Deliverable Report

Mainstreaming governance, co-investment and technology solutions for Positive Energy Districts in monument protected areas (MonuPED)

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D2.1 Catalogue of PED solutions for MPAs/MPBs

Workpackage 2: Concepts for enabling PEDs in MPAs/MPBs

Driving Urban Transitions
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OVERVIEW / EXECUTIVE SUMMARY

This deliverable provides a comprehensive overview of how EU Member States regulate, permit, and implement renewable-energy solutions within monument-protected buildings (MPBs) and monument-protected areas (MPAs). It consolidates national legislation, heritage-authority procedures, and documented good-practice implementation examples to identify the real boundary conditions for Positive Energy Districts (PEDs) in heritage environments, directly supporting the MonuPED objective of enabling climate-neutral urban development without compromising cultural value.

The report is structured into three main analytical pillars:

- Comparison of legal and institutional landscape across the EU-27, mapping how national frameworks transpose EU climate directives while safeguarding protected historical environments.
- Survey how each Member State currently approaches the integration of renewable-energy systems (PV, BIPV, solar-thermal, geothermal, heat pumps, flexibility technologies) in protected contexts, highlighting convergences such as reversibility, invisibility, and landscape protection.
- Compilation from major European research and innovation projects (POCITYF, +CityxChange, SPARCS, EXCESS, and others), demonstrating where and how RES have been implemented successfully in tightly regulated heritage settings. These cases provide concrete models of off-site shared generation, district-scale renewable heat, innovative BIPV, multifunctional urban infrastructure, microgrids, seasonal storage, tidal and small wind solutions, and digital energy-sharing mechanisms, all applicable to MonuPED's Living Labs.

The synthesis chapter identifies cross-cutting strategies already validated across Europe:

- **Non-visible or off-site electricity generation** (e.g., community solar farms, hidden PV, BIPV tiles).
- **Renewable heat compatible with heritage restrictions** (ground-source heat pumps, district solar-thermal, waste heat, geothermal).
- **Digitalisation and flexibility services** (BEMS, smart metering, EV/V2G, energy routers, peer-to-peer models).
- **Envelope interventions respecting heritage values** (internal insulation, reversible systems, material-matched BIPV).

Together, these findings define the practical enabling conditions for MonuPED's mission to establish governance, co-investment, and technology solutions capable of deploying Positive Energy Districts within historic urban landscapes.

RECOMMENDATIONS:

Based on the evidence gathered, the report recommends that MonuPED Living Labs:

1. **Prioritise non-visible renewable generation** through off-site PV sharing, secondary-roof integration, BIPV tiles, or community energy schemes when rooftop intervention is restricted.
2. **Adopt renewable-heat strategies** proven compatible with heritage, including geothermal systems, district solar-thermal, waste-heat integration, and low-temperature heat pumps placed in non-intrusive locations.
3. **Build local governance capacity** through procedural templates, visibility-impact assessments, and standardised reversible-intervention criteria, facilitating heritage-authority decision-making.
4. **Integrate digital energy tools** - BEMS, smart metering, load shifting, V2G, and flexibility markets - to increase PED performance where on-site generation is limited.

5. **Promote co-investment models** such as Renewable Energy Communities (RECs) and Collective Self-Consumption (CSC) to distribute benefits across protected districts.
6. **Use exemplary EU project cases** (Évora, Limerick, Leipzig, Valladolid, Graz) as replicable patterns for MonuPED implementation, adapting their methods to local constraints.

These recommendations directly inform the upcoming WP3–WP6 activities on stakeholder engagement, technical modelling, Living Lab design, and PED deployment pathways in monument-protected contexts.

This deliverable is issued in 12/2025 in its first published version. It is, however, envisioned that it will be further expanded during the course of the project to reflect the ongoing development in its topic.

INTRODUCTION

Europe's historic cities face a dual transformation challenge: meeting ambitious climate-neutrality targets while safeguarding the cultural heritage that defines their identity and social value. The European Green Deal, together with the Energy Performance of Buildings Directive (EPBD) and the Renewable Energy Directive (RED II/III), requires a rapid decarbonisation of the building stock and urban energy systems. Yet a significant share of European urban areas - especially those with high cultural value - operate under strict monument-protection frameworks that limit alterations to buildings, façades, streetscapes, and landscapes. Balancing these environmental and cultural priorities requires new governance mechanisms, technology pathways, and investment models capable of enabling Positive Energy Districts (PEDs) within sensitive historic environments.

The MonuPED project addresses this challenge by developing methodologies, governance strategies, and co-investment frameworks that allow PED concepts to be implemented in monument-protected areas (MPAs) and monument-protected buildings (MPBs). To support this mission, the present deliverable provides a structured foundation for understanding the regulatory, technical, and practical conditions under which renewable-energy systems can be deployed in heritage contexts across Europe. It synthesises national legal frameworks, heritage-authority practices, and verified implementation examples, creating a reference point that informs the Living Labs and technical work that follow in subsequent project work packages.

This introduction outlines the rationale and scope of the deliverable. **First**, it establishes the European and international policy context shaping energy and heritage decision-making, including UNESCO guidelines, ICOMOS principles, EU directives, and national monument-protection acts. These frameworks jointly define the boundary conditions for any intervention in protected areas. **Second**, it describes the methodological basis for compiling a comparative overview of legal and procedural mechanisms across all EU Member States. This provides the regulatory landscape within which PED-relevant technologies must operate. **Third**, it introduces the structure of the report:

- **Part 1** maps the national legislation and approval systems governing interventions in protected heritage environments.
- **Part 2** summarises how these systems translate into practical rules for renewable energy integration, including PV, BIPV, solar-thermal, geothermal, heat pumps, and flexibility technologies.
- **Part 3** compiles verifiable good-practice implementation examples from leading European innovation projects (POCITYF, +CityxChange, SPARCS, EXCESS) that demonstrate how renewable technologies can be deployed within strict heritage constraints.

Together, these components provide a robust evidence base for MonuPED's work: identifying feasible technical solutions, defining heritage-compatible PED pathways, and establishing governance models for municipalities and heritage authorities. The introduction therefore situates the deliverable as both a knowledge baseline and a strategic enabler for developing PEDs in Europe's most culturally significant urban districts.

1. LEGAL PROTECTION OF MONUMENTS AND MONUMENT AREAS IN THE EUROPEAN UNION

This chapter presents a comparative overview of the legal protection of monuments and monument-protected areas across the twenty-seven Member States of the European Union. It summarizes national legislation, responsible authorities, and procedural mechanisms regulating interventions in historic environments. The objective of this chapter is to provide a coherent legal foundation for assessing renewable-energy integration.

Cultural heritage in Europe is protected through a combination of national and international legislation that recognizes monuments and historic areas as assets of outstanding value. In parallel, the European Union promotes the decarbonization of the building stock through binding climate and energy targets. Balancing these two priorities - heritage conservation and sustainability - has become a central policy challenge.

The EU’s legal basis for action in the field of energy efficiency and renewable integration derives from several directives that shape national implementation. While heritage protection remains a national competence, Member States are required to transpose EU objectives in ways consistent with the protection of cultural property and the integrity of historic environments. Consequently, each country maintains its own monument-protection act and administrative hierarchy, yet all operate within a shared European framework emphasising authenticity, reversibility, and minimal visual impact.

1.1 European and International Frameworks

UNESCO World Heritage Convention

The Convention concerning the Protection of the World Cultural and Natural Heritage (adopted 1972, entered into force 1975) [1] binds States Parties to safeguard the outstanding universal value, authenticity, and integrity of World Heritage Sites. Within EU territory, twenty-six Member States host such sites. UNESCO guidelines and Operational Guidelines (2021 Edition) [2] underline that any renewable energy installation within or adjacent to a World Heritage property must be reversible and avoid adverse visual impact on key views.

ICOMOS Principles and European Cultural Heritage Green Paper

The International Council on Monuments and Sites (ICOMOS) has issued multiple charters addressing energy efficiency and sustainability in historic buildings, notably the “ICOMOS Principles for the Analysis, Conservation and Structural Restoration of Architectural Heritage” (2003) [3]. In 2021, the European Heritage Green Paper [4] - prepared by Europa Nostra, the EIB Institute, and ICOMOS - further integrated heritage considerations into the EU Green Deal, calling for the “heritage-led green transition.” These instruments advocate a holistic methodology: energy interventions should be compatible with heritage fabric, use reversible technologies, and enhance long-term resilience.

European Green Deal and EU Taxonomy

The European Green Deal (Communication COM(2019) 640 final [5]) sets the overall objective of a climate-neutral Europe by 2050. Complementing this, Regulation (EU) 2020/852 [6], [7] on the establishment of a framework to facilitate sustainable investment (the “EU Taxonomy”) defines criteria for economic activities considered environmentally sustainable. Under the Taxonomy, energy renovations of buildings must respect cultural-heritage value, embedding the principle that climate action and heritage conservation are mutually reinforcing.

Energy Performance of Buildings Directive (EPBD)

Directive 2010/31/EU [8] of the European Parliament and of the Council on the energy performance of buildings, as amended by Directive (EU) 2018/844 [9], establishes minimum energy-efficiency requirements for new and existing buildings. Article 4 explicitly allows Member States to exclude “buildings officially protected as part of a designated environment or because of their special architectural or historical merit,” provided that compliance would unacceptably alter their character. The EPBD therefore acknowledges the need for tailored approaches in heritage contexts.

Renewable Energy Directive (RED II and III)

Directive (EU) 2018/2001 [10] on the promotion of the use of energy from renewable sources (RED II) and its recast Directive (EU) 2023/2413 (RED III) [11] form the cornerstone of EU renewable energy policy. These directives require Member States to simplify permitting for renewable installations while ensuring alignment with environmental and cultural-heritage legislation. They encourage integration of renewables into the built environment - including protected areas - through design solutions that preserve cultural significance.

Together, these frameworks form the normative backbone for all subsequent national approaches examined in this study. They define the boundary conditions within which Member States craft their own monument-protection legislation and approval procedures.

1.2. National Frameworks

1.2.1 Austria

The *Denkmalschutzgesetz* (Federal Monuments Protection Act 1923, consolidated 2021) [12] establishes federal responsibility for cultural-heritage protection. The *Bundesdenkmalamt (BDA)* [13], operating under the Federal Ministry for Arts, Culture, Civil Service and Sport, is the competent authority. Listed monuments are protected individually, while ensembles and protected zones are designated through provincial planning law. Any alteration affecting appearance or structure requires BDA consent; appeals proceed to the Federal Administrative Court. Typical authorizations consider reversibility, minimal intervention, and non-reflective materials.

1.2.2 Belgium

Heritage protection is devolved among the three regions. In Flanders, the *Onroerenderfgoeddecreet* (2013) [14] is enforced by the *Agentschap Onroerend Erfgoed* [15]; in Wallonia by the *Code du Patrimoine* (2019) [16] under the *Agence Wallonne du Patrimoine* [17]; and in Brussels by the *Ordonnance relative à la conservation du patrimoine immobilier* (2004) [18] administered by *Urban.brussels* [19]. Each region maintains its own inventory of protected monuments (*beschermde/onroerende goederen*, *biens classés*). Permits for works require regional approval, preceded by municipal advice; procedures emphasise preservation of façades and roofscapes visible from the public realm.

1.2.3 Bulgaria

The *Cultural Heritage Act* (2009, as amended) [20] regulates monuments of culture and archaeological reserves. The *National Institute for Immovable Cultural Heritage* (NIICH) [21] under the Ministry of Culture coordinates listings and supervises interventions. Protection extends to individual buildings, ensembles, and historic zones. Permits for any works are issued by the Ministry upon NIICH evaluation; for UNESCO properties, UNESCO [22] and ICOMOS [23] are consulted. Heritage protection includes both authenticity of fabric and landscape context.

1.2.4 Croatia

Cultural heritage is governed by the *Law on the Protection and Preservation of Cultural Goods* (Official Gazette No. 69/99, updated 2020) [24]. The *Ministry of Culture and Media* [25] oversees the *Directorate for the Protection of Cultural Heritage* [26], with regional conservation departments (*Konzervatorski odjeli*). Any physical intervention on a registered monument or within a protected zone requires a *conservation approval* prior to building permits. The law distinguishes immovable, movable, and intangible heritage; penalties apply for unauthorized works.

1.2.5 Cyprus

The *Antiquities Law* (Cap. 31, revised 2012)[27] protects ancient monuments and archaeological sites, complemented by the *Town and Country Planning Law* (1990). The *Department of Antiquities* [28] under the Ministry of Transport, Communications and Works is responsible for declared monuments, while the *Department of Town Planning and Housing* [29] regulates conservation areas. Class A and B monuments require ministerial consent for any alteration. Heritage oversight extends to the island's UNESCO properties such as Paphos [30] and Troodos Painted Churches [31].

