D2.1

ELIGIBLE BUILDINGS OVERVIEW

WP2

Pipeline review and methodology improvement

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EXECUTIVE SUMMARY

This document provides a comprehensive overview of the buildings and infrastructures typologies targeted by Powering Energy Hub (PEH), offering the initial analysis to create the strategic planning, technical interventions, and stakeholder engagement. Evolving from PEER project, PEH expands its scope to encompass a wider variety of buildings and infrastructure, energy efficiency and renewable energy solutions, supporting a more integrated and scalable approach to the energy transition.

The typological mapping presented is key to understand PEH physical and functional landscape. It reflects the diversity of the built environment and infrastructure systems across the pilot regions, covering residential, commercial, public, industrial, and tourism-related buildings, as well as energy production, energy sharing and storage assets, such as e-mobility systems, and digital and operational infrastructures.

By identifying the most relevant building and infrastructure categories for PEH intervention, this document supports the effective deployment of energy efficiency measures, the integration of renewable energy solutions, and the establishment of smart and interconnected local energy systems. Ultimately, it contributes to the project's ambition to accelerate the national energy transition and reinforce the EU's climate and energy goals that must be achieved by 2050 through tailored, evidence-based action.

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1. Introduction

1.1. Project Background – Powering Energy Hub

Powering Energy Hub (PEH) is a 3-year long project led by a consortium of four Portuguese partners, leveraging the achievements and lessons learned from the Horizon 2020 project Porto Energy ElevatoR (PEER). PEH aims to scale up the support to energy renovation across Portugal by expanding its geographic reach, widening the scope of building and infrastructure typologies, and energy solutions, and introducing new financial and legal models to overcome persistent barriers to energy transition investments.

PEH main goal is to promote large-scale energy efficiency renovations, renewable energy production and energy sharing through self-consumption schemes, in line with the European Union's climate and energy objectives, particularly the goal of achieving the "nearly zero-energy buildings" target by 2050. While the PEER project focused primarily on the residential sector within the Porto Metropolitan Area (north of the Douro River), PEH extends its ambition to include both public and private buildings and infrastructures nationally.

PEH follows a dual approach to implementation, combining local and national strategies. At the national level, PEH will establish a virtual one-stop-shop (OSS) directed at municipalities and municipal companies. At the local level, PEH will reinforce and expand the physical one-stop-shops – branded as *Energy Hubs* — to provide direct support to private stakeholders, including citizens, businesses, and NGOs. These local hubs are built upon PEER and are key to increasing the accessibility and uptake of renovation services.

The project expects to mobilise approximately EUR 26,3 million in investments, resulting in 58,5 GWh/year of primary energy savings. Essentially, PEH intends to be a strategic and operational catalyst for Portugal's energy transition, acting as an aggregator of investment opportunities and a facilitator of new legal and financial frameworks to accelerate the decarbonisation of the Portuguese building sector.

1.2. Objectives

This document intends to provide a clear and structured characterisation of the building and infrastructure typologies to be targeted by PEH. This mapping paves the ground for technical, operational and financial planning of the project, giving the basis of the energy efficiency and renewable energy projects to be sought for and supported. Specifically, this report aims to:

- Provide territorial context and mapping to support decision-making processes related to pilot implementation, stakeholder engagement, and scalability across different regions.
- Identify and classify the types of buildings and infrastructures eligible for support under the PEH, including residential, commercial and services, and industrial buildings, as well as energy-related infrastructures such as renewable energy systems, storage, public lighting, and electric mobility.

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- Establish criteria for prioritisation, based on technical potential, energy performance, investment needs, and replicability, to support the strategic deployment of Energy Hubs' services.
- Align typology definitions with the project's operational model, ensuring that the services, financial schemes, and technical solutions developed under PEH are tailored to the specific characteristics and needs of each category.
- Support investment aggregation and tailored renovation pathways, by clearly framing the opportunities and constraints associated with each typology.

Therefore, this deliverable plays a key role in translating the project's strategic goals into actionable interventions, enabling efficient resource allocation, stakeholder alignment, and measurable impact across diverse building and infrastructure types.

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2. Territorial context

Understanding the territorial context is essential to ensure that the interventions proposed under PEH are both relevant and effective. This chapter provides a brief overview of the Portuguese geographic, socio-economic, and energy-related characteristics. It enables identifying suitable building and infrastructure typologies and supports the design of tailored approaches for local implementation. The analysis focuses on three main dimensions: the physical and administrative scope of the intervention, the energy and urban profile of the different regions in Portugal, and the key challenges and opportunities shaping the local energy transition.

2.1. General characteristics

PEH intends to have a national coverage, covering the Portuguese territory to support the implementation of energy transition projects. It expands from PEER project geographical coverage which focused on the Porto Metropolitan Area north of Douro River (AMP-ND).

PEER covered ten municipalities of the AMP-ND, associates of AdEPorto – Gondomar, Maia, Matosinhos, Paredes, Porto, Póvoa de Varzim, Santo Tirso, Trofa, Valongo, and Vila do Conde – with a population over 1 million citizens (INE, 2022). AMP-ND is the second biggest urban area in Portugal and Porto, is one of the oldest cities in Europe, dating to the VI century. The AMP-ND gathers around 11% of the national population within 1% of the country's territory, highlighting its nature as a highly urbanised and densely populated area. In this context, the building stock is responsible for over 30% of regional CO_2 emissions linked to energy use.

Figure 1. Porto Metropolitan Area north of Douro River

PEER sought to improve energy efficiency and mitigate energy poverty vulnerability by acting in the residential sector, mainly in public social housing.

On the other hand, PEH seeks to support the energy transition nationwide. Portugal has approximately 10,64 million citizens (INE, 2023) spread across 92 152 km² with an average density of 115 citizen/km², being divided in 25 sub-regions (NUT III).

