (2023) emphasizes that much of Italy's housing stock predates the energy-saving regulation of 1976, with regional differences: Northern Italy has benefited more from incentives, while Southern regions and islands fall behind. The research also examines specific vulnerable household groups, such as the elderly. Regional differences are also evident here, with Lombardia showing high concentrations of vulnerable populations, while Campania and Sicilia have the lowest income levels, worsening the impact of poor housing conditions.

According to the Energy Poverty Indicators Dashboard (European Commission, 2024), the following figures have been reported for Italy:

- Inability to keep home adequately warm: 8.6% (2024)
- Households in arrears on utility bills: 4.5% (2024)
- Low absolute energy expenditure: 10.1% (2020)

8 PEDs decreasing energy poverty

Positive Energy Districts (PEDs) are increasingly framed not only as tools for decarbonisation and energy system resilience but also as potential instruments to address energy poverty. Energy poverty arises when households struggle to access affordable, reliable, and sustainable energy, and PEDs—by design—directly engage with these issues through efficiency, renewable generation, demand-side management and community-based energy models. Understanding how PEDs can both mitigate and, in some cases, exacerbate energy poverty is therefore crucial to ensure that their development contributes to a just and inclusive energy transition. (Derkenbaeva et al., 2022).

In this section, we discuss how PEDs could decrease energy poverty by specifying the impact mechanisms how the typical characteristics of PEDs may affect the four central dimensions of energy poverty: low income, high energy costs, inefficient buildings and low adoption of energy-saving behaviours (see Section 3.3).

8.1 Impact mechanism through income

In terms of income, the direct influence of PEDs on energy poverty is limited as PEDs do not provide additional revenues to households to boost their incomes. In some cases, electricity feed-in from surplus generation can create additional revenue streams, but these are typically modest—often well below €100 per month—and building owners are more likely to profit from these revenue streams than energy poor residents who typically are renters. If such revenues do reach households, they function less as direct payment and therefore passive increase in income, but rather as a reduction of the net electricity bill, which makes them more appropriately understood within the impact mechanism of energy costs rather than income.

8.2 Impact mechanism through energy costs

The most significant way in which PEDs can mitigate energy poverty is by decreasing household energy costs. By producing more renewable energy than they consume, at significantly lower costs than the energy market or even near-zero costs, PEDs are able to substantially lower, or in some cases even eliminate, energy bills, which are disproportionately high for people experiencing energy poverty (Casamassima et al., 2022). For energy-poor households, whose expenditures on electricity and heating amount to disproportionately high share of overall costs of living, these reductions can free up resources for other essential needs.

Furthermore, the enhanced capacity of PEDs to self-sufficiently cover energy demand from their own production provides resilience against energy price fluctuations. This might be particularly relevant in response to potentially rising prices for fossil fuels due to carbon pricing and geopolitical factors (Bruck et al., 2022; Hearn et al., 2022). Energy poor households tend to have low savings, because they spend most of their available income on covering their everyday living expenses. Thus, energy poor households cannot buffer energy price fluctuations by themselves, but PED self-production may do so.

However, it is important to consider that if the high upfront investment costs of PEDs are passed onto residents through increased rents, the energy cost savings from PED self-production may be partly offset, limiting the overall impact on reducing energy poverty. Therefore it is important to combine the energy efficiency measures of PEDs with measures ensuring affordable housing to ensure that PEDs can considerably mitigate energy poverty (Hearn et al., 2022).

Overall it can be assumed that in practice, if low-income households manage to take residence in a PED, they are no longer likely to be affected by energy poverty. This is because PEDs, by their very design, keep energy bills low. From this perspective, the impact mechanims of energy costs generally helps to reduce energy poverty inside PEDs. The bigger question, however, is not whether PED residents benefit, but whether people who are already struggling with energy poverty are actually able to find housing in these districts. If low-income households are excluded or pushed out, the positive effects of PEDs on energy poverty remain very limited. This issue will be discussed in Section 9, which focuses on the possible negative effects of PEDs on energy poverty.

8.3 Impact mechanism through building energy efficiency

Enhancing building energy efficiency is a key way in which PEDs can help alleviate energy poverty. By integrating highly efficient building envelopes, advanced insulation, and smart energy management systems, PEBs drastically reduce the amount of energy required for heating, cooling, lighting, and appliances. This inherent high efficiency minimises energy waste and lowers total energy demand, leading to substantial reductions in household energy consumption. Even if these efficiency gains are partially offset by larger floor areas (rebound effect; Sorrell 2007), or because energy poor households no longer need to cut back on heating expenses and can now afford to heat to normal temperatures (IEA 2014), the substantial reduction in energy demand still accrues to lasting benefits.