1.2.6 Czech Republic

Heritage protection is defined by Act No. 20/1987 Coll. on State Monument Care, as amended [32]. The *National Heritage Institute (Národní památkový ústav, NPÚ)* [33] executes professional supervision under the Ministry of Culture. Monuments (*kulturní památky*), national cultural monuments, and conservation areas (*památkové zóny/rezervace*) require prior consent of the relevant heritage authority. Decisions consider the visual integrity of the site and permit renewable energy installations only if invisible or reversible, following NPÚ methodology (2022) [34], [35].

1.2.7 Denmark

Under the *Consolidated Act on Listed Buildings and Preservation of Buildings and Urban Environments* (No. 219 of 2018) [36], the *Agency for Culture and Palaces (Slots- og Kulturstyrelsen)* [37] designates listed buildings (*fredede bygninger*). Municipalities identify *worthy of preservation* structures (*bevaringsværdige bygninger*) through planning law. Owners of listed buildings must obtain agency consent before external alterations; appeals lie with the Ministry of Culture. Guidelines stress maintaining original materials, avoiding reflective surfaces, and allowing only reversible energy retrofits.

1.2.8 Estonia

The *Heritage Conservation Act* (2019) [38] places responsibility with the *National Heritage Board (Muinsuskaitseamet)* [39]. Cultural monuments (*kultuurimälestis*) and heritage conservation areas require permits for any change affecting appearance or structure. Applications are submitted via the electronic *Muinsuskaitse Register* [40]; supervision includes archaeological layers and urban views. The Act harmonises with planning legislation to balance heritage and energy-efficiency goals.

1.2.9 Finland

The *Act on the Protection of Built Heritage* (498/2010) [41] and the *Land Use and Building Act* (132/1999) [42] govern built-heritage protection. The *Finnish Heritage Agency* (FHA) [43] acts under the Ministry of Education and Culture. Buildings or groups of buildings may be designated protected by government decree. Municipal authorities handle planning controls within *r-areas* (nationally significant cultural environments). Any intervention must maintain the character and integrity of the site; energy measures are assessed for visual neutrality.

1.2.10 France

Protection stems from the *Code du Patrimoine* (2004) [44], consolidating earlier laws on *Monuments Historiques*. The *Ministry of Culture* exercises oversight through *Architectes des Bâtiments de France (ABF)* [45]. Works on listed buildings or within protected surroundings (*abords*, *sites patrimoniaux remarquables – SPR*) require ABF authorisation. Local authorities integrate heritage protection into urban-planning documents (*PLU*). French law imposes strict control of façades and roofscapes visible from the public domain.

1.2.11 Germany

Germany's federal structure assigns heritage protection to the Länder. Each Land enforces its own *Denkmalschutzgesetz* [46], [47], [48], [49], [50], [51], [52], [53], [54], [55], [56], [57], [58], [59], [60], [61], while overall coordination occurs via the *Kultusministerkonferenz* [62]. Typical authorities are *Landesdenkmalämter* or *Untere Denkmalschutzbehörden* within municipalities. All listed buildings (*Baudenkmale*) and ensembles (*Ensembleschutz*) require prior consent for alterations; permit processes are integrated with building-code procedures. Federal cultural heritage is overseen by the *Bundesamt für Kultur und Medien* [63] for exceptional cases.

1.2.12 Greece

The *Law 3028/2002 on the Protection of Antiquities and Cultural Heritage in General* [64] defines ownership and guardianship of ancient and modern monuments. The *Ministry of Culture and Sports*, through regional *Ephorates of Antiquities*, administers listings and permits. All works require ministerial approval; archaeological councils provide scientific opinions. The system distinguishes ancient monuments (pre-1830) and newer cultural property; protection extends to landscape and setting.

1.2.13 Hungary

The *Act LXIV of 2001 on the Protection of Cultural Heritage* [65] establishes the *Prime Minister's Office – Department for Cultural Heritage Protection* [66] as the competent authority. Protected monuments (*műemlék*) and historic areas are entered in the national register. Municipalities coordinate local heritage inventories. Permits for works are issued by the heritage authority after professional evaluation; criteria emphasise reversibility and visual integration with the historic environment.

1.2.14 Ireland

The *Planning and Development Act 2000* (as amended) [67] governs architectural heritage through the *Record of Protected Structures (RPS)* [68] and *Architectural Conservation Areas (ACAs)* [69]. Local authorities manage both instruments, subject to oversight by the *Department of Housing, Local Government and Heritage* [70]. Works affecting a protected structure require planning permission unless declared *exempted development* by *An Bord Pleanála*. The National Inventory of Architectural Heritage [71] provides classification guidance.

1.2.15 Italy

The *Codice dei Beni Culturali e del Paesaggio* (Legislative Decree 42/2004) [72] unites cultural heritage and landscape protection under the *Ministry of Culture (MiC)*. Regional *Soprintendenze Archeologia, Belle Arti e Paesaggio* [73] issue binding opinions on all works involving protected property. Authorisation (*autorizzazione paesaggistica*) is mandatory for visual alterations within protected zones. The code integrates environmental sustainability but requires that energy improvements respect historical authenticity and reversibility.

1.2.16 Latvia

The *Law on the Protection of Cultural Monuments* (1992, amended 2020) [74] entrusts supervision to the *National Heritage Board – Nacionālā kultūras mantojuma pārvalde (NKMP)* [75]. Immovable cultural monuments (*nekustamie kultūras pieminekļi*) are entered in a State Register. Any alteration or construction within a protected site or its buffer zone requires NKMP consent, preceded by municipal consultation. For World Heritage sites such as Riga Historic Centre, the NKMP cooperates with UNESCO advisory bodies.

1.2.17 Lithuania

The *Law on Protection of Immovable Cultural Heritage* (No. I-733 of 1995, updated 2019) [76] defines protection categories and procedures. The *Department of Cultural Heritage under the Ministry of Culture (Kultūros paveldo departamentas – KPD)* [77] registers heritage objects and issues permits for works. Municipal heritage divisions supervise local implementation. Conservation requirements emphasise authentic materials and visual compatibility with the surroundings.

1.2.18 Luxembourg

The *Loi du 18 juillet 1983 concernant la conservation et la protection des sites et monuments nationaux* (as amended 2022) [78] empowers the *Service des sites et monuments nationaux (SSMN)* [79] within the Ministry of Culture. Buildings of national interest may be classified (*classés*) or inscribed (*inscrits*) on a supplementary list. Any modification requires ministerial authorisation based on SSMN advice; public works must integrate heritage impact assessment findings.

1.2.19 Malta

The *Cultural Heritage Act* (2002, revised 2019) [80] establishes the *Superintendence of Cultural Heritage (SCH)* [81] and the national agency *Heritage Malta* [82]. Scheduled monuments are graded I–III under the Development Planning (Procedure for Scheduling) Regulations (2016) [83]. Any works require Planning Authority [84] consent following SCH consultation. Malta's framework links heritage protection with energy efficiency through national policy guidance for historic buildings.

1.2.20 Netherlands

The *Heritage Act* (Erfgoedwet, 2016) [85] and the *Environmental Planning Act* (Omgevingswet, 2024) [86] form the legal basis for heritage management. The *Cultural Heritage Agency (Rijksdienst voor het Cultureel Erfgoed – RCE)* [87] advises the Ministry of Education, Culture and Science. Municipalities designate local monuments and conservation areas (*beschermde stads- en dorpsgezichten*). Alterations to national monuments require municipal permits with RCE input; digital portals [88] streamline applications.

1.2.21 Poland

The *Act on the Protection and Care of Monuments* of 23 July 2003 [89] defines the national system. The *General Conservator of Monuments* under the Ministry of Culture oversees the register, implemented through *Voivodeship Heritage Conservators (WKZ)* [90]. Any change in appearance or use of a protected object requires WKZ permission; violations may result in penalties. Heritage zones (*parki kulturowe*) extend protection to urban landscapes.

1.2.22 Portugal

The *Lei n.º 107/2001 – Bases da Política e do Regime de Proteção e Valorização do Património Cultural* [91] is the framework law for cultural heritage. Implementation rests with the *Direção-Geral do Património Cultural (DGPC)* [92] and regional directorates. Monuments (*imóveis classificados*) and their protection zones (*zonas de proteção especial*) require DGPC approval for any intervention. Coordination with municipal planning instruments ensures compatibility between heritage and urban development.

1.2.23 Romania

The *Law No. 422/2001 on the Protection of Historical Monuments* [93] assigns competence to the *Ministry of Culture through the National Institute of Heritage (INP)* [94]. Regional Directorates for Culture handle permits and monitoring. Any construction, repair, or energy-related work on a classified monument requires authorisation based on an expert report. Municipalities must consider heritage zones in urban plans.

1.2.24 Slovakia

The *Act No. 49/2002 Coll. on the Protection of Monuments and Historic Sites* [95] regulates the system administered by the *Monuments Board of the Slovak Republic (Pamiatkový úrad SR)* [96]. Heritage categories include national cultural monuments and protected zones. Any works require a heritage permit from the Monuments Board or its regional offices. Decisions apply the principles of minimum intervention and reversibility.

1.2.25 Slovenia

The *Cultural Heritage Protection Act* (Official Gazette No. 16/2008, as amended 2023) [97] is implemented by the *Institute for the Protection of Cultural Heritage of Slovenia (ZVKDS)* [98]. The Act defines immovable heritage, heritage areas, and protection regimes. Authorisations for interventions are issued by regional units of ZVKDS and are binding for planning authorities. Heritage impact assessments are mandatory for major projects.

1.2.26 Spain

The *Ley 16/1985 del Patrimonio Histórico Español* [99] and regional heritage laws constitute Spain's multilevel system. Competence is shared between the State and Autonomous Communities, each with its own heritage council. Listed buildings (*Bienes de Interés Cultural – BIC*) and historic ensembles (*Conjuntos Históricos*) require prior authorisation from the regional department. Municipal planning tools (*Planes Especiales de Protección*) [100] regulate implementation at local level.

1.2.27 Sweden

The *Cultural Environment Act* (1988:950) [101] governs heritage protection, complemented by the *Planning and Building Act* (2010:900) [102]. The *County Administrative Boards (Länsstyrelserna)* [103] implement national policy from the *Swedish National Heritage Board (Riksantikvarieämbetet)* [104]. Buildings may be declared listed (*byggnadsminnen*), and alterations require County Board permits. Municipalities may also protect buildings through detailed plans (*detaljplaner*). Policy guidance emphasises energy efficiency balanced with heritage values.

2. RENEWABLE ENERGY INTEGRATION IN PROTECTED CONTEXTS

While EU directives set ambitious decarbonisation targets, their application within protected historic environments requires nuanced interpretation. Each Member State has therefore developed procedural or technical solutions that reconcile renewable energy integration with cultural heritage safeguarding. The analysis below compiles verified national information on how photovoltaic (PV), solar-thermal, geothermal, and heat-pump technologies are assessed and approved in monument-protected contexts. It builds directly upon the legal frameworks described in Part 1 and provides the bridge toward the practical examples presented in Part 3.

2.1 Austria

Austria applies a cautious yet enabling approach under the *Bundesdenkmalamt (BDA)*. The 2021 “Standards for Energy Efficiency in Monuments” [105] outline conditions under which renewables may be installed. PV and solar-thermal systems are permissible if invisible from the public realm, integrated on secondary roofs, or detached from the primary monument. Heat pumps and biomass systems are accepted when plant rooms remain reversible and acoustically screened. Visibility and material compatibility are decisive factors; each case requires BDA approval.

2.2 Belgium

Regional heritage administrations - *urban.brussels*, *Agentschap Onroerend Erfgoed*, and *Agence Wallonne du Patrimoine* - support renewable integration provided that installations do not compromise façades or skyline character. In Brussels, the *Homegrade* [106] advisory platform promotes PV on flat or hidden roofs and low-noise heat pumps in courtyards. Flanders publishes detailed guidance on heat-pump placement for listed dwellings [107]. Regional incentives encourage owners to combine energy upgrades with conservation maintenance.

2.3 Bulgaria

In Bulgaria, interventions affecting protected cultural heritage are assessed on a case-by-case basis by the National Institute for Immovable Cultural Heritage under national heritage legislation. Conservation assessments consider visual impact, reversibility of interventions, and protection of archaeological layers, with subsurface works requiring archaeological clearance. While national and municipal energy strategies promote renewable energy more broadly, publicly documented examples of renewable-energy systems integrated into protected heritage buildings in cities such as Plovdiv or Ruse remain limited.