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The Lisbon Metropolitan Area (*Área Metropolitana de Lisboa – AML*) is the most densely populated NUTS III subregion in Portugal, concentrating approximately 2,87 million inhabitants in an area of around 3 015 km², resulting in a population density of nearly 950 inhabitants per square kilometre. The region includes major urban centres such as Lisbon (Portugal's Capital), Amadora, Oeiras, and Almada, where densities can exceed 5 000 inhabitants/km². AML hosts a large share of national employment, public services, and infrastructure, as well as a significant portion of the national building stock, greatly constructed before the implementation of any energy efficiency standards.

In contrast, Beira Baixa is one of the least densely populated NUT III subregions, with just over 80 000 inhabitants spread across 4 614 km², representing a population density of ~17 inhabitants/km². The region is predominantly rural, located in the interior central part of the country, marked by low urbanisation, aging demographics, and a relatively high rate of building vacancy or underuse. While its building stock tends to be older and less efficient, the low density and socio-economic challenges also pose significant barriers to the implementation of large-scale renovation projects. Nonetheless, Beira Baixa holds potential for decentralised energy systems and community-led initiatives tailored to local needs.

Figure 2. Portuguese NUT III subregions

When looking at the national energy consumption, in 2023 buildings account for approximately 28,5% of total final energy consumption – 53 114 GWh - with the residential sector contributing 16,9%, 12,6% by commercial and public services sector, and 27% by Industry (IEA - International Energy Agency, 2023).

Looking for the public sector, ECO.AP 2030 program aims a 40% reduction in primary energy consumption, a 10% share of self-energy production from renewable energy and, a 20% reduction in water and material usage by

2030 (ECO.AP 2030). It also aims to achieve an energy renewal rate of 5% in public buildings, contributing 0,64 TJ in savings.

These Portuguese contrasting territorial, demographic, and socio-economic realities reinforces the importance of tailored approaches to local energy transition efforts under the PEH project. While metropolitan areas such as AMP and AML offer scale and concentration of building stock suitable for aggregated investment models, rural and low-density regions like Beira Baixa or Alto Tâmega, require decentralised, locally tailored solutions and stronger institutional support. The national coverage of PEH ensures that the tools, services, and financial mechanisms developed can be adapted to diverse regional contexts, addressing energy poverty, enhancing building performance, and promoting equitable access to the benefits of the energy transition throughout the country.

2.2. Portuguese urban and energy profiles

As said, Portugal has a structurally diverse and largely inefficient building stock, influenced by historical construction practices, uneven urban development, and socio-economic disparities across its regions. These characteristics strongly shape the country's energy profile, being key to deploy effective energy transition interventions under the PEH project.

The building stock is predominantly old and energy inefficient. Approximately 70% of residential buildings were constructed before 1990, prior to mandatory national energy performance regulations (Portugal, 2021). Approximately 15% were built before 1945, especially in urban areas and historical villages. These buildings lack adequate insulation, have poor airtightness, and rely on inefficient heating or cooling systems.

Most buildings underperform in energy efficiency, representing 67% of the issued Energy Performance Certificates (EPC), rating of C or a lower level (ADENE, 2025). Furthermore, 35% of residential buildings require repairs to some extent. When looking to the EPC statistics, around 25% of the building stock is certified, presenting in total EUR 12 million investment and up to EUR 1,5 million per year savings.

The construction typologies vary between urban and rural areas. In urban centres residential buildings typically feature multi-family buildings, while single-family houses dominate in rural and suburban settings. According to data from the Long-Term Renovation Strategy (ELPRE, 2021), around 85% of buildings are used for residential purposes, with the remainder allocated to services, commerce, and public functions.

In terms of ownership, the residential building stock in Portugal is largely privately owned, with over 73% of households living in owner-occupied dwellings. However, a large proportion of social housing remains under the responsibility of municipal authorities, particularly in metropolitan areas like AML and AMP, especially in Porto.

In households, cooking accounts for the largest share of energy consumption, representing 34,8% (Figure 3). It is followed by domestic hot water production (22,0%), and electrical appliances (21,4%). Space heating represents 19,1%. Electrical appliances and lighting represent 1,7% and 1%, respectively (INE, DGEG. 2021).

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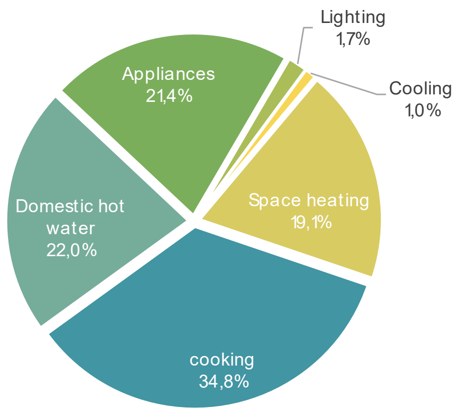

Figure 3. Energy consumption distribution per household in Portugal
Source: INE,2021

When looking at commercial and service buildings, 59% score level C or lower in their EPC, requiring an average investment of EUR 14 805 per building, representing EUR 1 761 per year savings as to increase its energy performance. Most of the recommendations (35%) regard lighting improvements, followed by HVAC systems (29%) and façade insulation (8%).

Regarding public buildings (Eco.AP, 2025), as of the first quarter of 2025, there were 62 registered PV installations and 44 solar thermal systems. Public buildings and infrastructures, such as public lighting, water and wastewater treatment and waste collection, were responsible for the consumption of approximately 3 964 GWh of electricity – around 8% of the electricity consumption in the country – 440 GWh of natural gas and 17,44 GWh of crude oil and petroleum products.