For people affected by energy poverty, this means that even if energy prices rise, their efficient homes require significantly less energy to maintain comfortable living conditions, thereby buffering the impacts of increasing energy prices. However, while improved energy efficiency reduces operational costs, the high initial investment required for such advanced building standards may still pose barriers if not mitigated by targeted subsidies or financing schemes.

PEDs also improve indoor environmental quality by providing more stable temperatures, better humidity control, reduced noise, absence of indoor air pollution from burning improvised fuels, and enhanced natural light, which directly supports health and well-being. Energy poor households tend to live in buildings with inferior indoor environmental quality; if they move to a PED, they may significantly improve their living conditions.

PEDs are typically either new constructions or thoroughly renovated buildings built to the highest standards, their efficiency and comfort benefits are ensured by design. In summary, the high levels of building energy efficiency embedded in the PED concept naturally reduce energy demand and therefore contribute to lowering the risk of energy poverty. However, as with the energy cost mechanism, the main challenge is not whether PEDs are efficient, but whether energy-poor households are able to benefit from these efficiencies—either by affording to live in new PED developments or by having their existing, less efficient homes renovated to PED standards. Without addressing this accessibility issue, the efficiency gains of PEDs risk bypassing those who need them the most.

8.4 Impact mechanism through energy-saving behaviour

PEBs and PEDs can influence energy poverty by fostering energy saving behaviour among residents. Through integrated smart systems, real-time energy monitoring, and user-friendly feedback technologies, PEBs raise awareness of personal energy consumption patterns and encourage behavioural changes to reduce unnecessary usage. This behavioural shift can lead to further energy savings beyond the building's inherent efficiency, empowering low-income households to learn about the main reasons for their energy consumption in order to actively manage and reduce their energy expenses. Educational programmes and community engagement initiatives often embedded within PED projects can further strengthen these behavioural impacts by enhancing knowledge and skills for long-term energy-aware living or by introducing social feedback among neighbours. However, it is important to recognise that behavioural change depends on user motivation, comprehension, and time availability, which may vary, limiting its effectiveness without adequate support.

Because inclusiveness with a special focus on the affordability and prevention of energy poverty is explicitly included in the guiding principles for PEDs outlined in the White Paper of PED Reference Framework, the PED concept portrays an opportunity to improve procedural justice through engaging participants in a non-discriminatory and inclusive manner in processes and decision-making. This might also support distributional justice not only in energy provision but also concerning inclusive financing, affordable housing and other measures aiming at mitigating energy poverty (Hearn et al., 2021).

9 PEDs increasing energy poverty

PEDs may also exacerbate energy poverty through high investment costs and low accessibility of energy poor households. So, PEDs face several concerns that could hinder their role in alleviating energy poverty. The most pressing concern are the cost for constructing or renovating buildings and for installing the energy technologies that are characteristic for PEDs. The high initial investment required for PED implementation, particularly in economically disadvantaged areas, risks excluding energy vulnerable people and thereby increasing energy poverty (Bouzarovski, 2014; Hearn et al., 2021). The following subsections outline possible negative impact mechanisms of PEDs via the four dimensions of energy poverty. The issues regarding affordability and gentrification are discussed in the impact mechanism regarding energy efficiency (Section 9.3).

9.1 Impact mechanism through income

PEDs have a limited direct impact on income because they do not affect the earnings of the households living in these districts. However, PEDs can have an indirect negative effect on income by potentially reallocating public funding. As public budgets are limited, prioritising substantial funding for PED projects can divert resources away from social housing programmes specifically targeting energy-poor households or other social services. This reallocation of public funding risks neglecting direct support measures for those most in need, potentially deepening existing income inequalities and leaving vulnerable groups without adequate affordable housing solutions.

9.2 Impact mechanism through energy costs

Basically, PEDs reduce energy costs as outlined in the previous section 8. However, in some cases, these effects could be rather limited as the advanced technologies and integrated systems of PEDs could lead to complex pricing structures and high maintenance costs, especially if PEDs are pilot projects where unforeseen costs may emerge because of experimental technologies that require ongoing technical support. These costs may be transferred to residents through elevated service charges or energy tariffs within the district. Additionally, if the PED business model prioritises cost recovery or private returns on investment, locally produced renewable energy might be sold on the market, leading to conventional energy prices for all PED residents, including energy poor households.

