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ZEB4ZEN

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Zero energy buildings for zero Energy neighborhoods

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JOINTLY DEVELOPED PILOT ACTIONS REPORT

A. INTRODUCTION

The transition towards low-carbon, energy-efficient and climate-resilient historic neighbourhoods represent one of the core ambitions of the ZEB4ZEN project. Heritage-protected urban areas such as Palmanova (IT), Karlovac (HR) and Zamość (PL) face unique challenges in balancing conservation requirements with the need to reduce energy consumption, integrate renewable energy sources and decrease greenhouse gas emissions. Within this context, **Work Package 1** focuses on establishing a comprehensive understanding of methodology for current energy flows at the neighbourhood scale, while **Work Package 2** introduces and implements small-scale demonstration investments to test feasible, replicable solutions for historic urban environments.

Deliverable D1.5.1 – Jointly Developed Pilot Actions Report: Energy Flow consolidates the analytical and practical components of this process. It brings together:

(1) the results of the Energy Flow analysis for buildings, public lighting and transportation, and

(2) the findings from the three pilot investments implemented in Palmanova, Karlovac and Zamość.

The deliverable therefore provides a unified reference document that connects baseline energy conditions with concrete demonstration actions carried out by project partners.

The Energy Flow analysis establishes an overview of the neighbourhood energy systems including building stock characteristics, electricity and thermal energy consumption, heating systems, mobility patterns, public lighting technologies, and associated carbon emissions. This analysis, based on extensive data collection, GIS tools, field surveys, utility data, historical records and modelling, quantifies current energy needs and identifies the main drivers of consumption within each neighbourhood.

Complementing this analytical work, the three pilot actions implemented under WP2 demonstrate real-life applications of innovative energy solutions adapted to heritage constraints. The **Palmanova** pilot focuses on the establishment of a **Renewable Energy Community (REC**) supplying historic buildings from photovoltaic generation installed outside the UNESCO-protected city walls. The **Zamość** pilot showcases the full cycle of **preparation, design, permitting and construction of thermal retrofitting measures** in a listed building at Ormiańska 11. The **Karlovac** pilot introduces an **integrated system combining a rooftop solar plant, bidirectional electric vehicle charging (V2G/V2H), energy storage and a digital monitoring platform** within the historic city hall building.

By merging the Energy Flow assessment with the documentation of pilot investments, Deliverable D1.5.1 provides:

- a baseline for understanding current energy performance in three heritage neighbourhoods,
- a practical demonstration of feasible low-carbon solutions compatible with cultural protection requirements, and
- a replicable methodological framework to guide other cities in Central Europe facing similar challenges.

B. METHODOLOGY

The methodological framework applied in Deliverable D1.5.1 builds on the bottom-up modelling concept adapted for use in the 4 pilot heritage neighbourhoods of Karlovac, Quedlinburg, Palmanova and Zamość. The approach provides a harmonised yet locally sensitive system for identifying, quantifying and comparing energy flows across buildings, public lighting and transportation in historic urban environments. The methodology integrates multi-source data collection, building-level energy modelling, end-use distribution, fuel-mix analysis and model calibration.

2.1 Overall Approach

The methodology follows a bottom-up, building-level modelling process, integrating locally validated data to reflect the specific conditions of each heritage district. This process combines:

- building stock characterization,
- modelling of useful and delivered energy demands,
- distribution of final energy use by purpose,
- analysis of multiple heating energy carriers, and
- calibration against real-world consumption data.

This framework ensures methodological consistency across pilot sites while allowing for differences in climate, urban form, building typology, heritage status, and data availability.

2.2 Data Collection and Processing

A comprehensive multi-source data collection process underpins the model. The following datasets were gathered and integrated:

GIS and urban-planning datasets

Used to determine building footprints, heights, storeys, spatial configuration and block structure, enabling calculation of gross and useful areas.

National registries and cadastral data

Provided official information on parcel boundaries, building purpose, ownership and recorded building characteristics.

Energy Performance Certificate (EPC) databases

Where available, EPCs provided specific annual heating demand (Qh,nd) and energy indicators for individual buildings; these values were used directly for model inputs.

SEAP/SECAP documents

City-level Sustainable Energy Action Plan data were used to verify top-down consumption totals and calibrate neighbourhood-scale calculations.

Field surveys and questionnaires

Targeted surveys among residents and building users supplied information on actual heating practices, occupancy, fuel types, cooling use, and appliance behaviour—critical for estimating real operational patterns.