Though the adoption of renewable energy technologies in buildings is progressing, there is still a large path for improvements. Solar thermal systems for domestic hot water are the most common, followed by solar PV, particularly in newer detached homes. Public buildings are gradually integrating self-consumption units under simplified legal frameworks, yet the upfront investment costs, technical complexity, and lack of skilled professionals continue to limit broader adoption, especially in low-income households or smaller municipalities.

Infrastructures managed by public authorities — including municipal buildings, public lighting, water and wastewater systems, and other infrastructures— offer substantial energy-saving potential. The

Digitalisation and smart energy systems remain underdeveloped in Portugal's building stock. While the national rollout of smart meters is ongoing, smart building management systems are still rare, primarily limited to new buildings or large infrastructures. This lack of digital capacity constrains real-time monitoring and user engagement in energy-saving actions but also signals a major opportunity for PEH support.

Finally, several socio-economic factors influence energy consumption and the feasibility of renovation measures. Approximately 17,5% of households report being unable to adequately heat their homes (Eurostat, 2025), indicating significant levels of energy poverty, especially in rural and interior regions. An ageing population, low renovation culture, and limited awareness of energy performance issues further hinder progress. At the same time, highly urbanised regions such as Lisbon and Porto Metropolitan Areas offer opportunities for investment

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aggregation, while rural areas may benefit from community-led and decentralised solutions tailored to local realities.

Given this diverse and unevenly efficient building landscape, PEH project adopts a differentiated and strategic approach to target renovation and energy transition interventions. Understanding the characteristics, energy performance, and ownership patterns of both residential and non-residential buildings across regions is essential to design tailored solutions that reflect real needs and opportunities. As such, the following sections outline the specific building and infrastructures typologies that fall within the scope of PEH, with a focus on those with the highest potential for energy savings, replicability, and alignment with national and European decarbonisation objectives.

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3. Building typologies

Powering Energy Hub targets a wide and representative range of building typologies across Portugal, reflecting the country's structural diversity and the need for tailored energy renovation strategies. This chapter provides an overview of the key categories of buildings within the scope of PEH, highlighting their structural and functional characteristics, energy performance trends, and renovation potential. This typological assessment informs the development of targeted technical support, investment aggregation mechanisms, and OSS services, ultimately guiding PEH's contribution to accelerating energy efficiency improvements across the national building stock.

The following sections detail the main building typologies: residential, commercial and services, sports and warehouses, independently of their ownership or specific functions. For instance, administrative public buildings or cultural facilities are considered under commercial and services buildings. Infrastructures are detailed in a dedicated chapter.

3.1. Residential buildings

Approximately 53,2% of Portuguese population lives in single-family houses —36,5% detached and 16,7% semi-detached, in 2020 (EUROSTAT, 2020) —averaging ~120 m² of usable floor area, while 51,9% of the houses have between 60 and 119 m^2 usable floor area. Nearly all houses are connected to the electricity network, prevailing as the main energy source used by families (43,1%), followed by biomass (27,2%) and different types of gas - natural gas 11,5%, bottled LPG 12,4% and piped LPG 2,1%. Looking at their energy profile, single-family buildings, according to the EPC data, typically lack efficient insulation and HVAC systems, having also high-end use for cooking (34,8%), hot water (22%), and appliances (21,4%). As already mentioned, only 23,2% of the energy is spent for heating, representing approximately 36 kWh/m^2 (odyssee-mure, 2025).

Detached or semi-detached houses, often with 1 or 2 floors, are constructed with traditional masonry (brick or stone). Roofs are typically pitched and covered with ceramic tiles. In rural areas, older buildings may have stone walls with minimal insulation and wooden windows. In suburban areas, homes built post-1990 tend to follow standardised architectural plans, with reinforced concrete structures and improved, though still basic, thermal performance. The common pathologies rely on poor envelope insulation, single glazing, inefficient heating (e.g., space heaters or fireplaces), and poor airtightness.

When looking at multi-family buildings, these are typically located in the densely populated urban and metropolitan areas, representing approximately 38% of Portugal's housing stock.

Multi-family buildings predominantly have three to eight floors, with reinforced concrete frames and brick inner walls. Most were built between the 1960s and 1990s, often without insulation, mechanical ventilation, or thermal breaks. Facades are generally rendered with plaster and painted, and roofs may be flat or pitched, with minimal insulation. Vertical alignment of services (water, sewage) allows for easier collective renovations, though

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ownership fragmentation poses challenges. Common pathologies rely on thermal bridging at slab edges, poorly insulated roofs and facades, outdated heating systems, and low airtightness.

These residential buildings offer significant potential for aggregated renovation strategies, particularly due to shared structural elements and technical systems such as facades, centralised heating or hot water supply, and accessible rooftops suitable for the installation of solar PV systems. This potential increases considerably when these upgrades are coupled with co-financed renewable energy retrofit programmes.

Furthermore, multi-family buildings represent a growing opportunity for the deployment of digital energy management systems, particularly in shared areas such as stairwells, entrance halls, garages, and elevators. The implementation of Building Energy Management Systems (BEMS) or simplified digital platforms can enable real-time monitoring and control of lighting, HVAC and other energy-consuming equipment in these common areas. These systems not only reduce operational costs but also improve overall energy performance, user comfort, and data-driven decision-making for condominium administrators. The integration of such tools is especially relevant in the context of collective renovation projects and energy communities.

Overall, 50,2% of residential buildings were built before 1980 and 31,9% between 1980 and 2000 and are classified as energy inefficiency. 35,8% of these buildings need repair measures to some extent. Therefore, renovation measures such as envelope insulation, efficient HVAC and windows, PV and solar thermal—can yield up to 46% energy savings (Fuinhas, et al., 2022).