PEDs typically have a positive net energy balance. This means that they generate more energy than they consume within a timespan of one year which should lead to low energy costs and therefore a positive effect on energy poverty. However, this presumes that feed-in revenues are received by residents and not only by investors or building owners.

Another negative impact mechanism that could undermine the positive effects could be a deliberately high energy price in PEDs. The PED project Hunziker Areal in Zurich has deliberately set high energy prices in order to avoid rebound effects, i.e. low energy costs, as they are typical in PEDs, incentivizing higher energy use. While this is counter-balanced by the highly energy-efficient infrastructure, it may be perceived as an energy injustice for lower income groups (Hearn et al., 2021).

In summary it can be said that all in all it is not expected that PEDs will increase energy costs for residents due to its high energy efficiency and low energy consumption. However, the positive effects on energy costs could be limited in some cases by high service fees, maintenance costs or other charges.

9.3 Impact mechanism through building energy efficiency

Households experiencing energy poverty typically live in dwellings with inadequate insulation, outdated heating systems, and generally low energy performance. By definition, however, Positive Energy Districts (PEDs) consist of highly efficient, well-insulated buildings, which means that the negative effects of low energy efficiency do not apply within PEDs themselves. In this sense, PEDs do not directly exacerbate energy poverty through the efficiency mechanism. The central challenge instead lies in ensuring that energy-poor households can access these highly efficient dwellings. This raises critical questions about affordability, the inclusion of existing low-income housing in PED frameworks, and how risks of gentrification and displacement can be minimized. Consequently, this subsection focuses on the interrelated issues of affordability, gentrification, and accessibility of PEDs for energy-poor households.

High energy efficiency comes with high upfront construction or retrofit costs. These costs may be passed on to tenants or owners through higher rents, service charges, or purchase prices, potentially excluding lower-income groups from accessing the benefits of energy-efficient living (Healy et al., 2017; Walker et al., 2016). Investments by renovating existing buildings to PED standard could even trigger the displacement of previous low-income residents who cannot afford an increased rent ("renoviction"), especially in areas where housing markets are already under pressure. This affordability challenge is exacerbated by the heavy reliance on private sector investment in PED development. Unless regulatory frameworks enforce inclusivity, this dependence on investments form the private sector may prioritize profit over social equity (Hearn et al., 2022). Studies have shown that retrofit policies relying on market-based mechanisms tend to have regressive effects, reproducing or even deepening existing energy inequalities (Rosenow 2012; Rosenow, Platt, & Flanagan 2013; Willand et al., 2020). These considerations on affordability and social equity within financing are particularly relevant in the context of PEDs, as the European SET-Plan for PEDs estimates that €0.74 billion public investment will need to be matched by at least €100 billion from private investment and cities (JPI Urban Europe, 2020), highlighting the scale of private influence on implementation.

Beyond implementation costs, the post-upgrade affordability of housing within PEDs also matters. As energy efficiency and renewable technologies raise property values, living spaces within PEDs may become unaffordable for lower-income households. So, without regulatory frameworks PEDs are at risk for becoming exclusive domains for wealthier populations, resulting in gentrification and the potential ghettoization of the energy poor as they are pushed out to cheaper and less efficient housing (Hearn et al., 2021).

Finally, energy-poor households and buildings may face structural exclusion from PED projects altogether. PEDs are often new private-sector developments that target high-efficiency standards in new constructed buildings. As a result, existing buildings with poor energy performance—such as aging public or social housing stock where energy poverty is most prevalent—are less likely to be included. This exclusion reinforces spatial and social divides, as those who would benefit most from reduced energy demand and improved comfort lack access to high-efficiency PEDs. Furthermore, energy efficiency upgrades in existing buildings, especially in older municipal housing, are often costly and complex, making them less attractive to private investors or PED planners. Integrating low-performing, affordable housing into PED frameworks must therefore be a priority if PEDs are to support, rather than hinder, a just energy transition.