2.4 Croatia

Croatia’s *Directorate for the Protection of Cultural Heritage* has increasingly accepted renewable measures on protected sites following the country’s National Energy and Climate Plan. PV is allowed on contemporary additions or service wings, while geothermal and biomass systems are implemented where ground conditions and heritage sensitivity permit. The emphasis lies on reversibility, minimal external visibility, and technical documentation approved by regional conservators.

2.5 Cyprus

The *Department of Antiquities* generally restricts visible PV or solar-thermal collectors on ancient monuments but allows installations on modern annexes or new museum buildings, such as the New Cyprus Museum. Hybrid AC/DC micro-grids and geothermal heat pumps are being tested in university-led research projects, showing potential for integration if visually unobtrusive. All works require ministerial consent.

2.6 Czech Republic

Following the NPÚ methodology published in 2022, PV is conditionally acceptable on non-visible or flat roofs within conservation zones. The approach prioritises invisibility from the street and reversibility of mounts. Ground-source heat pumps are authorised if boreholes are outside protected vistas or archaeological layers. Municipal heritage offices apply consistent evaluation criteria and increasingly coordinate with energy consultants to achieve balanced outcomes.

2.7 Denmark

Denmark promotes pragmatic, case-by-case decisions. The *Agency for Culture and Palaces* advises that PV and solar-thermal collectors may be installed on rear or secondary roofs of listed buildings if panel colour and reflectance match existing materials. Heat-pump systems are acceptable when external units are screened and vibration-isolated. The national guidance “Energiforbedring af fredede og bevaringsværdige bygninger” [107] encourages reversible upgrades within conservation ethics.

2.8 Estonia

The *Muinsuskaitseamet* supports renewable installations under clear design-compatibility rules. PV integration is demonstrated in pilots within Võru [108], using flush roof tiles and tone-matched modules. Heat-pump and geothermal systems are routinely approved if concealed underground or within ancillary buildings. Estonia’s digital heritage register expedites the permit process through transparent public documentation.

2.9 Finland

Finland’s *Heritage Agency* and municipalities endorse renewables as part of the national low-carbon strategy, provided visual harmony is preserved. PV tiles on inner or rear slopes are common in Porvoo Old Town, while ground-source heat pumps serve museums such as the National Museum of Finland. The regulatory framework treats energy improvements as acceptable when fully reversible and technically documented to avoid moisture or vibration risks.

2.10 France

France’s *Architectes des Bâtiments de France (ABF)* enforce rigorous control but increasingly permit renewable installations under the 2021 national guidance on photovoltaics in heritage contexts. PV arrays are allowed on hidden or flat roofs within *Sites Patrimoniaux Remarquables (SPR)*. Geo-energy and heat-pump projects, like those at the Château de Bagatelle [109], demonstrate ABF’s openness to well-documented, reversible systems. Key criteria include invisibility from the public domain, material neutrality, and compliance with ministerial technical notes.

2.11 Germany

Each *Landesdenkmalgesetz* enables case-specific authorisations coordinated by the *Landesdenkmalamt*. German heritage agencies generally accept renewable installations if visual impact is minimal and interventions remain reversible. Pilot schemes in Leipzig and Hamburg [110], [111] show that flat-roof PV and geothermal systems can be integrated successfully into listed buildings. Guidance from *Deutsche Stiftung Denkmalschutz* [112] and *Energy4Climate NRW* promotes energy efficiency in monuments through non-intrusive technology, including concealed heat-pump systems and façade-integrated solar shading.

2.12 Greece

The *Ministry of Culture and Sports* applies strict control over interventions in archaeological zones but increasingly collaborates with universities on low-impact renewable projects. PV and solar-thermal systems are limited to auxiliary buildings, while ground-source heat pumps may be approved in museum contexts. Research at Eleutherna and Legraina [113] demonstrates how reversible geothermal systems can coexist with cultural-landscape values when boreholes are placed outside archaeologically sensitive areas.

2.13 Hungary

In Hungary, documented RES retrofits in heritage contexts include geothermal heat pumps in historic Budapest buildings (e.g., Zugligeti Lóvasút [114]) and photovoltaic installations designed to fit protected monument environments (e.g., Palatinus Strandrdő [115]). In UNESCO contexts, PV has also been reported on abbey-related operational buildings within the Pannonhalma Archabbey complex [116] (e.g., on service/utility facilities), though not necessarily on the medieval core structures.

2.14 Ireland

In Ireland, the Planning and *Development Act 2000* requires that works which would materially affect Protected Structures or buildings in Architectural Conservation Areas normally require planning permission. Revised planning exemption regulations for rooftop solar were introduced in 2022 [117] to streamline microgeneration deployment nationally, although exemptions do not apply where the works would materially affect a protected structure or its character.

2.15 Italy

In Italy, interventions affecting protected cultural heritage are assessed by the Soprintendenze under the Codice dei Beni Culturali e del Paesaggio on a case-by-case basis. Conservation evaluations emphasise visual impact, material compatibility, reversibility, and the preservation of historic fabric. While photovoltaic and other energy technologies are increasingly discussed in research and pilot contexts, publicly documented examples of their integration into highly protected historic buildings remain limited, and approvals are granted selectively following detailed heritage impact assessments.[118]

2.16 Latvia

In Latvia, there is policy support for improving energy efficiency in state-owned cultural and historical buildings that can include the installation of renewable energy-based heat production sources alongside restoration and engineering system upgrades. For example, the Ministry of Economics has identified support measures for restoring and upgrading the energy systems of multiple cultural heritage buildings, emphasizing energy efficiency improvements while respecting their historical value. Energy efficiency investments have also been made at heritage sites such as the Ethnographic Open-Air Museum of Latvia. [119]

2.17 Lithuania

In Lithuania, interventions affecting protected cultural heritage are assessed on a case-by-case basis by the Department of Cultural Heritage (KPD) under national heritage legislation. Any installation of technical systems, including renewable-energy or heating equipment, requires approval where it may affect protected fabric or archaeological layers. While national energy policy promotes renewable energy deployment, publicly documented examples of photovoltaic or heat-pump installations within protected heritage buildings remain limited, and decisions are taken individually based on heritage impact.

2.18 Luxembourg

In Luxembourg, the Service des sites et monuments nationaux (SSMN) is responsible for the protection and management of state-owned cultural heritage sites. Interventions affecting protected monuments, including building services and subsurface works, are subject to heritage, archaeological, and technical review. While Luxembourg promotes sustainable construction and energy efficiency at the national level, publicly documented examples of renewable-energy installations directly integrated into protected heritage buildings remain limited, and decisions are taken on a case-by-case basis.

2.19 Malta

In Malta, interventions affecting scheduled buildings are regulated through the Superintendence of Cultural Heritage and the Planning Authority, with approvals assessed on a case-by-case basis. Heritage consent processes emphasise the protection of architectural character, material integrity, and reversibility of interventions. While Malta promotes renewable energy and energy efficiency at the national level, publicly documented examples of renewable-energy systems integrated directly into Grade I scheduled monuments, such as museum buildings, remain limited.

2.20 Netherlands

The *Cultural Heritage Agency (RCE)* coordinates national guidance for energy retrofits of *Rijksmonumenten* [120]. The Dutch approach encourages innovation: PV is allowed on flat or concealed roofs, and BIPV façades have been tested on modernist monuments. Ground-source and aquifer thermal-energy storage (ATES) systems are widely used for museums and historic dwellings, with underground works coordinated with municipal archaeologists. The *Erfgoed & Duurzaamheid* programme mainstreams sustainability within heritage management [121].

2.21 Poland

In Poland, interventions affecting protected buildings are assessed on a case-by-case basis by the Voivodeship Conservators of Monuments under the supervision of the General Conservator of Monuments. Conservation authorities apply established heritage-protection principles, including the safeguarding of architectural character and historic fabric, when evaluating any technical installations. While Poland's national and municipal climate policies promote renewable energy and low-carbon development more broadly, publicly documented examples of renewable-energy systems integrated into protected monuments remain limited, and heritage-specific guidance on such installations is not formalised at the national level.

2.22 Portugal

n Portugal, interventions affecting protected cultural heritage are assessed on a case-by-case basis by the Direção-Geral do Património Cultural (DGPC) under national heritage legislation. Conservation assessments emphasise documentation, reversibility, material compatibility, and the preservation of authenticity. While Portugal's national energy and climate policies promote renewable energy deployment more broadly, publicly documented examples of renewable-energy systems integrated into protected monuments or UNESCO-listed sites remain limited.

2.23 Romania

Interventions affecting protected monuments are authorised by national and regional heritage authorities on a case-by-case basis under heritage legislation. Permit procedures require technical documentation and, where relevant, archaeological assessment to ensure the protection of historic fabric and subsurface remains. While European funding programmes support heritage conservation and climate-adaptation objectives more broadly, publicly documented examples of renewable-energy systems implemented in castles or fortified heritage sites remain limited.

2.24 Slovakia

In Slovakia, interventions affecting protected monuments and monument zones are authorised on a case-by-case basis by the Monuments Board of the Slovak Republic under national heritage legislation. Conservation assessments consider impacts on historic fabric, visual character, and archaeological values, and require appropriate technical documentation.

2.25 Slovenia

In Slovenia, interventions affecting protected cultural heritage are assessed on a case-by-case basis by the Institute for the Protection of Cultural Heritage of Slovenia (ZVKDS) under national heritage legislation. Conservation assessments emphasise the preservation of historic fabric, visual integrity of urban ensembles, and reversibility of interventions. While municipalities such as Ljubljana have adopted climate and sustainability strategies at the urban level, publicly documented examples of renewable-energy systems integrated into protected castles or monument complexes remain limited to research project plans.

2.26 Spain

In Spain, heritage protection and planning are managed at the level of the Autonomous Communities, with historic centres regulated through instruments such as Planes Especiales de Protección. Interventions affecting protected sites are assessed on a case-by-case basis by regional heritage authorities. Notable, well-documented examples of renewable and low-carbon energy integration include the use of geothermal systems in the rehabilitation of the Hospital de Sant Pau in Barcelona [122] and thermo-active structural solutions at the Sant Antoni Market [123], [124], both demonstrating advanced integration of building-services technologies within protected heritage contexts. Conservation assessments generally emphasise visual impact, material compatibility, and reversibility, in line with international heritage doctrine.

2.27 Sweden

In Sweden, heritage protection is implemented by the County Administrative Boards under national guidance from Riksantikvarieämbetet, which explicitly recognises the need to balance energy efficiency with the preservation of cultural heritage values. Conservation assessments require detailed documentation of impacts on historic fabric and visual character, and interventions are evaluated on a case-by-case basis. Sweden has extensive experience with ground-source heating and other low-carbon systems in historic public and industrial buildings. National research and innovation programmes supported by the Swedish Energy Agency further promote knowledge exchange between heritage professionals and energy engineers [125], [126]

3. SOLUTIONS IDENTIFIED IN OTHER RESEARCH

POCITYF: Community Solar Farm (CSF) for Évora's UNESCO Historic Centre [127], [128]

Évora's walled medieval centre is a designated UNESCO World Heritage Site with highly restrictive conservation rules that prohibit visible modern energy installations on most roofs. According to the POCITYF project documentation, the municipality cannot place photovoltaic systems on heritage buildings within the perimeter of the old town because such elements would alter the character and silhouette protected under national and UNESCO guidelines. This regulatory constraint means the city must pursue Positive Energy District goals without rooftop PV in the urban core, making Évora a representative case of how heritage restrictions shape decarbonisation pathways.

To address this limitation, Évora partnered with POCITYF to create a Community Solar Farm (CSF) located outside the protected area. The CSF is explicitly described in the project deliverables as being implemented through Portugal's Decree-Law 162/2019, which enables Renewable Energy Communities (RECs) and collective self-consumption models. Under this legal arrangement, electricity generated on land outside the walls can be allocated virtually to participating consumers inside the historic centre. This is done through smart metering and regulated crediting mechanisms that allow consumption and generation to be shared among community members.

While the project materials do not specify the exact capacity or layout of the solar plant, they state clearly that the CSF is structured as a shared PV installation whose output can be divided among municipal buildings and private consumers located within the UNESCO zone. The allocation follows the REC rules, enabling each user to receive a proportional share of generation as if the PV were installed on their own premises. This makes it possible for the city to increase renewable electricity penetration in buildings where heritage authorities forbid rooftop or façade interventions. The municipal administration positions the CSF as a cornerstone for decarbonising the protected core.

The Community Solar Farm is explicitly highlighted in POCITYF's documentation as a replicable strategy for historic cities facing similar restrictions. It demonstrates how positive-energy goals can be met through off-site, non-visible generation combined with energy-sharing mechanisms, thus avoiding visual impacts on sensitive cultural landscapes. This model is presented as a way to ensure that heritage conservation and renewable energy deployment are not in conflict, providing a template where legal, social, and technical measures are integrated to preserve authenticity while enabling climate transition. The project notes that this approach could inform national-level policy adjustments for other UNESCO sites.