3.2. Commercial and service buildings

3.2.1. Private Commercial & Service Buildings

Commercial and service buildings in Portugal include a diverse range of infrastructure such as offices, retail spaces, light industrial units, and hospitality establishments. This sector represents a significant portion of the national building stock yet is marked by suboptimal energy performance. Approximately 59% of these buildings have Energy Performance Certificates (EPC) rated C or lower, indicating high levels of inefficiency. This is largely due to the age and technical obsolescence of many structures, coupled with a historical lack of investment in energy efficiency.

Energy consumption in the service sector has been increasing. According to the European platform Odyssee-Mure, in 2022, electricity consumption per employee reached approximately 4,819 kWh, reflecting a 13% increase compared to the year 2000 (odyssee-mure, 2025). This growth has been associated to greater reliance on digital technologies and electronic systems, expansion of usable floor area, and increased use of HVAC equipment.

To address these issues, renovation efforts, of which many supported by the Recovery and Resilience Plan (PRR), focused on upgrading lighting to LED technologies, replacing or improving HVAC system, and improving envelope insulation.

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These interventions have proven effective, delivering 30% reduction in energy consumption, with an average annual savings of EUR 1 761 per building. Co-benefits such as indoor comfort and environmental impact have also been improved.

These measures represent a strategic opportunity for cost savings and improved energy performance across the private commercial sector.

3.2.2. Public & Institutional Buildings

Public and institutional buildings—such as municipal offices, schools, hospitals, and social housing—form a strategic component of Portugal's building stock. The majority were built before 1990, and around 67% hold EPC ratings of C or lower, highlighting a pressing need for energy retrofitting. As of early 2025, public infrastructure in Portugal consumed 3 964 GWh of electricity, 440 GWh of natural gas and 17,44 GWh of fossil fuels, depicting the significant energy footprint of the public sector.

To tackle this, the national strategy ECO.AP 2030 programme sets ambitious targets for the public sector: a 40% reduction in primary energy consumption, 10% share of renewable self-generation, and a 5% annual renovation rate in public buildings, aiming to save about 178 GWh/year (Council of Ministers Resolution No. 104/2020).

To reach these goals, typical retrofit actions should include LED lighting replacement, upgraded HVAC systems, installation of photovoltaic (PV) panels, solar thermal systems and public tenders.

In schools, several municipalities have adopted both active and passive solutions to ensure thermal comfort and enhance natural lighting, such as thermal insulation, shading devices, centralized HVAC and biomass heating systems and building management systems.

In municipal buildings, efforts have also focused on setting local reduction targets. For example, Guimarães aimed to reduce energy consumption by 30% by 2020, while also prioritizing natural gas over more polluting fossil fuels.

These combined actions are essential to enhance energy efficiency, lower greenhouse gas emissions, and reduce operating costs in public services across the country.

3.2.3. Sports facilities

Sports buildings, such as municipal gyms, sports pavilions, or swimming pools, were mostly built between the 1970s and early 2000s. These structures typically feature steel or reinforced concrete frames, large-span roofs, metal or sandwich panel facades, and wide open-plan interiors. However, their thermal performance is generally poor due to insufficient insulation, limited natural ventilation, and outdated, inefficient heating systems—particularly in older buildings. Swimming pool facilities often have glazed facades and large water volumes, further increasing their energy demands.

These buildings are among the most energy-intensive in the public sector, primarily due to significant needs for space heating, air treatment, hot water preparation, and lighting. Heating, Ventilating and Air Conditioning (HVAC) systems are often oversized or obsolete, and swimming pools infrastructure require continuous heating and humidity control.

Renovation strategies for these facilities pose significant reductions in energy consumption and operational costs. Effective measures include should include solar thermal systems, high-efficiency HVAC systems, LED lighting and improved envelope insulation.

One of the most impactful approaches to improving the energy efficiency of sports buildings is the replacement of outdated systems. For instance, in a Portuguese stadium, replacing aging boilers with modern heat recovering systems can result in ~670 kW of extra heating capacity, savings ~EUR 120 000 per year (TRANE, 2025).

Another key strategy can be the implementation of an Energy Management System (EMS), enabling real-time monitoring and optimisation of energy consumption. These systems help identify inefficiencies and consumption peaks, supporting targeted interventions. When integrated with automated lighting and HVAC controls, EMS can significantly enhance energy performance, particularly in facilities with irregular or event-based use-patterns.

Finally, the adoption of renewable energy systems (RES), such as solar PV or wind turbines, contributes to both reducing energy costs and greenhouse gas (GHG). Emissions. These systems are particularly effective when coupled with storage or self-consumption schemes, ensuring long-term sustainability for sports infrastructures.

3.2.4. Cultural buildings

Cultural buildings include libraries, museums, theatres, auditoriums, and other public facilities dedicated to cultural and educational activities. Many of these were constructed between the 1950s and 1980s, typically using reinforced concrete structures, masonry infill walls, and large open interior spaces. Older buildings, especially those located in historical centres, may be built from traditional stone or mixed materials, with minimal thermal insulation and single glazing. Roofs are usually pitched or flat, often poorly insulated, and facades are rendered or tiled. Acoustic design and high ceiling heights are common features, which further increase energy demands for heating and cooling (BUILD UP, 2019).

These buildings generally require high levels of heating, cooling, and ventilation, particularly in auditoriums and exhibition spaces. Lighting needs are also substantial given extended operating hours and architectural features. Despite this, many cultural buildings do not have building management systems nor energy monitoring tools. Therefore, they pose a high renovation potential, particularly referring to measures such as envelope insulation, highly efficient windows, lighting improvements, and installation of RES.

Many cultural buildings have intermittent occupancy profiles or operate outside standard business hours, which makes them particularly suitable for the implementation of intelligent Energy Management Systems (EMS). These systems can optimise energy use through adaptive scheduling, presence detection, and real-time control, thereby reducing energy waste during periods of low or no activity.