9.4 Impact mechanism through energy saving behaviour

PEDs may unintentionally deepen energy poverty through the impact mechanism of energy saving behaviour. While PEDs often rely on user engagement to optimise energy performance—such as through demand-response systems, dynamic pricing, and energy monitoring tools—they also demand a high level of energy proficiency and digital literacy. This can unintentionally exclude residents with lower educational backgrounds, language barriers or limited experience with technology. Moreover, actively engaging with these systems often requires a significant time investment: households must understand new technologies, participate in decision-making processes, review contracts, and configure settings for automated energy management. For low-income households—often under greater mental and emotional strain due to daily life challenges—this added cognitive and time burden can be overwhelming. Furthermore, meaningful participation in PED governance or community energy models requires negotiation skills, organisational capacity, and the ability to make one's voice heard, which may disadvantage already marginalised individuals. As a result, instead of empowering residents, PEDs risk reinforcing inequalities by structurally favouring more educated, resource-rich, and time-flexible households.

Making effective use of dynamic pricing schemes and flexibility options – which are often key revenue streams within PEDs – requires a certain level of smart household devices, energy literacy, digital access, and time availability that energy-poor households may lack, preventing them from benefiting fully and potentially exposing them to higher costs during peak price periods. Consequently, instead of lowering energy expenditures for vulnerable groups, PEDs could risk increasing them, thereby worsening energy poverty for residents already struggling to afford their basic energy needs.

10 Recommendations related energy poverty and PEDs

10.1 Prioritise social housing and energy poor districts for PED retrofits

To ensure that energy-poor households benefit from PEDs, renovation programmes should explicitly target social housing and low-efficiency districts where energy poverty is most concentrated. Housing stock owned by the public or by non-profit housing cooperatives is often easier to retrofit systematically than mixed-ownership buildings, making it a strategic entry point (Hearn et al., 2022). Large-scale, publicly funded deep renovations to PED standards in these areas would not only reduce energy bills and improve living conditions but also prevent the exclusion of the most vulnerable households from the energy transition.

10.2 Inclusion of low-income households in PEDs

Public authorities should require PED projects to meet clear social inclusion criteria, such as allocating a share of housing units to low-income households or integrating energy-poor buildings into the district's scope. Without binding inclusion mechanisms, PEDs risk becoming exclusive developments for wealthier populations. Planning regulations should link public funding or zoning approvals to measurable equity outcomes, ensuring that PED benefits extend to those most vulnerable to energy poverty.

10.3 Public financing for social housing

Public investments in PEDs should come with binding social conditions. Access to EU or national subsidies could be tied to inclusion criteria, such as allocating a fixed share of housing units for low-income households, rent caps, or anti-eviction clauses. This ensures that the efficiency and comfort benefits of PEDs are not offset by rising rents or displacement. Long-term affordability covenants should be required to maintain inclusivity over decades, not just at the point of construction or renovation.

This means that a portion of public PED funding should be ring-fenced for retrofitting and integrating older, energy-inefficient social and affordable housing within PED boundaries. Energy-poor households are often concentrated in under-maintained municipal housing, which is typically left out of high-tech PED projects. Targeted financial support is essential to overcome the technical and economic challenges of upgrading this stock and ensuring these residents are not structurally excluded from the energy transition. Willand et al. (2020) even find that a non-targeted subsidy approach may be regressive and (re)produce energy inequalities. Instead, interest-free loans and full grants could improve participation and ensure that retrofitting initiatives reach vulnerable population segments (Hearn et al., 2022).

10.4 Protect housing affordability after renovation

Renovation-driven gentrification poses one of the biggest risks to energy-poor households. To counter this, policymakers should guarantee existing tenants the "right to return" after renovations at affordable rents. Legal mechanisms such as rent stabilization, affordability guarantees, or targeted tax incentives for landlords can help balance investment costs with tenant protection (Hatz, 2021; Hearn et al. 2022). One such example is the "Affito Condizionato" in Milan which was implemented to avoid gentrification risk after retrofitting projects (Hearn et al., 2022). These safeguards are critical to ensure that deep renovations raise living standards without forcing low-income residents out of their homes and pushed them to cheaper but low-quality housing.

10.5 Empower municipalities and communities as PED developers

Municipalities should be supported to act as champions for PEDs in disadvantaged areas, ensuring that local needs and affordability remain central. Public ownership or cooperative models for PED energy systems can allow residents to share the financial benefits of surplus energy generation. By reinvesting revenues locally—for example, into community services or further building renovations—municipal and community-led PEDs can create a virtuous cycle of inclusivity, resilience, and affordability that private market-led developments often overlook.

Municipalities may enter public-private partnerships with private developers and energy providers to develop inclusive PEDs with guaranteed affordability measures (Hatz, 2021; Truci et al., 2024).