POCITYF: Renewable Energy Community (REC) of Municipal Buildings in Évora's Historic Centre [129], [130]

Within the UNESCO-protected centre of Évora, the POCITYF project established a Renewable Energy Community (REC) composed of ten municipal buildings situated inside the historic perimeter. Because rooftop PV installations are generally prohibited on protected structures, the project focuses on energy optimisation, flexibility measures, and storage rather than on-site generation. According to the project description, the intention is to improve self-consumption, reduce energy costs, and facilitate energy sharing among public buildings while adhering to strict heritage rules. The REC is therefore conceived as a functional Positive Energy Block operating primarily through energy management rather than new RES capacity within the sensitive heritage envelope.

The documentation explicitly states that energy routers equipped with batteries were installed across these ten municipal buildings. These devices enable coordinated operation, load management, and real-time control of energy flows between the buildings. In addition, the historic centre was equipped with smart lamp posts that integrate LED lighting, electric vehicle charging, and telecommunications hardware, forming multifunctional urban elements. These lamp posts support efficient lighting while also enabling distributed EV charging within the heritage zone, using existing urban infrastructure without altering façades. All interventions were designed to be reversible, modular, and visually consistent with the protected area.

The REC includes a charging management platform for electric vehicles, which is designed to schedule charging according to local solar production (from outside the walls), user-defined constraints, and grid conditions. This system supports smart charging and is capable of handling bi-directional power flows with the ability for V2G (vehicle-to-grid) operation. Such functionality allows EVs parked within the historic centre to serve as mobile storage units that can support the local low-voltage grid. The platform integrates both operational data and consumption patterns, allowing users to manage charging events while ensuring compatibility with grid constraints and heritage-related restrictions on physical modifications to buildings.

POCITYF presents this REC as a demonstrative model for heritage cities where intrusive energy retrofits are limited. By focusing on operational optimisation, shared resources, digitalisation, and non-invasive charging infrastructure, the project shows how a cluster of protected buildings can move toward PED principles despite the absence of visible RES on building envelopes. The emphasis on flexibility tools, small-scale storage, and the shared management of energy demand demonstrates that significant carbon reductions can be achieved without compromising architectural authenticity. The Évora REC is framed as a replicable solution for municipalities facing similar constraints in protected urban cores.

POCITYF / Évora: Solar “Invisible Tiles” on the 15th-Century Palace of the Counts of Sortelha [131]

The Palace of the Counts of Sortelha, located within the historic centre of Évora, is a 15th-century structure identified as lying inside the area protected under the UNESCO World Heritage designation. Heritage restrictions in this zone generally prohibit the installation of conventional photovoltaic modules on roofs because such interventions would disrupt the appearance and material authenticity of the medieval-Renaissance urban fabric. The palace is therefore a representative case of a building where renewable energy integration is extremely limited by conservation criteria. The project documentation and local reporting emphasise that Évora’s heritage authorities require any energy intervention to be visually indistinguishable from the historic roofing materials.

In this context, the city implemented a system composed of approximately 3,350 solar tiles, designed to replicate the appearance of traditional clay roofing. According to the project news release, these tiles are made from recyclable resin and were engineered specifically to mimic the visual and material characteristics expected by the heritage authority, while still generating electricity. The total installed capacity is reported as around 25 kW, making the palace one of the first heritage buildings in Évora to incorporate electricity-generating roofing elements without altering the historical silhouette. The installation was completed in early 2024 and is presented as a flagship demonstration within the POCITYF framework.

The tiles function simultaneously as weather-protective roofing elements and photovoltaic generators, which eliminates the need for mounting structures or visible panels. Their resin-based construction enables fine colour and texture matching, which was central to securing approval from the regional heritage authorities. The published information emphasises that the visual integration was a decisive factor in permitting the installation, as the palace roofline remains consistent with its historic appearance. Although detailed performance metrics are not provided in the release, the system is described as being capable of harnessing solar energy in a way that preserves the integrity of the monument. This dual compliance - technical functionality and aesthetic neutrality - underpins the project’s acceptance.

The solar-tile installation is presented by Évora and POCITYF as a breakthrough solution for deploying renewable energy in areas with very high heritage sensitivity. It demonstrates that photovoltaic systems can be introduced on protected monuments when designed to be indistinguishable from original materials. Because the palace is within the strictest conservation zone, the approval of this intervention establishes an important precedent for the city and for other European heritage sites facing similar challenges. The official reporting frames the project as an example of how photovoltaic integration can occur without compromising architectural authenticity, thereby offering a replicable path for historic-city decarbonisation where conventional PV is not permissible.

Alfama (Lisbon): Historic District PED Model (Frontiers in Sustainable Cities) [133]

The Alfama district in Lisbon is described in the cited study as a dense historic neighbourhood characterised by narrow medieval streets, traditional housing, and a valuable architectural identity. The paper emphasises that Alfama faces significant constraints when considering renewable energy deployment, particularly due to its cultural and architectural heritage, strong public attachment to the neighbourhood's visual character, and local topographic limitations. These factors make conventional solar photovoltaics difficult to implement without negatively affecting the district's appearance. The study frames Alfama as an ideal example of a historic quarter where decarbonisation must be achieved while respecting visual integrity and morphological constraints.

The study undertakes a detailed analysis of Alfama's heterogeneous building stock, noting different typologies with varying orientations, roof geometries, and envelope conditions. It evaluates the potential for energy retrofit measures, including insulation of exterior walls and roofs and the replacement of windows with improved thermal performance. These interventions are quantified to estimate their impact on energy demand across the district. The authors stress that while thermal improvements are technically feasible, heritage sensitivity requires that such retrofits remain consistent with the district's architectural features, and thus the modelling accounts for solutions that do not alter protected façades.

A central component of the Alfama PED model is the evaluation of ten photovoltaic technologies suitable for historic settings: eight rooftop PV technologies and two solar-window technologies. The study explicitly states that these options include building-integrated PV (BIPV) and solar tile solutions, which were assessed for their applicability within a historic district. The evaluation considers multiple criteria: visual compatibility, energy generation potential, installation feasibility, and levelised cost of energy (LCOE). Based on these metrics, the authors identify the "best technology" for rooftop applications and the "best technology" for window applications, selecting the options offering the most favourable balance between historic-district applicability, energy yield, and economic performance.

The authors present the Alfama model as a template for developing Positive Energy Districts in heritage contexts. Rather than focusing solely on maximising generation, the study prioritises compatibility with historic morphology, public acceptability, and architectural preservation. The conclusions highlight that the methodology - combining retrofit potential, PV-technology benchmarking, and district-scale energy modelling - provides a structured decision-making tool for historic neighbourhoods where conventional renewable installations are restricted. The paper is cited in POCITYF documentation as a reference for understanding how heritage-compatible PV and deep retrofits can contribute to PED strategies in culturally sensitive environments.

+CityxChange: Limerick Distributed Positive Energy Block (DPEB) [134]

Limerick's demonstration area in +CityxChange is centred around its historic Georgian core, which includes formally protected buildings and a conserved urban layout. The Smart Cities Marketplace description notes that the area presents heritage-related limitations that prevent heavy structural interventions or extensive modifications to building envelopes. Because of these constraints, the project adopted the concept of a Distributed Positive Energy Block (DPEB) - a spatially discontiguous block of buildings that collectively balance energy production and consumption without needing to be physically adjacent. This model allows the district to achieve PED characteristics even though many buildings in the Georgian centre cannot host on-site renewable installations.

The Limerick DPEB incorporates a mix of energy carriers, including solar thermal energy, hydropower, waste heat, biogas, ambient air, district heat, and green electricity, according to the Smart Cities Marketplace project page. Importantly, the project highlights the development of tidal turbines in the River Shannon as a key renewable source supporting the energy balance of the DPEB, with GKinetic technologies displayed as part of a public demonstration about future renewable energy on the estuary. Because many buildings in the Georgian area cannot accommodate rooftop PV, the project relies heavily on external renewables - particularly tidal energy - to achieve the positive energy balance across the distributed block.

Although large-scale PV deployment is limited in the Georgian core, the project documentation cites specific examples of solar PV installations on suitable buildings: St Michael's Rowing Club and St John's Band Hall. These sites serve as local demonstrators of renewable generation within the historic district's influence area. To enable energy-sharing and collective operation across the DPEB, the project introduced Smart Link Units (SLUs) in key buildings, which provide real-time electrical data to support community-grid modelling and potential peer-to-peer energy trading. The Smart Cities Marketplace description identifies the SLUs as a foundational component of establishing a functional local energy community in Limerick.

A University of Limerick article adds that approximately 30 "smart energy champions" in the historic core are expected to adopt new clean-energy technologies as the programme expands, including photovoltaic cells, wind turbines, and tidal turbine participation. This information reinforces the project's emphasis on integrating a diverse set of renewables, particularly where architectural constraints limit traditional rooftop solutions. Because regulatory structures in Ireland prevent the immediate creation of a physically isolated microgrid, the DPEB operates as a virtual community grid, allowing energy coordination without needing to reshape the existing distribution network. Together, these approaches demonstrate how +CityxChange positions Limerick as a model for combining heritage preservation with multi-source renewable integration.

Best practices identified during project were shared with all partners across Europe (from Ireland, Norway, Czech Republic, Spain, Bulgaria, Estonia, Italy, Netherlands, Denmark and Romania), in Alba Iulia being organized a Climathon for generating ideas used in defining local strategies for achieving city objectives related to energy and emissions.

SPARCS Leipzig: Baumwollspinnerei (Heritage Industrial Complex) [135]

The Baumwollspinnerei is introduced on the SPARCS Leipzig project page as a redeveloped industrial site dating from 1884, identified as protected premises and now functioning as a centre for cultural activities. The site consists of several large factory buildings that have been converted into exhibition spaces, artist studios, and creative industries. This historically protected status, combined with its active contemporary use, makes the Baumwollspinnerei a significant demonstration environment for SPARCS. The project views the site as an opportunity to implement energy innovations while maintaining the architectural character and cultural function of the former cotton mill.

The SPARCS documentation states that the Baumwollspinnerei demonstration includes the installation of photovoltaic panels on the roof of building 7 or 11. These PV arrays are complemented by a battery storage system, forming a localised energy-generation and storage node within the protected complex. The project also highlights the conversion of a former petrol station roof into a solar PV carport, representing a reuse of a non-heritage structure to support renewable-energy generation. These installations are part of the broader microgrid that integrates the site into Leipzig's renewable energy strategy. The use of roof-mounted PV and secondary-structure PV is presented as compatible with the heritage constraints of the complex.

According to the project description, the Baumwollspinnerei buildings participate in a local microgrid that incorporates multiple elements: a CHP unit, PV systems, battery storage, and a bidirectional EV charging station. The bidirectional charging capability allows electric vehicles to support the microgrid by providing stabilisation and flexibility services. The documentation further notes that the site makes use of a building's old walls as thermal storage, allowing heating systems to exploit the thermal inertia of the historic structures. This approach reduces energy fluctuations and increases the efficiency of heating control without altering the building's architectural surfaces.

The SPARCS page describes the Baumwollspinnerei as a 9,000 m innovation quarter at the centre of local energy transformation efforts. It emphasises that additional nearby areas could be included in subsequent replication phases, enabling an expanded demonstration of renewable systems linked to the heritage complex. The project positions the site as a model for integrating distributed energy resources and smart-grid technologies in historic industrial environments. Its combination of PV, battery storage, CHP operation, thermal-mass utilisation, and EV flexibility is presented as a replicable strategy for other cities seeking to preserve heritage while modernising energy infrastructure.

SPARCS Leipzig: Leipzig-West / Duncker-Neighbourhood (Historic & Social Housing Context) [136]

The SPARCS project page describes Leipzig-West, specifically the Duncker-Neighbourhood, as an area characterised by historic building stock that also includes substantial social housing. The neighbourhood is supplied by the district heating network and features a high proportion of residential buildings that are not easily modified due to architectural or socioeconomic constraints. The project identifies this area as an important demonstration environment where energy transition measures must be compatible with both the heritage value and the socially sensitive housing context. The combination of old buildings and vulnerable tenants requires solutions that avoid invasive retrofit strategies while still contributing to Leipzig's carbon-reduction goals.

A central innovation in Leipzig-West is the use of a large-scale solar thermal plant located in Leipzig-Lausen that feeds heat into the district heating system which supplies the neighbourhood. The SPARCS description states that this system supports a more sustainable heat demand and reduces reliance on conventional fuel sources. By integrating solar thermal energy at the district level rather than at individual building level, the project provides a renewable-heat solution that does not require any modifications to historic façades or roofs. This approach allows the neighbourhood to benefit from renewable heat without altering architecturally sensitive buildings.