In terms of energy performance, museums in Porto and Lisbon present the lowest energy requirements among the European cities, with 45 kWh/m²/year and 64 kWh/m²/year, respectively. In Lisbon, cooling accounts for 74% of total energy consumption, while in Porto, heating is the dominant energy need stream (Silva, 2023).

3.3. Industrial buildings and warehouses

Industrial buildings and warehouses are usually large-volume structures with simplified occupancy patterns. Renovation opportunities may include insulation improvements, lighting upgrades, HVAC system optimisation, and integration of on-site or community driven renewable energy systems.

The industrial sector accounted for approximately 27,5% of Portugal's final energy consumption in 2022 (around 4,48 Mtoe), despite a 28% reduction since 2000. Paper, pulp, and printing industries represent about 30% of this consumption (odyssee-mure, 2025).

In Portugal, industries with an annual energy consumption equal to or exceeding 500 toe (tonnes of oil equivalent) - energy-intensive industrial facilities - need to comply with the national Energy-Intensive Consumption Management System (SGCIE) framework (Decree-Law No. 71/2008). Within this compliance, industries must develop and implement an Energy Consumption Rationalisation Plan (PREn) and are required to achieve a minimum 6% reduction in primary energy consumption over an eight-year compliance period, relative to predefined baseline. The PREn must include detailed efficiency measures, performance indicators, timelines, and independent technical verification.

However, there are several other industrial facilities that do not fall under this obligation, demanding extra support as to improve their energy performance through, for instance equipment upgrades, enhanced energy management systems, preventive maintenance and energy monitoring and installation of RES.

3.4. Summary

Table 1 summarises the main characteristics of each of the building typologies described in the previous sections.

Table 1. Summary of buildings main characteristics

Typology	Main Structural Characteristics	Average Floor Area	Energy Profile	Savings Potential
Single-Family Homes (detached/semi-detached)	Masonry or concrete blocks; pitched roof; poor insulation pre-1990	~112.5 m²	Individual heating (biomass, LPG, electric), high envelope losses	30 –7 0%, especially via envelope insulation, windows, DHW
Multi-Family Dwellings	Reinforced concrete; brick infill; shared services and rooftop; often built 1960–1990	90 – 110 m²/unit	Common areas + individual units; potential for centralised heating, PV	30 – 60% via envelope insulation, HVAC, lighting, highly efficient windows
Commercial Buildings (retail, offices)	Concrete or steel frame; curtain walls or masonry; mixed age	150 – 5 000 m²	Lighting, HVAC, and plug loads dominate	20–40% via lighting, HVAC, BMS, insulation upgrades
Public/Institutional Buildings (schools, admin, health)	Concrete modules; 1–4 floors; many pre-1980	400 – 2 000 m²	HVAC, lighting and water heating major loads	30–45% with efficient systems, RES, insulation

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Typology	Main Structural Characteristics	Average Floor Area	Energy Profile	Savings Potential
Cultural & Sports Facilities (theatres, pools, gyms)	Large-span structures; steel/concrete frame; variable insulation	1 000 – +5 000 m²	High loads for HVAC, DHW, lighting; poor performance common	30–60%, especially in HVAC, lighting, RES, insulation
Warehouses & Industrial Units	Prefab steel/concrete; sandwich panel façades or bare masonry	>1 500 m²	Low insulation; localized heating/cooling; lighting-intensive	25–40% via LED, HVAC zoning, roof insulation, RES

4. Infrastructures

PEH aims to address an ecosystem of infrastructures to support a sustainable, efficient, and decarbonised energy system, rather than just buildings' energy renovation. This includes decentralised energy production units, smart energy management platforms, electric mobility assets, public lighting and critical municipal infrastructure related to water and waste systems, and digital control systems. This section presents an overview of the key infrastructure types considered under PEH, with a focus on their typical characteristics, current penetration levels, and potential for integrating the energy transition.

4.1. Public lighting

Public lighting is a key municipal energy consumer infrastructure, including not only street lighting but also lighting in urban parks, pedestrian pathways, or other public spaces. There are approximately 4,5 million public lighting fixtures, with an energy consumption of around 0,92 TWh, corresponding to 23% of the total electricity consumption in the country (DGEG, 2024). About half of this remains outdated, predominantly using sodium-vapour or fluorescent luminaires (EDP Distribuição, 2016). These systems are inefficient and inflexible, offering limited dimming capabilities or control over operating hours. Also, they typically lack smart monitoring or control systems, and maintenance is reactive and costly due to ageing infrastructure.

The replacement to LED systems in Portugal, in 2024, allowed 360 GWh/year of energy savings (E-REDES, 2025), which can represent more than 50% savings in each municipality. Additionally, when combined with smart lighting management systems (e.g., motion sensors, time scheduling, adaptive brightness), it can reach additional savings up to 80% compared to traditional technology. The integration of public lighting upgrades with solar PV systems, battery storage, and remote monitoring platforms enhances energy autonomy and reduces operational costs. Also, modern lighting systems can support multi-functionality, such as hosting sensors for air quality monitoring, closed-circuit television (CCTV), or EV charging guidance.

Several municipalities have in place Municipal Public Lighting Plans as to support their strategies for public lighting management and improvements. These instruments provide backbone information to identify the improvement potential, which can leverage from PEH support. Public lighting renovation is highly compatible with PEH model, as it allows municipalities to bundle interventions, access financing instruments (e.g., ESCO models), and promote visible and high-impact actions aligned with energy transition goals. PEH should promote replacement of outdated systems with LED technology, complemented by smart controls and, where feasible, solar PV systems for enhanced energy autonomy.