Historical and heritage documentation (D.3.1.1)

Provided typology, construction periods, material characteristics and conservation constraints, enabling typology grouping essential for modelling. All collected data were consolidated into an integrated database. Missing information was filled using controlled assumptions derived from statistically similar buildings or historical benchmarks.

2.3 Specific Energy Needs Assessment

The model estimates each building's useful energy demand using the key indicators:

- Specific annual heating energy demand (Qh,nd)
- Total specific annual energy demand for residential buildings
- Total specific annual energy demand for non-residential buildings

Where building certificates were not available, the following reference values, derived from research studies and/or guidelines and EU benchmarking, were applied:

- Residential buildings: 350 kWh/m²
- Non-residential buildings: 380 kWh/m²
- Cold climate Qh,nd: 241.9 kWh/m²
- Warm climate Qh,nd: 146.84 kWh/m²
- Palmanova EPC-based Qh,nd: 57.0 kWh/m²

These values reflect typical conditions in historic buildings where insulation levels are low, thermal performance is poor, and retrofitting is limited due to heritage constraints.

2.4 Energy Use by End-Use Purpose

To obtain full energy consumption (not only heating), total demand was distributed according to typical EU sectoral patterns.

Residential Buildings

EU average end-use distribution (Eurostat 2022) was applied:

- Space heating: 63.5%
- Domestic hot water: 14.9%
- Lighting & appliances: 14.7%
- Cooking: 6.3%
- Space cooling: 0.6%

Additionally, survey results from Karlovac (Zvijezda) informed local assumptions:

- 90% of usable floor area is heated
- 30% of usable floor area cooled

Non-Residential Buildings

Because non-residential building types vary significantly, energy use distributions were assigned based on function (administrative, educational, commercial, etc.). For example:

- Space heating: 35–70%
- Lighting: 7–15%

- DHW: 5–10%
- Appliances/others: 10–30%
- Cooling & ventilation: 3–10%
- Catering facilities: up to 35% for cooking

This functional approach allowed consistent modelling across the pilot districts despite limited statistical data for non-residential heritage buildings.

2.6 Model Calibration

Electricity calibration

Modelled electricity consumption was compared against real consumption from utility data (if existing). Deviations were corrected by adjusting end-use shares or appliance assumptions.

Calibration for public buildings

Thirteen public buildings in Karlovac provided annual metered data (electricity, gas, district heat). These were used to refine specific energy demand assumptions and validate heating energy allocation.

Limitations

Fuel oil, firewood and gas consumption at district level could not be measured directly thus, assumptions remained partially unvalidated and introduce uncertainty. Multiple-fuel systems in heritage buildings added further modelling complexity.

2.8 Recommendations for Future Improvement

The methodology's robustness can be further strengthened through:

- more granular building categories by age, condition and typology,
- improved collaboration with local utilities (gas, heat, biomass suppliers),
- integration of advanced modelling tools (urban energy modelling software),
- full standardisation of assumptions and data formats,
- establishing a system for ongoing updates (“living energy map”).

C. PILOTS ENERGY FLOW RESULTS

This chapter presents the consolidated results of the Energy Flow assessment carried out for the three ZEB4ZEN pilot neighbourhoods: Zvijezda (Karlovac, HR), Palmanova (IT) and Zamość (PL). The assessment covers buildings, public lighting and transportation.

3.1 Karlovac

3.1.1 Energy Needs - Karlovac

The Zvijezda district in Karlovac features a diverse mix of residential, public and mixed-use buildings, many dating from the 18th and 19th centuries, with significant cultural heritage value. The modelled total energy demand reflects both the age of the building stock and widespread use of individual heating systems.

BUILDINGS (151,923 m^2)

Final energy: 29.59 GWh/year (electricity, heating, cooking, PV production)

Primary energy: 33.90 GWh/year

CO_2 emissions: 5,948 t CO_2/year

PUBLIC LIGHTING

The public lighting system in Zvijezda relies primarily on older, inefficient lamp technologies (halogen, HPMV, HST). Total installed power across the district is 30.575 W, with annual electricity consumption of 151,572 kWh/year.

Final energy: 0.15 GWh/year

Primary energy: 0.23 kWh/year

CO_2 emissions: 35.84 t/year

The high share of sodium and mercury lamps indicates substantial potential for efficiency improvements once modern LED technologies are introduced.

TRANSPORTATION

Due to construction works during analysis, real traffic measurements were unavailable. Instead, fuel consumption for the Zvijezda district was downscaled from city-level transport statistics and calibrated by road length.