The project reports that approximately 300 apartments in the Duncker-Neighbourhood are equipped with smart heat meters. These meters are linked to human-centric demand-response programmes, which aim to optimise residents' heat consumption by adjusting thermal profiles in response to user needs and tariff signals. This strategy is important in a historic and socially diverse district because it improves energy efficiency without requiring deep retrofits or visible changes to protected structures. The SPARCS page highlights that smart metering enables tenants to benefit directly from renewable district heating, particularly solar thermal energy, while maintaining affordability and comfort.

According to the SPARCS description, the Leipzig-West demonstration supports the broader municipal strategy of decarbonising district heating and ensuring that vulnerable communities are not excluded from the benefits of the energy transition. The Duncker-Neighbourhood serves as a model for how historic residential areas can participate in Positive Energy District strategies through centralised renewable heat, smart measurements, and behavioural optimisation rather than intrusive fabric renovation. This case illustrates that meaningful carbon reductions in heritage-relevant urban districts can be achieved by upgrading the energy infrastructure around the buildings rather than on them, offering a replicable pathway for cities facing similar constraints.¨

EXCESS: Renaissance Palace in Valladolid (16th-Century Protected Building) [137]

The EXCESS project presents the Valladolid Renaissance Palace as one of its four Positive Energy Building (PEB) demonstration sites. The building is described as a 16th-century palace located in the historic centre of Valladolid, with its façade and architectural character protected under regional heritage rules. Because the façade could not be altered, all energy-related upgrades were required to respect strict conservation criteria. The project identifies this palace as a showcase for achieving a PEB standard in a protected historical structure, demonstrating how renewable energy and advanced building technologies can be introduced without compromising architectural authenticity.

According to the project documentation, the palace incorporates a combination of photovoltaic (PV) modules on the roof and photovoltaic-thermal (PVT) collectors dedicated to the production of domestic hot water (DHW). The PV installation supplies electricity to the building and also powers two electric-vehicle charging stations located on-site. The EXCESS materials emphasise that these installations were designed to remain non-visible from key viewpoints in order to comply with the heritage requirements. The preserved external appearance of the palace, particularly its Renaissance façade, is highlighted as a central constraint that guided the placement and integration of the RES technologies.

The Valladolid pilot is equipped with a 40 kW heat pump that provides heating and cooling to the building. To support flexibility and ensure continuity of supply, the system also includes a 60 kWh lithium-ion battery. Ventilation is managed through a combination of natural and mechanical systems, with heat recovery ventilation implemented to improve efficiency while remaining compatible with the preserved façade. The building's energy systems are monitored and coordinated through a Building Energy Management System (BEMS), which enables advanced control of generation, consumption, and storage. The EXCESS documentation emphasises that this digital layer is essential for ensuring that the building maintains its PEB performance over time.

A distinctive feature of the Valladolid demonstration is the inclusion of energy-sharing and trading functions based on smart contracts. These digital tools allow the palace to interact with the local energy ecosystem and exchange energy within a community framework, demonstrating how heritage buildings can participate in advanced market models. The project positions the palace as a replicable example for cities seeking to raise the energy performance of protected buildings: by combining roof-mounted RES on non-visible surfaces, internal envelope improvements, smart controls, and storage, it is possible to meet PEB criteria without modifying a legally protected exterior. The Valladolid case is therefore presented as a successful demonstration of achieving high-performance energy objectives within strict conservation regimes.

EXCESS: Tagger-Werk, Graz (Industrial Heritage Redevelopment) [138]

The EXCESS project page describes the Tagger-Werk site in Graz as a former industrial area undergoing redevelopment, where one of the demonstration buildings is a historic feed-silo structure converted into a student hostel. The site consists of 19 buildings, with a combined floor area of about 73,000 m, representing a typical industrial-heritage complex. Although the materials do not explicitly classify the silo or surrounding structures as legally protected monuments, the project clearly frames the area as a historic industrial environment that requires careful integration of energy technologies, making it a suitable location for testing approaches applicable to heritage-sensitive brownfield sites.

A defining feature of the Tagger-Werk demonstration is the installation of a prefabricated multifunctional façade equipped with integrated photovoltaic modules and component activation. The EXCESS documentation states that the façade was designed to work jointly with the existing building structure, using it as a “main thermal storage medium.” This means that the façade system both improves the thermal performance of the building envelope and generates renewable electricity through its integrated PV surfaces. The system also provides heating and cooling at low temperature levels, enabled by the activated building components that distribute energy efficiently throughout the structure.

According to the project description, the energy system at Tagger-Werk combines the multifunctional façade with a cascadic heat-pump system designed to deliver heating and cooling. The documentation specifies that this setup takes advantage of the building’s thermal inertia and allows efficient operation in combination with the façade elements. The broader local energy mix for the demonstration area is based on solar energy, groundwater heat pumps, and small hydropower, forming a diversified renewable supply. In addition, the system incorporates water storage tanks and batteries to support flexibility, balancing the renewable inputs and enabling continuous service under fluctuating production conditions.

The EXCESS project page emphasises the use of smart predictive control for managing the façade-integrated energy system, the heat pumps, the water tanks, and the battery storage. This control strategy is designed to interact with external markets, enabling the building to participate in demand-response and other flexibility services through collaboration with energy aggregators. These capabilities allow the Tagger-Werk demonstration to contribute to grid stability and efficient energy use beyond the boundaries of the individual building. The combination of prefabricated façade elements, renewable-energy integration, intelligent control, and participation in flexibility markets positions Tagger-Werk as a replicable model for industrial-heritage sites seeking to achieve PEB or PED-aligned performance without compromising their structural character.

+CityxChange Limerick: St Michael’s Rowing Club & St John’s Band Hall (Local Solar PV Demonstrators) [139]

The +CityxChange project identifies St Michael’s Rowing Club and St John’s Band Hall as two of the key buildings within Limerick’s demonstration area that have been fitted with solar photovoltaic (PV) installations. These buildings are situated within the wider historic Limerick city centre, which includes the Georgian core and surrounding heritage-influenced urban fabric. Because many protected Georgian structures cannot accommodate visible rooftop PV, these two buildings serve as practical, permissible sites for demonstrating local renewable generation within the energy community. The Smart Cities Marketplace page highlights them explicitly as examples of on-site renewable-energy implementation.

The project documentation lists the Rowing Club and Band Hall as solar PV demonstrators, but does not specify panel types, capacity, or system size. Their importance lies in the fact that they are among the few buildings in the demonstration area suitable for PV, due to heritage constraints on many surrounding structures. These two installations therefore contribute part of the local renewable generation feeding into the Distributed Positive Energy Block (DPEB) model used in Limerick. The presence of PV at these sites provides operational data for energy modelling, monitoring, and future planning of local energy communities.

Both buildings are integrated into the local energy community framework developed by +CityxChange. Although the project documentation does not detail the electrical configuration of each building, it states that Smart Link Units (SLUs) are used in the demonstration area to gather real-time electrical data and support community-grid modelling. These SLUs enable consumption and generation patterns from sites such as the Rowing Club and Band Hall to inform the development of peer-to-peer energy exchanges and virtual community-grid functionality. As such, even modest PV installations on these buildings contribute to the data and operational layers essential for establishing a functioning Renewable Energy Community in Limerick.

The inclusion of St Michael’s Rowing Club and St John’s Band Hall as PV demonstrators highlights how heritage-adjacent buildings can play a pivotal role in enabling renewable generation when protected structures cannot host visible technologies. These demonstrators show how +CityxChange leverages selected, non-protected buildings within a historic area to provide on-site RES contributions while respecting conservation constraints in the Georgian core. Their integration into the DPEB illustrates how even a small number of suitable renewable-generation sites can support broader district-level decarbonisation strategies. This approach is presented as an important component of creating a positive-energy district in a heritage-sensitive urban context.

+CityxChange Limerick: Planned Small Wind Turbines in the Georgian Core [140]

The University of Limerick article describing Limerick's participation in the +CityxChange project explains that the city's demonstration area includes a portion of the historic Georgian core, characterised by protected architectural structures and a conserved urban layout. This area imposes limits on building-integrated renewable energy, especially rooftop solutions such as PV panels, because of the strict requirements for visual preservation. As a result, the city must explore alternative renewable-energy options that do not conflict with the heritage considerations governing the Georgian streetscape. The article frames these constraints as motivating a search for diversified, small-scale, and culturally acceptable sources of clean energy.

According to the same source, approximately 30 "smart energy champions" - local building owners or organisations participating in the project - are expected to adopt a set of clean-energy technologies as part of the ongoing transition process. The article explicitly lists the technologies these participants are likely to implement: photovoltaic cells, wind turbines, and participation in tidal energy solutions via the Shannon River turbines. This confirms that the project envisions small wind turbines as part of the renewable-energy mix within or around the Georgian core, alongside PV and tidal energy contributions. The inclusion of wind reflects a multi-technology approach, broadening the portfolio of decentralised RES options available to local actors.

The article does not specify the number, size, placement, or model of the planned wind turbines. However, by listing them directly alongside rooftop PV and tidal energy as technologies to be adopted by energy champions, the source confirms that wind energy is part of the intended PED development pathway for the Georgian core. This is notable because small wind turbines are rarely referenced in the context of historic European urban districts, where visual and noise concerns often limit their application. The reference indicates that +CityxChange anticipates at least some degree of wind-energy deployment in areas influenced by heritage constraints, supported by participants who voluntarily integrate these technologies into their buildings or properties.

The explicit mention of wind turbines in the University of Limerick article positions Limerick's Georgian core as one of the few documented European heritage environments in which small wind generation is considered as part of a PED strategy. Their inclusion highlights the city's intent to diversify renewable sources beyond roof-based and façade-based options, which are often restricted by conservation guidelines. When combined with tidal energy and selective PV installations, wind turbines form part of a broader portfolio designed to minimise the pressure on protected building envelopes. The article's identification of these technologies demonstrates that +CityxChange is exploring heritage-compatible, unobtrusive, and distributed renewable-energy options that align with the preservation requirements of the Georgian architectural landscape.

+CityxChange Limerick: Tidal Turbine Deployment in the River Shannon [141]

The +CityxChange project identifies tidal energy as one of the key renewable sources supporting the development of the Distributed Positive Energy Block (DPEB) in Limerick. According to the Smart Cities Marketplace description, GKinetic tidal turbines are being developed for installation in the River Shannon, adjacent to the central urban area. These turbines are highlighted as a forward-looking renewable-energy solution that can contribute power to the DPEB, particularly given the constraints that limit rooftop PV deployment in the heritage-rich Georgian core. The documentation underlines tidal energy as part of the city's long-term strategy for transitioning to a low-carbon energy system.

The same source reports that GKinetic tidal turbine technology was showcased in Limerick's Climate Action Plan public exhibition, demonstrating how tidal energy could become a prominent renewable source for the city over the coming decades. This exhibit served to familiarise local stakeholders and residents with the technology and to illustrate its potential integration within the city's Clean Energy District. By presenting tidal energy in a public-facing format, +CityxChange positions the technology not only as an engineering intervention but also as a tool for shaping civic understanding of renewable-energy futures.

The project description mentions that installation of the GKinetic turbines is subject to obtaining a foreshore licence, a regulatory requirement for developments in Irish coastal and riverine environments. This indicates that the tidal deployment had not yet been completed at the time of the project page's publication, but was actively being pursued. The explicit reference to licensing underscores that tidal energy within an urban centre must pass through a structured approval process, aligning environmental, urban, and energy planning requirements. The project documentation notes the turbines' planned placement within the Shannon as part of Limerick's long-term renewable-energy vision.

The inclusion of tidal turbines in the DPEB model demonstrates an alternative pathway for energy generation in a historic urban district where rooftop-based solutions are limited by conservation rules. Tidal energy operates entirely outside the architectural envelope and therefore avoids visual conflicts with heritage protection in the Georgian core. The +CityxChange documentation presents tidal energy as part of a diversified mix of renewable sources - alongside solar installations on selected buildings and planned small wind turbines - that can collectively support a PED strategy. In this way, the Shannon tidal turbine initiative serves as a significant example of how heritage cities can integrate large-scale renewable resources without compromising protected structures.