4.2. Energy infrastructure

4.2.1. Renewable Energy Production

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Renewable energy systems as photovoltaic (PV) are among the most common system installed with PEH support. These systems can be installed on rooftops of public buildings, residential blocks, and commercial facilities, or on adjacent lands such as schoolyards, parking lots, or warehouse sites. Portugal benefits from high solar irradiation levels (1,600–2,200 kWh/m²/yr) making PV the most cost-effective and scalable renewable option (Energypedia, 2025).

The national regulatory framework, particularly Decree-Law 15/2022, of 14 January, supports the adoption of self-consumption systems (UPAC) and Renewable Energy Communities (REC). This legal document reflects the current European context and partially transposes Directives (EU) 2018/2001 and 2019/944, which encourage the production and consumption of renewable energy by citizens and communities. Therefore, PEH promotes the deployment of these integrated renewable solutions across the different building typologies and ownership, bringing co-benefits in carbon reduction and lower energy costs (ERSE, 2022).

Energy consumption under self-consumption schemes (individual, collective, or community-based) offers substantial economic advantages in Portugal, such as lower network access tariffs and, currently, full or partial exemption from production taxes for a period of seven years. These are demonstrating to be attractive factors for investors and self-consumers.

Biomass as energy source is also considered under PEH, particularly for industry, or thermal supply in rural and forested areas, including cooperative housing and social facilities. Wind energy, while typically addressed at utility scale, may be also relevant in specific municipal or industrial contexts through small-scale turbines. In this regard, Portugal is seeing significant growth. In November 2024, the National Electric System recorded historic highs: wind energy reached 110,4 GWh, representing 27% of consumption, making this the highest renewable share ever in national electricity usage (REN, 2025).

4.2.2. Energy Storage Systems

Energy storage systems play a vital role in modernizing Portugal's electrical infrastructure, contributing to the security of the national electrical system and supply. It enables better resource management, supports grid stability, and enhances flexibility in response to the intermittent nature of solar and wind energy. Storage also reduces reliance on fossil fuels and boosts self-consumption of locally produced renewables.

In 2024, the Portuguese government launched a EUR 99,75 million public auction under the PRR funds to install 500 MW of battery storage capacity by the end of 2025 (Fundo Ambiental, 2024). In early 2025, 43 projects were awarded. It should be noted that these fundings are focused only on co-located energy-storage, i.e., when energy storage systems (such as batteries) are installed in the same physical location as a power generation source.

PEH should involve Battery Energy Storage Systems (BESS) either at the building level (residential and public) or as part of community systems. Thermal storage (e.g., hot water tanks) is also relevant, particularly for domestic hot water (DHW) in social housing and sports facilities.

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Despite battery costs remaining a barrier, incentives and smart technologies (e.g., time-of-use tariffs) are improving feasibility. PEH will support demonstration and replication of these solutions in municipalities with appropriate load profiles, contributing to Portugal's goal of 85% renewable electricity by 2030.

4.2.3. Smart Grid and Energy Management Systems

Smart grids in Portugal enable two-way communication, allowing not only delivering electricity to consumers but also transmitting energy from consumers back to the grid. They support real-time data exchange between devices, systems, and operators, and facilitate the integration of distributed energy resources such as rooftop solar, battery storage, and electric vehicles (Simpla Project, 2025). Key components include may include smart metering infrastructure, Building Energy Management Systems (BEMS), district-level control platforms and digital tools for monitoring and optimization.

The Energy Management Systems (EMS) are digital platforms or software tools that enable real-time monitoring, control, and optimisation of energy consumption, production, and storage across buildings, facilities, or energy networks. At the buildings level, EMS can centrally monitor, and control HVAC systems, lighting, and other energy uses, offering automated scheduling, remote diagnostics, and integration with renewables and storage.

In line with Decree-Law No. 15/2022 (2022), which mandates smart grid integration for all low-voltage customers in Portugal mainland, the national distribution system operator had installed over 6 million smart meters by 2024 covering about 94% of customers (E-REDES, 2024). These enable access to advanced network services, although full smart grid functionality (e.g., automated fault detection, decentralized balancing) remains at early to mid-stage maturity.

Most public buildings still lack centralized EMS platforms, though pilot projects exist in municipalities as Lisbon, Cascais, and Vila Nova de Gaia, especially in schools and municipal buildings. EMS adoption is more common in new or EU-funded renovations, though still limited in small and medium-sized municipalities.

Under PEH, smart systems should include BEMS, smart meters and OSS-integrated digital platforms for project monitoring and evaluation, and will promote replicable smart renovation models, empowering building owners and facility managers with actionable data.

These systems are essential for dynamic pricing, collective self-consumption, and local energy markets.

PEH can promote the implementation of smart grids supporting the implementation of the infrastructure for flexible integration of renewables, electric vehicles, and storage systems.

4.3. E-mobility charging stations

Portugal is making a strong progress towards a sustainable mobility by promoting the expansion of electric vehicle (EV) charging infrastructure, in compliance with the provisions of Regulation (EU) 2023/1804 of the

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European Parliament and of the Council of 13 September 2023, on the deployment of alternative fuels infrastructure (AFIR).

Supported by the Environmental Fund of the Ministry of Environment and Climate Action, Portugal has been offering several financial and fiscal incentives to encourage the acquisition of electrical vehicles and the installation of its charging points (Fundo Ambiental, 2024 and 2025). Tax incentives (such as VAT deductions) are also currently in force for the acquisition of electrical vehicles. These efforts reflect Portugal's commitment to creating a reliable, widespread, and efficient national EV network.

Portuguese electric mobility market currently includes three types of players: the operators of charging stations (CPOs), the suppliers of electricity for electrical mobility (CEMEs) and the National Electric Mobility Network Managing Entity (which is an entity designated by the Portuguese government - Mobi.E, S.A.). National regulations are currently being revised to adapt the Portuguese legal system to the EU provisions from AFIR.