Final energy: 1.28 GWh/year

Primary energy: 1.42 GWh/year

CO_2 emissions: 396.53 t/year

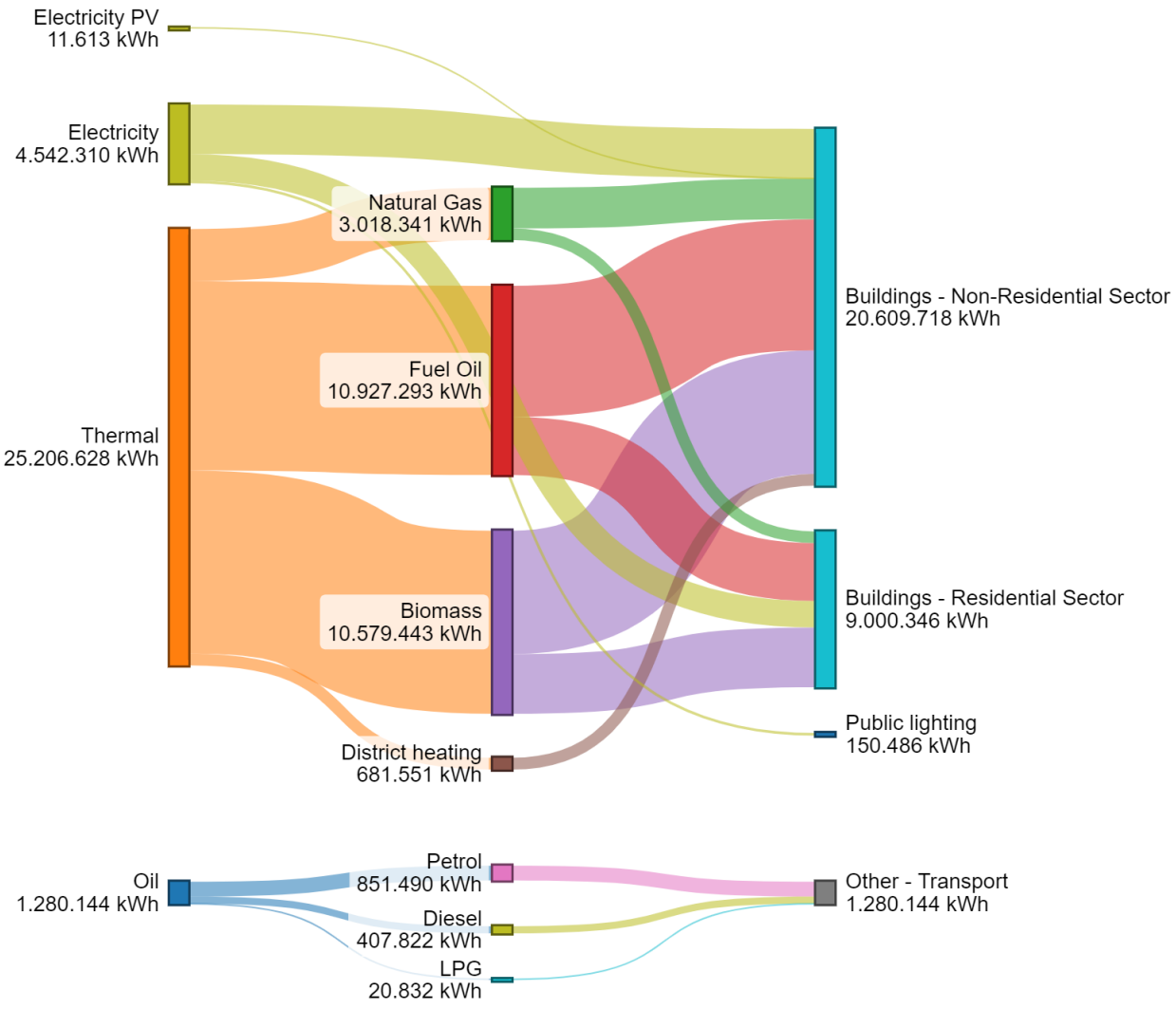
Fuel shares patterns: 58% diesel, 40% petrol, 2% LPG, with corresponding energy values calculated using standard conversion factors.