International Heritage Guidelines Referenced in POCITYF: Solar PV, BIPV, and Solar-Thermal Compatibility [142]

In its analysis of renewable energy integration in the Historic Centre of Évora, the POCITYF research paper references several international heritage guideline frameworks as examples of how different countries approach the compatibility of renewable energy systems with protected buildings. These include guidance documents from Scotland (2009), Historic Environment Scotland (HES, 2014), the U.S. National Renewable Energy Laboratory (NREL, 2011), the Austrian Bundesdenkmalamt (BDA), the Italian Ministry for Cultural Heritage and Activities (MiBACT), and multiple Swiss federal and cantonal authorities. The paper explicitly cites these as representative of established policies that define the acceptable use of photovoltaic and solar-thermal technologies in historic architectural contexts.

Across the referenced guidelines, the paper notes that several sets of regulations explicitly identify photovoltaic (PV) systems, building-integrated photovoltaics (BIPV), solar-thermal collectors, and building-integrated solar thermal systems (BIST) as technologies that can be compatible with historic buildings under certain conditions. These conditions generally concern visual impact, material integration, reversibility, and minimal interference with historic character-defining elements. The Évora paper presents these technologies as examples of renewable systems that heritage authorities outside Portugal have deemed permissible when they are carefully integrated and designed to respect architectural authenticity.

The heritage guidelines cited in the POCITYF document emphasise the importance of aesthetic and technical integration, requiring that renewable-energy systems be fitted in ways that minimise visual intrusion. The Swiss guidelines, for example, are described as including detailed handbooks on integrating PV, BIPV, solar thermal, and BIST systems in both historic and modern buildings, with a strong focus on visual coherence and material compatibility. Similarly, NREL's U.S. guidelines are referenced for balancing the preservation of historic appearance with the deployment of solar technologies, outlining methods for choosing installation locations and technologies that align with conservation requirements. These guidelines collectively highlight the need for renewable-energy installations to remain subordinate to the architectural values of protected structures.

The Évora paper cites these international guidelines specifically to demonstrate that renewable energy and heritage protection are not inherently incompatible. Instead, they require a structured framework based on integration principles already recognised in several countries. By compiling these references, the POCITYF study positions them as exemplary best-practice frameworks that can support decision-making in UNESCO cities or other heritage contexts. Their inclusion in the research underlines that PV, BIPV, solar thermal, and BIST have established precedents in heritage management, providing a validated foundation for designing Positive Energy District solutions in protected urban areas. This body of guidance is presented as an important comparative reference for shaping Évora's local approach.

POCITYF Évora: Smart Lamp Posts with Integrated EV Charging in the Historic Centre [143]

The POCITYF project documentation identifies smart lamp posts as one of the key interventions deployed inside Évora's historic centre, which lies entirely within a UNESCO World Heritage zone. Because this area is subject to strict conservation rules that severely limit changes to façades and rooftops, the project sought ways to introduce new energy-related services through non-invasive urban elements. The smart lamp posts provide an opportunity to deliver modern energy infrastructure without altering protected architectural surfaces. Their multifunctional design allows them to support EV charging, efficient lighting, and telecommunications in a compact form while remaining visually aligned with existing street-furniture typologies.

According to the POCITYF Évora description, each smart lamp post integrates high-efficiency LED public lighting, electric-vehicle charging, and telecommunications hardware such as 4G/5G and Wi-Fi connectivity. These elements are physically combined into a single vertical structure, reducing the need for separate installations throughout the protected district. By concentrating multiple utilities into a single street fixture, the lamp posts achieve infrastructure modernisation without increasing visual clutter. The documentation emphasises that this multifunctionality is central to their acceptance in the historic centre, where the introduction of new standalone technical equipment is strongly restricted.

The project page notes that the EV-charging function of the smart lamp posts is linked to a broader charging-management platform capable of implementing smart-charging strategies. This platform coordinates charging sessions according to local renewable-energy availability, user constraints, and low-voltage grid conditions. It is also designed to manage bidirectional power flows, enabling the potential for vehicle-to-grid (V2G) interaction. The smart lamp posts, therefore, are not isolated charging points but components of Évora's wider energy-management ecosystem, supporting flexibility services that help reduce peak loads in the UNESCO centre while maintaining compliance with heritage-preservation requirements.

POCITYF presents these smart lamp posts as a heritage-compatible pathway for introducing modern energy infrastructure into protected city centres. Because the structures replace or enhance existing public-lighting poles rather than altering building envelopes, they offer a method for adding energy services with minimal visual impact. They also provide a platform for multiple smart-city functions, reducing the need for intrusive retrofits on historic buildings. The project documentation highlights them as an example of how distributed energy solutions, EV integration, and digital services can be implemented inside UNESCO areas using reversible, modular, and visually neutral interventions. This approach demonstrates how PED-aligned technologies can be successfully deployed in sensitive cultural-heritage contexts.

POCITYF Évora: Energy Routers and Battery Systems in Ten Municipal Buildings [144]

The POCITYF project identifies a cluster of ten municipal buildings within Évora's UNESCO World Heritage historic centre as the core of a Renewable Energy Community (REC). These buildings form a functional Positive Energy Block (PEB), even though heritage restrictions prevent the installation of rooftop PV or visible renewable-energy systems on their envelopes. As such, the focus within these buildings is on optimising internal energy flows, storage, and flexibility, rather than introducing additional on-site generation. The documentation positions these municipal buildings as essential assets for demonstrating how public-sector properties in protected zones can contribute to Positive Energy District goals despite strict conservation conditions.

According to the POCITYF description, each of the ten municipal buildings was equipped with energy routers that incorporate battery storage. These devices allow buildings to manage their consumption patterns more effectively and to coordinate energy usage at block level. The routers can store surplus electricity - primarily originating from renewable sources located outside the historic core, such as the Community Solar Farm - and release it when required to improve self-consumption rates. The documentation highlights that these energy routers serve as the operational backbone of the municipal REC, enabling advanced control and load-balancing capabilities that are especially important in heritage areas where physical modifications are limited.

The project notes that these devices help "improve self-consumption and reduce costs," forming a shared operational layer that interconnects the protected buildings. The routers' ability to communicate and coordinate allows the municipal buildings to behave as a collective system rather than isolated energy consumers. This is essential to Évora's strategy, because the absence of visible PV inside the UNESCO zone requires the REC to rely heavily on digital energy management, rather than on local generation. Through these routers and batteries, municipal buildings can participate in load-shifting, smoothing consumption peaks, and preparing for future integration with electric mobility solutions deployed in the historic centre, such as smart lamp posts and EV charging.

POCITYF presents this intervention as a prime example of how cities with highly protected architectural environments can still implement PED principles. By concentrating on behind-the-meter technologies, internal storage, and building-level intelligence, the project demonstrates that significant improvements in local energy performance can be achieved without modifying external architectural features. The energy routers and batteries are fully contained within existing buildings, ensuring full compliance with UNESCO conservation rules. The project documentation frames this strategy as replicable for other European historic centres, showing that PED development does not require extensive visible RES installations if flexibility, storage, and coordinated management are intelligently deployed.

EXCESS Valladolid: Smart Contracts and Energy Sharing in a Protected Renaissance Palace [145]

The EXCESS documentation on the Valladolid Renaissance palace identifies digitalisation as a central pillar supporting the building's transformation into a Positive Energy Building (PEB). According to the project description, the palace uses an integrated Building Energy Management System (BEMS) that coordinates renewable generation, storage, and consumption across the building. This system monitors the performance of the heat pump, rooftop PV installation, PVT collectors, battery storage, and ventilation systems. The EXCESS page emphasises that this digital layer is essential for maintaining the palace's PEB status while adhering to its heritage restrictions, which require the building's historic façade to remain unaltered.

The EXCESS project explicitly states that the Valladolid palace incorporates "energy sharing" features supported by digital management tools. These allow the building to interact with a local energy ecosystem, meaning that surplus electricity generated on the palace's roof - primarily from the PV system - can be shared within the community under defined operational rules. This positions the palace not as an isolated renewable-energy site but as a participant in a broader energy network, where sharing mechanisms help distribute renewable electricity and enhance local flexibility. The project description notes that this is facilitated through the BEMS, which allocates flows based on real-time data.

A distinctive feature of the Valladolid demonstration is the incorporation of smart contracts to enable energy trading. The EXCESS page states that these smart contracts are used for "energy management" and allow interactions between the palace and other market actors based on predefined rules. Such contracts automate and secure the exchange of energy or flexibility services, providing transparent, rule-based transactions. This approach demonstrates how protected heritage buildings can still participate in advanced energy-market mechanisms without requiring visual modifications to the building envelope. The system forms part of the digital architecture that connects the building to the surrounding energy community.

The Valladolid palace serves as a rare example of a heritage-protected building integrating smart contracts, energy sharing, and digital market participation as part of its renewable-energy strategy. The EXCESS documentation highlights that these features are essential for achieving PEB performance in a context where alterations to the façade or external structure are not allowed. Because digital systems operate entirely within the building and through software-based rules, they offer a non-invasive method for unlocking PED-level performance. The project positions this combination of smart contracts and energy sharing as a replicable model for other protected historical buildings seeking to join local energy communities without compromising their architectural integrity.

EXCESS Tagger-Werk: Participation in Flexibility Markets [145]

The EXCESS project page for the Tagger-Werk demonstration in Graz explicitly highlights the role of smart predictive control in managing the various energy subsystems deployed in the building. This predictive control system interacts with the façade-integrated photovoltaics, the cascaded heat-pump system, the water-storage tanks, and the battery storage. The project documentation frames predictive control as a key function that enables the building to operate efficiently by forecasting energy needs and renewable-generation patterns. It ensures that the building can optimise internal energy flows before interacting with the external grid or local energy community.

According to the EXCESS description, the Tagger-Werk system is designed to enable participation in flexibility services in collaboration with aggregators. These aggregators coordinate groups of distributed flexible assets and allow buildings like the Tagger-Werk demonstration to offer demand-response capabilities or other flexibility contributions to the energy system. The EXCESS page explicitly states that the building uses predictive control not only to optimise internal operation but also to contribute flexibility to the wider grid, with the help of these aggregator frameworks. This is presented as an integral part of the building's energy strategy.

The EXCESS project states that the Tagger-Werk demonstration incorporates water tanks and battery storage in its energy system. These components are actively managed through predictive control to support flexibility operations. Water-based thermal storage and electrical batteries allow the building to adjust when it consumes or supplies energy, which is essential for its ability to engage in flexibility markets via aggregators. The documentation highlights that this combination of storage technologies - coordinated digitally - supports the building in providing both thermal and electrical flexibility in response to system needs.

The EXCESS page positions Tagger-Werk as a relevant example of how industrial-heritage buildings can integrate into advanced energy-market structures without altering their architectural identity. The flexibility-market participation described in the project documentation operates entirely through digital and operational means, avoiding the need for intrusive modifications to the building envelope. By embedding predictive control, storage optimisation, and aggregator-based flexibility in a historically significant industrial complex, Tagger-Werk demonstrates how heritage-sensitive sites can support grid stability and renewable-energy integration. This positions the building as a replicable model for similar brownfield or industrial-heritage redevelopments seeking to contribute to Positive Energy District goals.

SPARCS Leipzig: Bidirectional EV Charging at the Baumwollspinnerei [146]

The SPARCS project page identifies the Baumwollspinnerei, a protected industrial complex from 1884, as one of Leipzig's core demonstration sites for innovative energy solutions. Among the technologies implemented at this site, the documentation explicitly lists a bidirectional EV charging station as part of the local energy system. This charging infrastructure forms an important component of the microgrid deployed at the Baumwollspinnerei, enabling electric vehicles to interact actively with the building's energy flows. The presence of this bidirectional station also aligns with the project's broader emphasis on enhancing energy flexibility through digitalised and decentralised devices.

According to the project page, the microgrid at the Baumwollspinnerei incorporates photovoltaic installations, battery storage, and a CHP unit, all of which are coordinated to supply the demonstration buildings. The bidirectional EV charging station is integrated into this system, allowing electric vehicles to serve not only as consumers but also as potential sources of energy. This situates EVs as part of the energy-storage and flexibility architecture, complementing the fixed battery systems already installed on site. The documentation highlights that bidirectional charging supports the optimisation of the site's renewable consumption and overall system balancing.

The SPARCS description states that the local microgrid is designed to "demonstrate innovative solutions in the fields of sustainable, renewable energy systems." Within this environment, the bidirectional EV charging station provides an additional point of interaction between mobility and energy. While the project page does not detail operational strategies such as charging schedules or V2G dispatch rules, it explicitly recognises the station as an element that enables bidirectional power flows. This capability positions EVs as distributed flexibility assets that can inject power back into the microgrid when conditions require it, supporting energy stability and renewable integration.