The charging infrastructure includes public-access and private-access EV charging stations installed in municipal buildings, schools, commercial centres, street parking areas, private buildings, highways service stations, among others. These installations are typically grid-connected, with the potential for solar PV integration.

Public access charging stations are currently connected to a public electric public grid, managed by the National Electric Mobility Network Managing Entity (Mobi.E), which ensures interoperability of all operators. Private access charging stations are typically installed in houses or private buildings.

According to the National Electric Mobility Network Managing Entity, there are four types of EV charging available in Portugal (MOBI.E, 2025):

- Normal power station for slow charging.
- Normal power station for medium-speed charging.
- High-power station for fast charging.
- High-power station for ultra-fast charging.

Additionally, when combined with EMS, these charging stations can optimize charging times based on grid availability or renewable energy peaks. This reduces pressure on the grid and enhances energy efficiency.

Through the Environmental Fund, in 2024 a public financial assistance was available for up to 80% of charger costs, capped at EUR 800 per station, lowering entry barriers for businesses aiming to develop or expand charging networks (Fundo Ambiental, 2024 and 2025).

The government has been demonstrating a proactive approach to fostering sustainable transportation through various other incentives in 2025:

- Financial support for EV acquisition (Fundo Ambiental, with a total amount of EUR 4 000,00 per individual applicant).

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- Tax incentives (acquisition tax exemptions and reduced circulation tax).
- Mandatory EV acquisition targets for public entities.
- Development of the public network of charging stations across all areas of the country, to meet the targets defined by the AFIR regulation.

With these incentives, Portugal is not only accelerating the transition to EVs but also positioning itself as a leader in green mobility. Expanding EV infrastructure is key to decarbonising the transport sector and improving air quality. Public EV infrastructure must also incorporate universal design principles, ensuring accessibility for users with reduced mobility, as outlined in European standards for inclusive urban mobility.

PEH supports municipalities in planning and installing EV charging stations, particularly in synergy with energy renovation projects and new public procurement cycles.

Through PEH, municipalities and other entities can deploy charging infrastructure coupled with building energy efficiency renovations or public service upgrades, often connected to renewable energy sources such as solar PV. The OSSs will provide technical guidance on grid capacity, PV integration, and smart charging opportunities.

4.4. Water and Waste Infrastructure

Public infrastructures such as water supply and wastewater treatment plants, solid waste sorting and transfer stations are among the largest municipal energy consumers. These facilities are typically energy-intensive, operating continuously and often relying on outdated equipment.

Water and wastewater infrastructures are primarily managed by municipal utilities or intermunicipal companies such as Águas do Norte and Águas do Centro Litoral. These systems usually include:

- Water and wastewater treatment plants, which have high energy intensity due to processes such as pumping, aeration, filtration, and chemical treatment (ERSAR, 2022).
- Distribution networks, often aging leading to high real water losses, accounting for more than 70% of non-revenue water mainly due to leaks and inefficiencies (Meireles, 2023).
- Urban waste management systems that still rely heavily on landfills.
- Waste treatment plants depending on fossil fuels or inefficient electrical systems. Nevertheless, there is growing adoption of solar PV, small-scale hydro, and biogas valorisation for self- and community consumption — such as in the case of LIPOR, which generates 19 000 MWh of energy annually, and has recently created *ENNO – Associação Energias do Norte*, the largest energy community in Portugal and the only one using energy from waste valorisation (LIPOR, 2025).

In addition to being energy-intensive, these systems are also typically under-monitored, although, progress has been made in energy efficiency. For example, an initiative from Águas e Energia do *Porto*, a local company held by Porto Municipality, demonstrated a potential of advanced energy management systems and solar PV deployment with a power of 454 kWp allowing its self-sufficiency (ASCEND project, 2023).

A significant challenge facing water supply systems in Portugal is the ageing and deteriorated condition of the distribution networks. Many of these infrastructures were built several decades ago and have not undergone systematic renewal, resulting in high levels of water loss due to leaks, corrosion, and inefficient operations. According to ERSAR (2022), real water losses in some municipal systems exceed 30%. Renovating these networks is critical not only to reduce non-revenue water and improve operational efficiency, but also to lower the energy required for pumping and treatment, thereby contributing to both resource conservation and energy transition goals.

Also, biogas production through anaerobic digestion could be used to generate electricity and heat in large urban areas (e.g., LIPOR in Porto). However, many small and medium-sized municipalities still lack access to such infrastructure or resources to develop such projects.

Modernising water infrastructure not only improves energy performance but also enhances climate resilience, particularly through improved stormwater management, reduced leakage during drought conditions, and flood control in urban areas.

4.5. Summary

Table 2 summarises the main characteristics of each of the infrastructure typologies described in the previous sections.

Table 2. Summary of infrastructures main characteristics (ADENE, 2025) (DGEG, APA, ADENE, 2025) (IEA, 2024) (INESCTEC, 2024) (MOBI.E, 2025)

Typology	Main Characteristics	Energy Profile / Potential	Estimated Savings
Public Lighting Systems	Street lighting in urban and rural areas; mostly sodium lamps	Up to 60% of municipal electricity in small towns	LED + smart control = 50–70% savings
Renewable Energy Production (Solar PV, biomass, micro-wind)	Rooftop PV in public and residential buildings; biomass in rural areas; limited urban wind	High solar potential (4.6–5.4 kWh/m²/day); scalable across building types	PV self-consumption can reduce bills by 30–50%
Energy Storage Systems (Batteries, thermal)	Lithium-ion batteries in buildings; water tanks for DHW; hydrogen not in current scope	Enhances PV self-consumption, peak shaving	Up to 20% increased self-consumption; reduced grid stress
Smart Energy Management Systems	BEMS, smart meters, monitoring platforms linked to OSS	Enables real-time energy use optimisation	Up to 10–15% savings via behavioural and operational improvements
EV Charging Stations	AC/DC chargers in public buildings, schools, urban areas; PV coupling potential	Promotes clean transport; needs grid capacity assessment	Infrastructure + PV reduces transport emissions up to 100% locally