10.6 Develop tailored financing tools for low-income households

Energy-poor households often lack the resources to invest in energy efficiency upgrades, even when the long-term return on investment is obvious. Financing tools such as zero-interest loans, pay-as-you-save schemes, or on-bill financing models with public guarantees can lower these barriers. State-backed financing models and guaranteed returns on energy efficiency investments can mitigate this barrier (Hearn et al., 2022). By aligning repayments with actual energy savings and shielding households from upfront costs, these mechanisms ensure that vulnerable groups can access high-efficiency living without additional financial burden. However, these financing tools must consider renter fluctuation and include rules for fair loan transfer, if renters do not stay in the flat long enough for the entire payback/discounting period of loans.

10.7 Balance upscaling of PEDs with social policy

PEDs raise the overall efficiency standard of the building stock and therefore make an important contribution to reducing long-term energy demand and costs. From this perspective, any measure that accelerates renovation rates or promotes new PED developments indirectly helps to reduce energy poverty in total, as other buildings most be renovated as well in order to be able to compete on the housing market.

However, it is neither realistic nor desirable to expect private investors and developers alone to shoulder the responsibility of solving energy poverty. Overregulation of the housing sector could reduce incentives to build or renovate, slowing down the overall transition. Instead, an Efficiency-Plus Approach is needed: policies should prioritise the most cost-effective structural efficiency gains while addressing affordability and energy poverty through parallel social measures, such as targeted subsidies, income support, or housing allowances. This combined strategy ensures that the benefits of PEDs are maximised without constraining investment or slowing down renovation momentum.

11 CONCLUSIONS

This document presented the work undertaken in RESPED project related to new concepts for energy resilience of PEDs, and how energy poverty could be mitigated and how affordability could be improved via PEDs. The deliverable provides a conceptual foundation for understanding the energy resilience of Positive Energy Districts (PEDs) in relation to current and future challenges, as well as their role in alleviating energy poverty. The same elements of PEDs that may alleviate energy poverty (e.g. improved energy efficiency, local energy production, smart energy management) could also improve the energy resilience of the district. That is why these subjects are highly interrelated, and it is worth studying their prerequisites and effects in the same context.

First, the work described in this report aimed at identifying:

- the close concepts with resilience,
- the challenges and stressors,
- the building stock characteristics role in resilience,
- the impact of mixed districts.

To fully understand and assess resilience, it's relevant to break it down to key components. Therefore, an analysis on close concepts including stability, reliability, redundancy, flexibility, robustness, recoverability, transformability, and antifragility was conducted. It was concluded that these terms operate at different timelines, however, resilience is a broader concept that spans across all these dimensions. By analyzing these different terms together, a more holistic understanding of energy resilience was gained. After looking into the related concepts, the next step was to facilitate expert workshops. These together provided fundamental insights and allowed for a working definition of an energy-resilient district to be made:

"An energy resilient district is a geographically defined and interconnected cluster of buildings, energy infrastructure, and local resources that can anticipate, withstand, adapt to, and recover from energy-related stressors and disruptions, whether physical, operational, or economic, while ensuring continuity of critical services, particularly thermal and electrical supply, and supporting the health and well-being of end users and communities".

Once the definition and conceptual foundations of energy resilience at district level were established, the important step was to start looking at the stressors and challenges that test the resilience. These stressors have an important link back to conceptual terms and definition. They reveal the context where these different aspects of resilience become meaningful. This makes resilience not just a theoretical construct, but a context-dependent property of the district. The stressors were grouped into six categories including Climate & Environmental, Market & Economic, Infrastructure & Technical, Geopolitical & Security, Policy & Governance, and Social, Behavioral & Cyber each representing possible sources of disruption.

To contextualize these categories, an expert workshop was conducted, complemented by an analysis of past disruptions. This approach enabled the identification of country-specific stressors across four European contexts:

- Finland: cold climate, geopolitical challenges, cybersecurity threats, and peak demand gaps
- Czechia: grid instability, cyber threats, price volatility, and geopolitical tensions
- Austria: gas dependency, cyber threats, energy price volatility, and the rapid expansion of photovoltaics

- Italy: heatwaves, institutional challenges, price volatility, and aging infrastructure