Introducing a bidirectional charging station in a protected industrial site such as the Baumwollspinnerei demonstrates how mobility-related infrastructure can contribute to Positive Energy District strategies without altering historic building envelopes. Because charging infrastructure is typically installed in courtyards, parking areas, or non-character-defining exterior zones, it avoids visual impacts on the heritage structures. The SPARCS documentation positions this integration as an example of how transport electrification and energy flexibility can be combined in heritage-sensitive redevelopment contexts. It showcases the expanding role of EV systems as contributors to renewable-energy utilisation and local grid stability within a preserved architectural environment.

POCITYF Évora: Collective Self-Consumption (CSC) in the UNESCO Historic Centre [144]

The POCITYF project identifies Collective Self-Consumption (CSC) as one of the enabling regulatory mechanisms for renewable-energy deployment in Évora. According to the project description, CSC is implemented in Portugal under Decree-Law 162/2019, which regulates self-consumption and renewable-energy communities. This law allows multiple consumers located in different buildings to share renewable electricity produced either locally or off-site. The documentation highlights this legal framework as essential for Évora's energy strategy, because strict heritage restrictions prevent rooftop PV installations on protected buildings within the UNESCO Historic Centre. CSC therefore provides the legal foundation that makes it possible for protected consumers to benefit from solar generation situated elsewhere.

The same POCITYF source explains that Évora uses CSC to allocate solar electricity produced at its Community Solar Farm (CSF) - located outside the historic walls - to consumers inside the protected centre. Through CSC rules, electricity produced by the CSF can be assigned virtually to municipal buildings and residential participants in the historic zone. This system ensures that even buildings where PV installations are prohibited can still receive renewable energy as if it were generated on their own roofs. The documentation identifies this arrangement as a key function of the REC model implemented in Évora.

POCITYF notes that Collective Self-Consumption is directly tied to Évora's Renewable Energy Community (REC), which consists of ten municipal buildings in the historic centre. Since these buildings cannot host PV due to heritage restrictions, CSC is essential for enabling them to participate in the REC and access renewable generation from the CSF. The documentation emphasises that the REC model leverages CSC to distribute production shares among participating buildings, combining shared electricity allocation with on-site flexibility measures such as energy routers and battery storage. This creates a functioning Positive Energy Block in a zone where on-site generation is largely impossible.

According to the POCITYF materials, Collective Self-Consumption is a critical mechanism for achieving Positive Energy District (PED) goals in UNESCO areas like Évora's walled centre. Because visible renewable-energy installations are heavily restricted on heritage buildings, CSC provides a non-intrusive pathway to decarbonisation by allowing protected consumers to use renewable energy produced in visually and architecturally permissible locations. The documentation frames CSC as an example of how legal and regulatory innovation can align climate objectives with heritage preservation, enabling protected historic cores to join PED strategies without altering their architectural character.

SPARCS Leipzig: Use of Historic Walls as Thermal Storage at the Baumwollspinnerei [147]

The SPARCS project page describes the Baumwollspinnerei as a historically significant industrial complex, built in 1884 and protected as part of Leipzig's industrial heritage. The buildings are characterised by their large-scale brick construction, high thermal mass, and robust historic walls, originally designed for textile manufacturing. These structural qualities allow the complex to maintain indoor environmental stability, which the SPARCS project leverages in its demonstration of innovative energy solutions. Because of the site's protected status, interventions must respect the original architectural features, making non-invasive, structure-compatible energy strategies particularly valuable.

According to the SPARCS documentation, one of the specific innovations implemented at the Baumwollspinnerei is the use of an existing building's old walls as a thermal storage system. The project page states that the site "uses the old walls as thermal storage," highlighting that the inherent thermal properties of the massive brick construction are integrated into the building's heating strategy. This approach takes advantage of the natural thermal inertia of the historic structure, enabling the walls to absorb heat during designated periods and release it later, thereby smoothing heating demand cycles and reducing peak energy loads.

The SPARCS project integrates this thermal-storage function into the broader local microgrid, which includes photovoltaic systems, battery storage, a CHP unit, and a bidirectional EV charging station. The documentation presents the walls' thermal-storage capability as part of a coordinated energy-management strategy, complementing the electrical storage and renewable generation components. Although the SPARCS page does not provide numerical performance data, it identifies this thermal approach as one of the ways the historic building contributes to system flexibility by reducing the volatility of heating loads without requiring the installation of intrusive or visually impactful technologies.

The explicit mention of using historic brick walls as thermal storage illustrates how heritage buildings can provide energy flexibility without any visible modification to their protected façades or rooflines. The SPARCS description positions this strategy as both non-invasive and highly compatible with conservation requirements, demonstrating that the inherent physical characteristics of historic structures can support energy-decoupling strategies in a Positive Energy District. By incorporating the thermal capacity of heritage walls into modern microgrid control, the project highlights an approach that can be replicated in other industrial-heritage sites where architectural interventions are restricted but structural thermal mass is abundant.

SPARCS Leipzig: Solar PV Carport Using a Repurposed Petrol Station Roof [147]

The SPARCS project identifies the Baumwollspinnerei as a protected historic industrial site from 1884, now functioning as a cultural and creative hub. Given its protected status and architectural significance, the introduction of renewable-energy technologies in this environment requires solutions that respect both the historic character and the functional needs of the site. The project emphasises that the Baumwollspinnerei is a location where sustainable-energy measures must be carefully integrated to preserve the visual and structural integrity of the historic factory buildings. This context shapes the choice of where and how renewable-energy technologies can be installed.

According to the SPARCS documentation, the project implemented a solar PV carport by converting the roof of a former petrol station located within the Baumwollspinnerei area. The project description explicitly notes that this carport “uses the roof of a former petrol station,” demonstrating an approach that relies on reusing non-heritage or low-significance structures for renewable-energy deployment. By placing PV modules on an already-existing utilitarian roof, the intervention avoids altering the façades or rooflines of the heritage buildings themselves.

The PV carport forms part of the broader microgrid established at the Baumwollspinnerei, which also includes photovoltaic arrays on selected building roofs, battery storage, a CHP system, and a bidirectional EV charging station. While the project page does not specify the capacity or configuration of the carport, it identifies the installation as one of the renewable-generation assets supporting the demonstration. Its placement on the repurposed petrol-station structure provides a way to increase on-site renewable generation capacity without physically impacting the historic industrial architecture of the main buildings.

The solar PV carport is presented as an example of how heritage-sensitive energy innovation can be achieved by utilising non-character-defining structures within or adjacent to a protected site. By converting a former petrol-station roof - a structure that holds no architectural heritage value - SPARCS demonstrates a method of integrating solar generation that does not conflict with conservation priorities. This approach offers a model for other heritage or industrial-brownfield districts: renewable generation can be expanded through adaptive reuse of existing non-historic elements, avoiding the need for interventions on protected façades or rooftops while still contributing meaningfully to Positive Energy District objectives.

EXCESS Valladolid: Internal Façade Insulation Due to Heritage Restrictions [138]

The EXCESS project identifies the Valladolid demonstration building as a 16th-century Renaissance palace situated in the historic centre of Valladolid. The project documentation specifies that the palace's façade is legally protected, which means that no alterations could be made to the external appearance of the building. As a result, any energy-efficiency improvements had to be implemented internally, with the preservation of the exterior envelope functioning as an absolute constraint. The protected status of the façade is explicitly highlighted as the reason why conventional external insulation or exterior-mounted efficiency measures could not be applied in this demonstration.

Because the façade could not be modified, the EXCESS materials state that internal insulation was used to improve the thermal performance of the palace. This internal approach was part of a suite of renovation measures aimed at achieving a Positive Energy Building (PEB) standard. The documentation does not provide the insulation type, thickness, or material composition, but clearly identifies internal insulation as a deliberate choice resulting directly from the building's heritage protection status. It is presented as a non-invasive method for increasing energy efficiency while ensuring full compliance with conservation requirements.

The internal insulation intervention complements the building's advanced energy systems, which include rooftop photovoltaic panels, photovoltaic-thermal (PVT) collectors, a 40 kW heat pump, 60 kWh battery storage, and combined natural–mechanical ventilation with heat recovery. According to the documentation, these elements operate together through a Building Energy Management System (BEMS). By reducing heat losses through the internal side of the façade, the insulation improves the overall performance of the heat pump and the renewable-generation systems, helping the building meet the PEB performance criteria without altering its protected exterior walls.

The EXCESS project presents the internal insulation of the Valladolid palace as a key example of how deep energy renovation can be achieved in heritage-protected buildings. The case demonstrates that even where exterior modifications are entirely prohibited, it is still possible to significantly improve thermal performance through interventions inside the building envelope. EXCESS frames this solution as replicable for historic buildings across Europe that face similar constraints, showing that internal measures, combined with smart energy systems and rooftop renewables placed on non-visible surfaces, can enable high-performance outcomes in heritage contexts.

Alfama PED Model: Retrofit Measures for Walls, Roofs, and Windows in a Historic District [133]

The Alfama district in Lisbon is described in the cited study as a dense historic neighbourhood with narrow, irregular streets and architecturally valuable traditional buildings. These structures vary widely in age, orientation, and typology, forming a complex urban fabric that is heavily constrained by cultural-heritage considerations. The analysis emphasises that Alfama’s buildings have diverse thermal performances and envelope conditions, and that improving energy efficiency must be done with sensitivity to architectural preservation. The study positions the district as a representative example of the challenges faced by historic areas attempting to reduce energy use while respecting aesthetic and cultural constraints.

The study explicitly states that one component of the PED modelling includes the evaluation of retrofitting exterior walls and roofs with insulation. These measures are assessed for their potential to reduce heating and cooling demand at the district scale. The modelling work considers the thermal improvements that can be achieved through these interventions, though it acknowledges that heritage sensitivity may restrict the ability to perform such retrofits universally. The analysis incorporates these insulation measures into its baseline assessment of potential demand reduction, demonstrating how envelope upgrades would contribute to achieving a positive-energy balance if permitted by heritage authorities.

Alongside wall and roof insulation, the study identifies window replacement as an energy-efficiency measure analysed for its effect on reducing building-energy demand. The model considers the impact of new, higher-performance windows on thermal losses and solar gains across the district. Window replacement is highlighted as particularly relevant because many of Alfama’s traditional buildings suffer from poor airtightness and outdated glazing. Although the study does not prescribe specific window types, it includes window replacement in its quantitative evaluation of demand-reduction strategies that would support PED development in a historic context.

The study presents these envelope retrofit options - insulation of exterior walls, insulation of roofs, and window replacement - as part of a structured framework for reducing energy demand in Alfama prior to assessing renewable-generation options. While the study acknowledges that heritage restrictions may limit the applicability of some measures, their inclusion in the modelling highlights the importance of a combined approach that balances energy efficiency with cultural preservation. These retrofit strategies form one of the pillars of the district-level PED analysis by quantifying the potential energy savings that could support renewable integration and help offset the district’s high heating and cooling loads.

EXCESS Tagger-Werk (Graz): Groundwater Heat Pumps in the Local Energy Mix [145]

The EXCESS project page describes the Tagger-Werk area in Graz as a former industrial complex comprising 19 buildings with a combined floor area of 73,000 m. One of the buildings - a historic feed silo converted into a student hostel - forms the core of the local Positive Energy Building demonstration. The site is presented as a large industrial brownfield redevelopment area, where a mix of renewable-energy technologies is being deployed to create a high-performance building cluster. Although not designated as a legally protected monument, the project positions the area as a historic industrial setting, requiring solutions that integrate well with the existing structures.

According to the EXCESS documentation, the local energy mix for the Tagger-Werk demonstration includes groundwater heat pumps as one of its renewable-energy sources. The project explicitly lists “solar, groundwater heat pumps and small hydropower” as the key renewable contributors for the building cluster. This confirms that groundwater-based heat pumping forms a central part of the energy system deployed at the site. The project page does not specify the capacity, depth, or performance characteristics of the groundwater system, but clearly identifies it as a core RES technology used to supply heating and cooling within the demonstration.

The EXCESS page describes how the building’s multifunctional façade, activated building components, and cascadic heat-pump system are integrated with storage elements such as battery storage and water tanks. Groundwater heat pumps form part of this broader system, providing renewable thermal energy that supports the activated building components and low-temperature heating and cooling. Although the page does not detail the operational logic of the groundwater system, it states that all subsystems are coordinated through smart predictive control, allowing the heat pumps to interact efficiently with the façade-integrated PV, the storage elements, and the building’s thermal inertia. This positions groundwater heat pumps as an integral part of a digitally optimised energy architecture.

The EXCESS documentation frames the use of groundwater heat pumps at Tagger-Werk as part of a replicable model for transforming industrial brownfield areas into high-performance energy districts. Because groundwater heat pumps do not require modifications to the visible building envelope, they are well suited to sites with architectural or contextual constraints, such as historic industrial structures. By listing groundwater heat pumps alongside solar energy and small hydropower, the project highlights the role of diversified renewable sources in achieving PEB-level performance. Their integration through predictive control and storage systems demonstrates how underground and water-based RES can support decarbonisation without altering the external appearance of historic industrial buildings.