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Typology	Main Characteristics	Energy Profile / Potential	Estimated Savings
Water and Waste Infrastructure	Water supply, wastewater, waste collection centres	6–10% of municipal electricity; 24/7 load	High potential with pumps, PV and process control
ICT and OSS Digital Tools	Web portals, dashboards, GIS tools, cloud systems	Enables data-driven renovation, tracking, aggregation	Indirect savings via higher project efficiency

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5. Contribution to PEH objectives

Acting in the buildings and infrastructures described, PEH can achieve its objectives and, at a broader scale, support complying the national and European energy transition goals. This chapter presents an overview of the key PEH objectives and how this can be achieved.

5.1. Decarbonization Potential

The selected building typologies present substantial energy and CO_2 emissions savings potential. Depending on the depth and scope of intervention, primary energy consumption reductions can range from 30% to more than 70%, especially in cases of deep renovation involving building envelope, HVAC, and lighting systems (European Commission, 2019; PEER, 2023). Beyond energy efficiency gains, the implementation of renewable energy systems, can further reduce operational emissions particularly when combined with passive design measures and energy management tools. Estimations from PEH and PEER pipeline case studies confirm that combining PV, HVAC upgrades and passive design solutions (e.g. envelope insulation and highly efficient glazing) can reduce energy consumption to more than 90%, while PV alone may cover more than 30% of a building/infrastructure energy demand, depending on its characteristics (Fernandes, 2024; PEER, 2023; PEH, 2025).

Digitalisation tools such as building energy management systems, smart meters, and OSS linked data dashboards can provide an additional energy savings through behavioural change, real-time feedback, and continuous performance optimisation.

Altogether, these building and infrastructure interventions can support mobilising, at least EUR 26,3 million in investments and achieve 58,5 GWh/year of primary energy savings – PEH key performance indicators – supporting national and EU targets for a climate-neutral building stock by 2050.

5.2. Integration with Innovative Solutions

PEH promotes an integrated approach that couples traditional renovation with digital tools, smart energy systems, and user-centric services. The typologies identified particularly multi-family dwellings, schools, and municipal facilities are well-suited for piloting and scaling smart renovation models, including BEMS, real-time monitoring, and data-driven decision-making platforms.

Residential buildings with centralised technical infrastructure (e.g., multi-family dwellings) and large public assets (e.g., schools, sports centres) offer ideal conditions for demonstrating collective self-consumption, dynamic energy sharing, and demand-side flexibility. These features align with national and European goals for energy communities and grid-interactive buildings.

Moreover, PEH leverages synergies with digital platforms providing municipalities, service providers, and private stakeholders with access to:

- Aggregated project pipelines, supporting investment bundling.

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- Standardised technical assessments, increasing replicability and cost-effectiveness.
- Tailored financing and legal frameworks, reducing upfront risk and administrative complexity.

By embedding these innovations into the project's operational model, PEH fosters a shift from isolated upgrades to system-level renovation strategies anchored in digitalisation, decarbonisation, and decentralisation.

5.3. Synergies Between Building and Infrastructure Typologies

The PEH approach explicitly promotes the integration of building renovation and infrastructure upgrades to achieve more systemic, cost-effective, and long-lasting impacts. Instead of isolated interventions, PEH fosters the development of multi-functional energy nodes that leverage synergies between public assets, decentralised energy resources, and digital management systems.

For instance, schools, sports centres, and administrative buildings undergoing envelope and HVAC renovations can simultaneously be engaged in a renewable energy community, sharing installed PV, energy storage, and EV charging infrastructures.

Likewise, the spatial and operational proximity between public buildings and infrastructure networks such as public lighting, water systems, and mobility nodes enables coordinated interventions. Municipal experiences in cities like Guimarães, Almada, and Porto show that integrating LED lighting retrofits, smart dimming systems, and shared PV generation can yield electricity savings of 50–70% and reduce operational costs significantly (AdEPorto, 2025).

The integration of buildings and infrastructure should be reflected in local energy and climate planning instruments, such as municipal master plans, ensuring institutional continuity and alignment with broader territorial strategies.

Beyond physical upgrades, the convergence of ICT infrastructure and energy systems including smart meters, dashboards, and building performance analytics, enhances transparency, supports real-time optimisation, and fosters behavioural change.

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6. Conclusions and Next Steps

This document establishes a detailed and structured mapping of eligible building and infrastructure typologies that are central to Powering Energy Hub implementation. By analysing the physical, functional, and energy-related characteristics of a wide spectrum of public and private building and infrastructures, including residential buildings, commercial and institutional facilities, industrial units, and critical infrastructure, this document sets the ground for strategic planning, investment aggregation, and technical interventions.

Portugal's building stock is structurally diverse yet inefficient, with significant regional and typological disparities. Public infrastructure and services such as lighting, water management, and ICT systems also face high energy intensities and limited digitalisation. However, these gaps highlight a clear opportunity to tailor PEH's services, financial mechanisms, and technical solutions to the specific needs and potential of each category.

The integration of data-driven tools and prioritisation criteria ensures that the project not only aligns with national energy transition targets but also responds effectively to local urban and rural realities, large and small municipalities, vulnerable and strategic segments. This framework guides pilot selection, stakeholder mobilisation, and replication pathways across Portugal.

This document paves the way to PEH's ambitions to become an enabler of wide-scale energy renovation and renewable integration, supporting Portugal's contribution to European decarbonisation goals. It will inform subsequent work and interventions, particularly in the definition of investment-ready projects, development of OSS digital platforms, and mobilisation of multi-level governance and financing.

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