RECAPITULATION

Table 1: Energy Needs - Karlovac, Zvijezda

PARAMETAR	TOTAL
Final Energy	**31,02 GWh/y**
Primary Energy	**36,26 GWh/y**
CO_2 Emissions	**6,534 t/y**

3.1.2 Sankey Diagram - Karlovac



3.2 Quedlinburg

3.2.1 Energy Needs - Quedlinburg

BUILDINGS (24,718 m^2)

Final energy: 4.85 GWh/year (electricity, heating, cooking)

Primary energy: 5.62 GWh/year

CO_2 emissions: 1,113 t/year

PUBLIC LIGHTING

Public lighting data are provided street-by-street, including lamp counts, installed power and annual electricity consumption within pilot location (3 blocks). Summation across all listed streets gives the total annual consumption.

Final energy: 0.025 GWh/year

Primary energy: 0.038 GWh/year

CO_2 emissions: 6.04 t/year

TRANSPORTATION

Transport energy consumption for Quedlinburg is modelled using mobility data from the "Mobility of City Quedlinburg" report, including average annual kilometres travelled per resident, modal split, and fuel shares.

Final energy: 0.80 GWh/year

Primary energy demand: 0.90 GWh/year

CO_2 emissions: 248.68 t/year

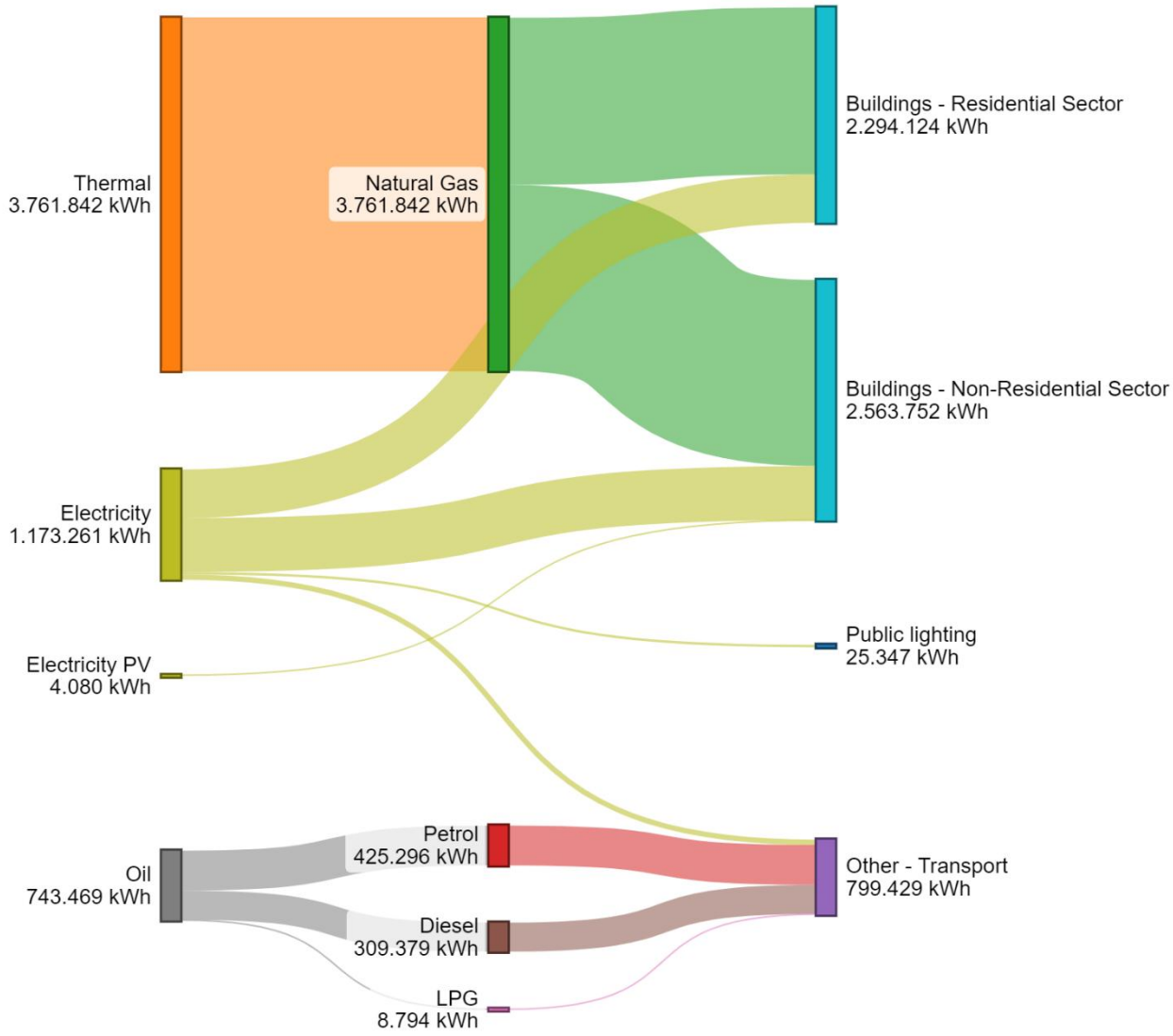
Fuel shares patterns: 53% petrol, 39% diesel, 1% LPG, 7% electricity with corresponding energy values calculated using standard conversion factors.