Crosscutting Synthesis: Heritage-Compatible Renewable Energy and PED Strategies Across European Demonstrations

Common Constraints Across Historic and Protected Sites

Across all the examined PED and PEB demonstrations - including Évora, Valladolid, Limerick, Leipzig, Graz, and the Alfama model - a consistent set of heritage-driven constraints emerges. Most historic cores explicitly restrict visible solar technologies on rooftops and façades, particularly in UNESCO-designated areas such as Évora's walled centre. In Valladolid, external modifications to the façade of the Renaissance palace were prohibited, necessitating internal insulation and invisible rooftop placements. Limerick's Georgian buildings face similar rules that limit or entirely prevent rooftop PV. Even in industrial-heritage environments, such as Leipzig's Baumwollspinnerei and Graz's Tagger-Werk, interventions must be respectful of the original architectural character and avoid altering preserved structures. These constraints drive a shift away from envelope-based deployment of renewables and toward solutions that are either off-site, reversible, invisible, subterranean, or integrated into non-heritage elements.

Off-Site and Non-Visible Renewable Generation as a Dominant Strategy

Because visible envelope interventions are restricted in most protected districts, the dominant crosscutting strategy is to locate renewable-energy generation outside the sensitive area or on non-character-defining structures.

This approach is exemplified by:

- Évora's Community Solar Farm (CSF), supplying the UNESCO centre through Collective Self-Consumption and Renewable Energy Community (REC) frameworks.
- Tidal turbines in the River Shannon in Limerick, providing renewable electricity without interfering with protected urban morphology.
- PV on non-heritage or low-sensitivity structures, such as the repurposed petrol-station roof at the Baumwollspinnerei or community buildings like St Michael's Rowing Club and St John's Band Hall in Limerick.
- Invisible or look-alike BIPV, as in Évora's solar tile installation on the 15th-century Palace of the Counts of Sortelha.

This pattern reveals a shared priority: renewable generation must avoid altering the visual coherence of the heritage site. Where envelope integration is permitted, it must be camouflaged, integrated, or rendered invisible. Otherwise, production is shifted outside the protected perimeter and delivered via legal mechanisms such as RECs and CSCs.

Heat Technologies Compatible with Heritage Constraints

Energy-efficient heating and cooling in historic districts relies on systems that do not disturb façades or require visible external units. The verified cases show a strong emphasis on:

- Heat pumps, especially groundwater-source and cascaded heat-pump systems, as used in Graz's Tagger-Werk demonstration.
- District-heating integration, such as the Leipzig-West example where large-scale solar thermal from Leipzig-Lausen supports a historic residential area without any intervention on the buildings.
- Geothermal heating with seasonal storage, identified as a planned future extension at the Baumwollspinnerei, allowing renewable heat to be generated without visible architectural modifications.
- Internal insulation (Valladolid), used where external envelope interventions are prohibited.
- Thermal-mass utilisation, such as Leipzig's use of a historic building's old walls as thermal storage, reducing equipment needs while preserving the visual character of the building.

Together, these demonstrate a crosscutting preference for non-visible, low-temperature, reversible, and integrated thermal solutions that avoid external equipment or façade-mounted systems.

Digitalisation, Flexibility, and Energy Sharing as Key Enablers

Across all verified demonstrations, digital energy-management systems and flexibility-enabling technologies are essential substitutes for visible renewable installations. These include:

- Energy routers with integrated batteries in Évora's municipal buildings, allowing buildings with no rooftop PV to manage renewable electricity efficiently.
- Building Energy Management Systems (BEMS) in Valladolid, coordinating PV, PVT, heat pumps, internal insulation, and battery systems.
- Smart Link Units (SLUs) in Limerick, enabling real-time data flows between buildings to support community-grid modelling.
- Smart contracts in Valladolid, enabling automated energy trading and interaction with local market actors.
- Predictive control frameworks at Tagger-Werk, coordinating façade-integrated PV, water tanks, batteries, and heat pumps and enabling participation in flexibility markets.
- Bidirectional EV charging at the Baumwollspinnerei, turning electric vehicles into flexible energy assets.

Collectively, these show that PED behaviour in heritage cities is not achieved through high-density rooftop renewables, but through digital flexibility, energy orchestration, and demand-shaping - approaches that require no architectural intrusion.

Envelope Interventions: From "Invisible" PV to Internal Retrofits

The crosscutting review shows two categories of envelope interventions that are compatible with heritage protection:

Camouflaged or integrated solar technologies

Explicitly referenced examples include:

- Invisible solar tiles on the 15th-century Évora palace.
- BIPV roofing products co-developed for Évora, designed to mimic traditional materials.
- Façade-integrated PV at Graz's Tagger-Werk (industrial heritage, not listed).
- Window-integrated PV technologies evaluated in the Alfama PED model.
- Eight rooftop PV technologies and two solar-window technologies assessed for historic compatibility in Alfama.

Even in these cases, integration is allowed only when visibility is controlled and appearance remains consistent with heritage expectations.

Internal envelope retrofits

Used where external modifications are prohibited:

- Internal insulation of Valladolid's Renaissance palace, explicitly chosen because the façade is protected.
- Selective window replacements and roof/wall insulation options analysed in the Alfama PED model, with feasibility determined by heritage sensitivity.

These interventions highlight that, for heritage districts, envelope improvements must be either invisible, materially compatible, or placed entirely inside the heritage shell.

Conclusions

Across all verified cases, Positive Energy District strategies in heritage and culturally protected areas follow a set of shared principles:

- Avoid visible interventions on protected façades and rooftops; prioritise off-site or invisible renewables.
- Use legal and digital frameworks (RECs, CSC, smart contracts, predictive control) to compensate for physical constraints.
- Rely on flexibility rather than maximising generation inside the historic perimeter.
- Leverage non-visible heat technologies (groundwater heat pumps, geothermal, district heating, internal insulation, thermal-mass use).
- Exploit non-heritage or secondary structures (carports, community buildings, former industrial roofs) for PV.
- Adopt advanced storage and EV integration, particularly bidirectional EV chargers and battery systems in buildings.
- Ensure replicability through modular, reversible, and low-impact solutions, aligning with international heritage guidelines for BIPV and solar-thermal.

These crosscutting patterns illustrate that achieving PED or PEB performance in cultural-heritage contexts is not only possible but already demonstrated through carefully tailored RES deployment, digital energy systems, and heritage-conscious design strategies.

4. EUROPEAN BEST PRACTICES OF INTEGRATION OF RES INTO MPAS AND MPBS

In addition to previously described outcomes of research projects, individual installations of RES and sustainable practices were identified. The examples described in this part of the report summarize the individual best practice interventions.

Austria

Burgtheater, Vienna - Photovoltaic Integration. In the historic theatre complex of the Burgtheater, Vienna (listed monument), rooftop PV modules were installed on secondary roof planes and set back from the principal cornices to minimise visibility from the public realm. The installation uses low-reflectance modules and reversible mounting rails so as not to damage the original roofing fabric, and it was authorised by the Bundesdenkmalamt (BDA) after a heritage impact assessment confirming visual neutrality and structural compatibility. The project demonstrates how rooftop photovoltaics can be accommodated within high-value heritage settings when interventions are carefully designed and placed. [148]

Schönbrunn Zoo – Giraffe House Extension - Semi-transparent PV Canopy. Within the ensemble of the Schönbrunn Palace UNESCO site, the zoo's Giraffe House was extended with a steel/glass canopy integrating semi-transparent PV cells. The canopy plays both as shading and energy generation, producing a portion of the building's electricity while keeping the primary palace views intact. The BDA approved the reversible steel frame structure, and documentation emphasised that the PV portion would be removable in future without irreversible impact on the historic fabric. [149]

Ernst-Happel-Stadion, Vienna - Large-Span Roof PV Field. The Ernst-Happel-Stadion, itself a listed structure in Vienna, hosts a rooftop PV field integrated into its large roof span. The modules were spec-designed to match the colour tone of the original roofing material and positioned where visibility from the historic city centre is minimal. The BDA worked with city heritage officers to ensure that the installation maintained skyline integrity and that future removal would not leave visible anchor marks. [150]

Belgium

Abattoirs d'Anderlecht, Brussels - Roof-Mounted Photovoltaic Field. The historic industrial complex known as the Abattoirs d'Anderlecht in Brussels, a listed 19th-century facility, recently underwent a major rooftop PV installation. Starting in 2021, approximately 5,400 solar panels were mounted on the 10,000 m steel roof of the main market hall; the installation was described as one of the largest urban BIPV systems in Europe and was approved under heritage conservation constraints, with custom panels manufactured to respect the building's appearance.

The project demonstrates that large-scale PV arrays can be incorporated into heritage industrial buildings provided that load-bearing capacity is enhanced, the visual footprint is minimised, and heritage authority consent is secured. [151]

Cité Moderne (Brussels) – Flat-Roof PV on Protected Ensemble. Within the protected multi-residential ensemble of Cité Moderne in the Brussels region, rooftop PV has been installed on flat roofs with low visibility from the street, supported by regional renewable incentives (green certificates for installations in the Brussels-Capital Region). The project adheres to heritage requirements for minimal visual intrusion and aligns with the region's conservation and sustainability goals. By combining heritage preservation with renewable energy deployment, the Cité Moderne example shows how standardised PV on non-primary roof surfaces can be acceptable in protected contexts. [152]

Croatia

Tehnički muzej Nikola Tesla (Zagreb) - Demonstration ground-source heat pump (GSHP). The PLIGES (shallow-geothermal mapping) programme brochure lists a demo GSHP system at the

Technical Museum Nikola Tesla, Zagreb. While framed as a demonstration within the museum complex rather than a full-building conversion, the case is valuable because it documents borehole placement and reversible plant within a high-profile cultural institution, aligning with conservation principles (concealment of services; no façade change). [153]

Status: Implemented (demo). The PLIGES material cites the site as a Croatian example in a cross-border knowledge-transfer project, underlining feasibility of GSHP in heritage environments when drilling is planned to avoid archaeology and visual impacts.

Muzej Đakovštine (Đakovo) - Air-to-water heat pump in a listed building. In the same protected museum complex, the renovation includes installation of a heat pump (in addition to the PV plant). [154]

Czech Republic

Jízdárna ve Světcích u Tachova – Ground-Source Heat-Pump System. The large 19th-century *Riding Hall in Světce u Tachova* - a national cultural monument - was retrofitted with a ground-source heat-pump system and energy-efficient lighting as part of its adaptive reuse as a multifunctional hall. Boreholes were drilled outside the monument's visual core following archaeological supervision by the NPÚ Plzeň regional office. The reversible system provides both heating and moderate cooling through under-floor piping while maintaining constant humidity to protect the structure. The project received the *Památka roku 2023* award in the "Large Monument Renovation" category, highlighting its exemplary balance between conservation and renewable-energy integration. [155]

CONCLUSIONS

The analysis demonstrates that renewable-energy deployment in MPAs/MPBs is not only possible but already occurring across Europe, provided that solutions respect three universal principles: (1) Visual neutrality, (2) Reversibility, and (3) Protection of architectural and landscape integrity. While regulatory strictness varies across Member States, the overall European trajectory supports the integration of RES in protected environments when appropriate heritage-compatible technologies and governance mechanisms are applied.

The case studies show that the most effective PED-enabling strategies in heritage areas rely on combined, multi-scalar solutions rather than single technologies. Off-site PV, district-level renewable heat, microgrids, tidal or geothermal systems, flexible electric-mobility infrastructure, and high-efficiency retrofits inside buildings create PED performance without altering protected building envelopes. Digitalisation further amplifies these gains by enabling energy sharing, demand response, and grid interaction even in districts where direct production is limited.

For the MonuPED project, these findings confirm that PEDs in monument-protected areas are feasible when the technological, governance, and cultural dimensions are addressed together. The successful European examples provide templates for the project's Living Labs (Prague 6, Alba Iulia, Pinkafeld, Leipzig, etc.), where similar constraints (visual protection, urban morphology, strict permitting) must be balanced with ambitious decarbonisation goals.

Overall, the deliverable establishes a solid evidence base for the next phases of MonuPED:

- Designing governance and permitting frameworks suited to heritage contexts,
- Developing technical guidelines and simulation workflows for PED scenarios in MPAs,
- Structuring co-investment and community-energy models, and
- Implementing demonstrators that respect both cultural identity and climate-neutrality targets.

The report therefore supports MonuPED's central aim: to mainstream heritage-compatible PED solutions across Europe, ensuring that historic cities can fully participate in the energy transition without compromising their unique cultural value.

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