Insights from previous studies highlight how the age and composition of districts influence resilience outcomes. Older districts often face challenges related to inefficient building envelopes and outdated heating systems, which can increase vulnerability. In contrast, newer districts typically benefit from better thermal performance and integrated energy systems but may still face risks related to system complexity. Mixed districts, combining old and new stock, present both opportunities and challenges. They offer a diversity in energy profiles but also an uneven resilience level across buildings. Building-level characteristics were further analyzed to understand how they contribute to or constrain resilience. Four key dimensions were considered:

- Age & Composition: Older buildings with weaker standards reduce energy efficiency and passive survivability, while the residential vs. non-residential mix influences demand profiles and the continuity of critical services.
- Thermal Efficiency: Stronger building envelopes reduce overall energy demand and improve thermal reliability during supply disruptions.
- Fuel Dependence: A diversified energy mix enhances system flexibility and reduces vulnerability to single-source failures.
- Policy Mechanisms: Renovation programs, subsidies, and financial instruments support large-scale upgrades and decarbonization, strengthening the long-term resilience of the building stock.

Now energy resilience at the district level is defined, not as a fixed attribute, but as a dynamic capability shaped by local vulnerabilities, building characteristics, and institutional support. However, resilience must also be understood in social context, particularly in relation to energy poverty. As districts face increasing pressures the ability of households to access affordable, reliable, and sufficient energy becomes a critical dimension of resilience.

To further clarify this aspect, the work described in this report aimed at identifying:

- how energy use in PEDs is shaped by the interaction between residents' practices and housing structures,
- the potential of PEDs to support energy-efficient behaviors among vulnerable groups,
- behavioral and technological patterns in different contexts,
- the foundation for a tailored methodology to be developed later in the RESPED project.

This work began with a short country analysis of energy poverty in the pilot countries. The aim was to gain understanding of the local conditions and differences between these countries. Comparing the pilot countries at EU level it was clear that Finland, Czechia, and Austria performed well, and Italy was neither amongst the best nor the worst. As it comes to the definition of energy poverty, it was broadly similar across countries. However, local analyses highlighted some differences. For example, in Finland seasonal energy poverty and the role of fireplaces during wintertime was studied, and in Italy the regional disparities emerged in studies.

This report also outlines the interlinkages and positive/negative impact of PEDs on energy poverty. The analysis concludes that the strongest positive effect of PEDs on energy poverty lies in their capacity to substantially reduce household energy consumption through the implementation of high building energy efficiency standards and local renewable energy production. Consequently, residents of fully operational PEDs are, by definition, unlikely to experience energy poverty, as their energy needs can be met reliably and affordably. Nevertheless, the key challenge concerns ensuring the affordability of new, energy-efficient buildings for low-income households, requiring targeted policy frameworks, financing mechanisms, and inclusive planning approaches. Equally important is the focus on renovating existing building stock, especially in areas where energy-poor populations are concentrated. Achieving a drastic increase in renovation rates is essential—not only to improve the efficiency and resilience of the building stock, but also to reduce energy poverty in the long term and advance a just and inclusive energy transition across Europe.

Hence, it can be concluded that energy resilience and energy poverty are intertwined aspects of districts and energy systems that must be understood as mutually reinforcing concepts rather than separate topics. Energy resilience directly shapes the vulnerability of households to energy poverty. When districts lack resilience (through aging infrastructure, inadequate thermal efficiency, or limited energy flexibility), the burden falls disproportionately on vulnerable households who cannot afford backup systems, emergency heating alternatives, or the consequences of prolonged disruptions. During energy supply disruptions, whether acute shocks such as extreme weather events or chronic stressors like price volatility, energy-poor households experience compounded hardship because they typically reside in poorly insulated dwellings with minimal passive survivability, forcing them into difficult choices between thermal comfort, health, and financial stability.

Addressing both energy poverty and resilience together brings the greatest overall benefits, across environmental, social, and economic domains. When these areas are tackled in an integrated way, investments in resilient infrastructure can also help reduce poverty, improve health, boost labour productivity, and strengthen community ties. In contrast, treating them as separate issues often leads to missed opportunities and unintended consequences. Such fragmented approaches can worsen inequalities, create poorly adjusted outcomes, and weaken progress toward long-term sustainability.

Moreover, climate actions that overlook vulnerable groups risk sparking social backlash and undermining political support. Recognizing that energy resilience and energy poverty are closely linked means policies need to address them together. Integrated frameworks should incorporate fairness and justice, both in how decisions are made and how benefits are shared, throughout all stages of district energy planning. This ensures that the advantages of greater resilience are distributed fairly and do not end up deepening existing inequalities.

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