RECAPITULATION

Table 2: Energy Needs - Quedlinburg, pilot location (3 blocks)

PARAMETAR	TOTAL
Final Energy	**5.67 GWh/y**
Primary Energy	**6.55 GWh/y**
CO_2 Emissions	**1,367 t/y**

3.2.2 Sankey Diagram – Quedlinburg



3.3 Zamosc

3.3.1 Energy Needs - Zamosc

BUILDINGS (7,940 m^2)

Zamość contains a complex and dense heritage environment, including UNESCO-protected structures, public institutions, and mixed-use buildings.

Final energy demand: 2.33 GWh/year (electricity, heating, cooking)

Primary energy demand: 3.64 GWh/year

CO_2 emissions: 953.54 t/year

The district heavily relies on district heating for space heating and DHW, complemented by electricity and natural gas. Consumption intensities are high, reflecting both cold climate conditions and the age of the building stock.

PUBLIC LIGHTING

Zamość's public lighting consists of a mix of LED lamps and high-pressure sodium (HST).

Final energy consumption: 0.01 GWh/year

Primary energy: 0.015 GWh/year

CO_2 emissions: 2.50 t/year

TRANSPORTATION

Transport energy consumption was modelled based on fuel type shares and typical annual mileage for the neighbourhood.

Final energy: 0.71 GWh/year

Primary energy: 0.78 GWh/year

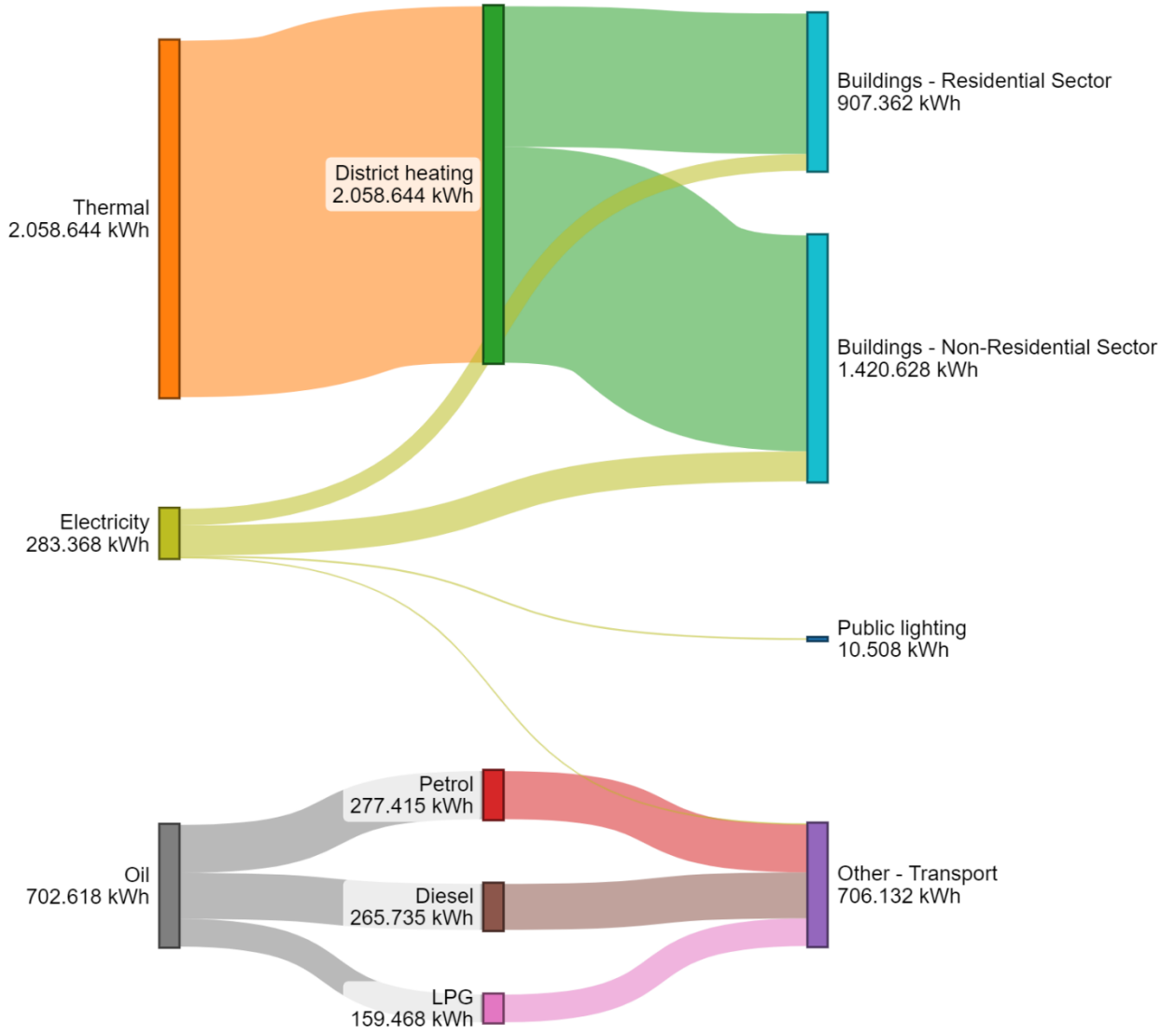
CO_2 emissions: 213.81 t/year

RECAPITULATION

Table 3: Energy Needs - Zamosc, pilot location

PARAMETAR	TOTAL
Final Energy	**3.04 GWh/y**
Primary Energy	**4.42 GWh/y**
CO_2 Emissions	**1,169 t/y**

3.3.2 Sankey Diagram – Zamosc



3.3 Palmanova

3.3.1 Energy Needs - Palmanova

BUILDINGS (9,782 m²)

Palmanova's pilot district has a significantly smaller and more compact building stock than Karlovac, yet still includes a mixture of public, residential and business uses. Many buildings date back to the 16th–17th centuries, with substantial heritage constraints.

Final energy: 0.83 GWh/year (electricity, heating, cooking)

Primary energy: 1.23 GWh/year

CO_2 emissions: 243 t/year

Heating is dominated by natural gas, while electricity is primarily used for appliances and cooling. A notable characteristic is the relatively efficient thermal performance of some buildings (e.g. Qh,nd = 57 kWh/m² for several EPC-certified buildings), reflecting recent renovations in the school and municipal building.

PUBLIC LIGHTING

The system consists primarily of LED technologies (20W, 25W, 36W, 40W) and a limited number of sodium fixtures.

Final energy: 0.015 GWh/year

Primary energy: 0.036 GWh/year

CO_2 emissions: 9.34 t/year

The lighting system is already largely modernised, resulting in very low overall consumption compared to Karlovac.

TRANSPORTATION

Transport energy use in Palmanova reflects medium traffic intensity and the mixed use of private vehicles around the historic centre.

Final energy: 0.33 GWh/year

Primary energy: 0.36 GWh/year

CO_2 emissions: 91.72 t/year

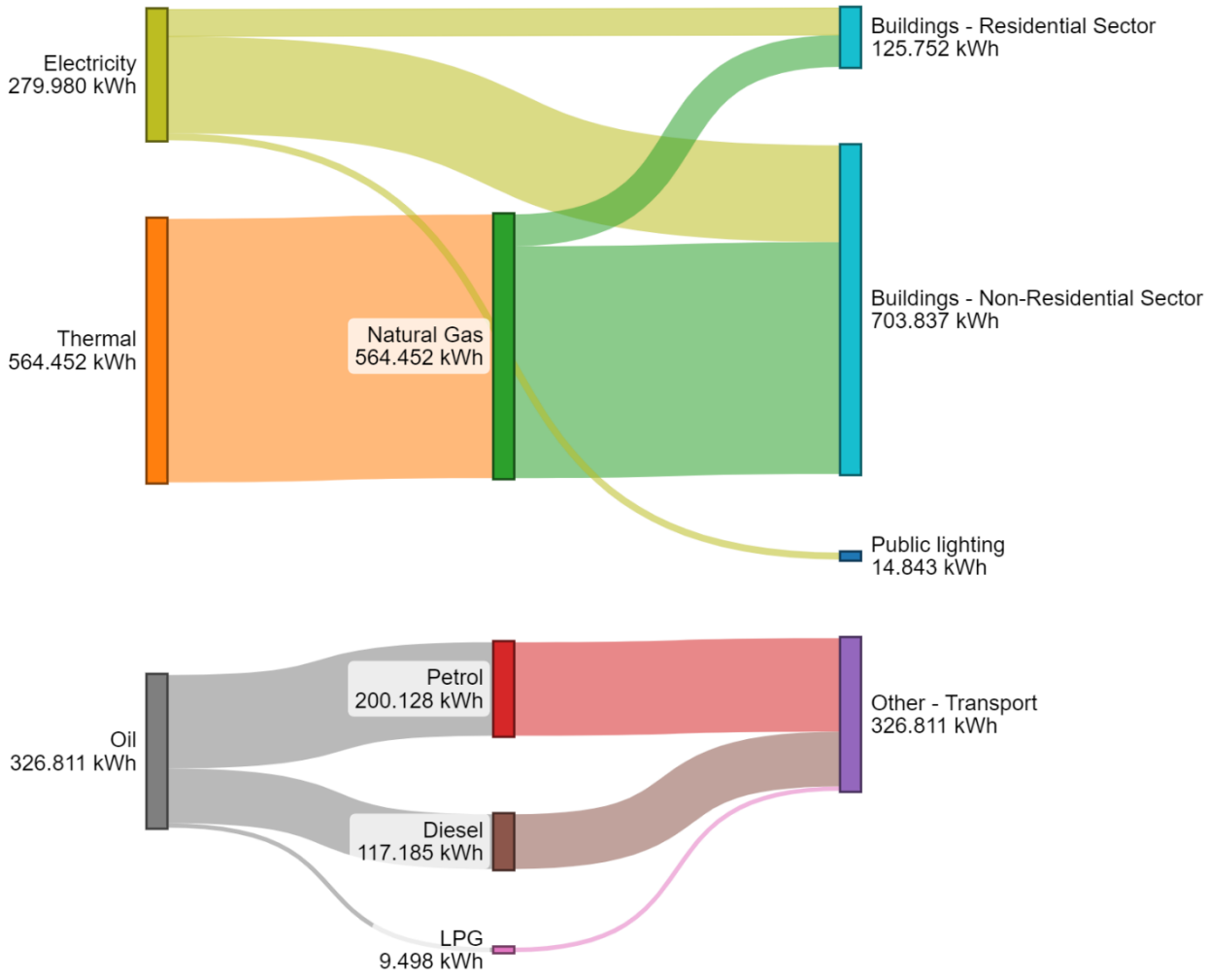
Fuel distribution: majority petrol and diesel, with minor shares of LPG.

RECAPITULATION

Table 4: Energy Needs - Palmanova, pilot location (1 block)

PARAMETAR	TOTAL
Final Energy	**1.17 GWh/y**
Primary Energy	**1.63 GWh/y**
CO_2 Emissions	**384.58 t/y**

3.3.2 Sankey Diagram – Palmanova



D.PILOTS INVESTMENT RESULTS

4.1 Pilot Investments in Karlovac

The pilot project in Karlovac, Zvijezda aims to test innovative approaches integrating renewable energy, energy storage, digital control, and advanced mobility concepts within historically valuable neighbourhoods. Karlovac's pilot is located in the historic star-shaped district "Zvijezda", with the City Hall (Gradska uprava) building selected as the demonstration site. The overarching goal is to demonstrate how renewable energy generation, energy storage, bidirectional EV charging and advanced software control can be deployed in a heritage-sensitive environment, supporting the long-term transition toward a zero-emission neighbourhood (ZEN). Karlovac implemented three core physical investments, complemented by advanced digitalisation measures:

1. PHOTOVOLTAIC (PV) POWER PLANT – 10 KW AC

A rooftop solar power plant was installed on the City Hall building in 2025, procured under public tender (Group 1: PV plant).

Key technical characteristics:

- Installed AC power: 10 kW
- PV module configuration: 26 monocrystalline panels × 450 W = 11.70 kWp DC
- Predicted annual generation: 13,964 kWh/year
- Inverter: Huawei SUN2000MA-10KTL-M1 (2 MPPT inputs)

The PV system is fully grid-connected and designed for parallel operation with the Croatian distribution system (HEP ODS), including lightning protection, DC/AC surge protection, and monitoring integration.

Investment value: 9,688 EUR (VAT excluded).

2. BIDIRECTIONAL EV CHARGING STATION (V2G)

Karlovac installed a bidirectional charging station capable of both charging an electric vehicle and returning electricity from the vehicle back to the building or the grid (Vehicle-to-Grid – V2G).

Procured under Group 2 of the public tender.

Key data:

- Technology: Bidirectional charger (V2G-compliant)
- Power rating: 11–22 kW
- Investment value: 16,540 EUR (VAT excluded)

This technology is essential for demonstrating the concept of mobile energy storage, where EV batteries contribute to balancing loads in historic city districts.

Local media also confirm that the V2G charger has already been installed and commissioned.

3. ELECTRIC VEHICLE WITH V2L/V2G FUNCTIONALITY

The pilot includes the acquisition of an electric vehicle supporting Vehicle-to-Load (V2L) and compatible with the V2G charging infrastructure.

The City acquired a BYD SEAL U Comfort model.

The vehicle acts as:

- A transportation asset for city operations
- A mobile battery for energy flexibility
- A demonstrator for the ZEB4ZEN concept of integrating EV storage into neighbourhood energy flows

Its battery can power appliances directly (V2L) or deliver power through the V2G charger back into the building.

4. ENERGY MANAGEMENT SOFTWARE AND DIGITAL INTEGRATION

Karlovac implemented an advanced software system supplied by Končar Digital, integrating:

- Real-time PV production
- Building electrical consumption
- EV charging/ discharging (V2G)
- Smart control and optimisation

Investment value: 15,890 EUR (VAT excluded).

This system forms the digital backbone of the Karlovac pilot, enabling the development of a Digital Twin for energy flows within the city block, aligned with the ZEB4ZEN methodology.

OVERVIEW & CONCLUSION

The Karlovac pilot investment aimed to demonstrate how renewable energy, electric mobility and digital energy management can be integrated into the historic "Zvijezda" district. The original plan included the installation of a rooftop photovoltaic (PV) system, a bidirectional charging station (V2G), an electric vehicle capable of flexible charging/discharging, and a centralised software platform for monitoring and optimisation. All planned components were successfully implemented:

- 10 kW AC photovoltaic system on the City Hall building, consisting of 26 monocrystalline panels with a total DC capacity of 11.70 kWp and expected annual production of 13,964 kWh.
- Bidirectional EV charger, enabling both conventional charging and Vehicle-to-Grid power export back to the building infrastructure.
- Electric vehicle (BYD SEAL U Comfort) functioning as a mobile battery with V2L/V2G capability, delivered to the City of Karlovac within the ZEB4ZEN project.
- Energy management software (Končar Digital) integrating PV production, building consumption and EV charging into one optimisation platform.

The combined system reduces the building's grid electricity demand by supplying up to 14 MWh/year of renewable electricity from the PV plant, directly lowering energy costs and emissions. The V2G charger and EV provide an additional flexibility resource that helps decrease short-term peak loads, which is particularly beneficial in historic urban zones with constrained electrical infrastructure. Even without a stationary battery, the implemented solution achieves meaningful improvements: reduced purchased electricity, increased self-consumption of locally generated solar energy, and enhanced operational resilience. Overall, the Karlovac pilot demonstrates that a compact, cost-effective combination of PV + V2G + EV + digital management can deliver tangible energy savings and operational benefits while fully respecting the constraints of a protected heritage district.

4.2 Pilot Investments in Zamosc

Zamość, located within a UNESCO-listed Renaissance old town, represents one of the most challenging environments for implementing energy efficiency measures due to strict heritage protection rules. As part of the ZEB4ZEN project, the city aimed to test internal insulation technologies, digital building modelling and scientific material evaluation, enabling a replicable methodology for thermally upgrading historic buildings without altering protected facades.

PREPARATORY PHASE: SCIENTIFIC MATERIAL TESTING

Extensive laboratory research was conducted at Lublin University of Technology to test thermal insulation materials intended for use in historic buildings. The testing campaign lasted over 12 months and covered:

- 9 insulation materials (mineral boards, Ytong Multipor, PUR foam, perlite, sheep wool, aerated concrete, etc.)
- testing λ values (thermal conductivity) at temperatures from −20°C to +50°C
- testing humidity influence on insulation performance (0–90% RH)
- over 180 measurement cycles for λ values alone.

The findings identified clear differences in thermal performance, humidity sensitivity and practical installation suitability.

KEY CONCLUSION

Material 1 (mineral board with lowest λ) consistently provided the best thermal performance, forming the basis for material selection in the pilot implementation.

IN-SITU THERMAL TESTING – ZAMOYSKI PALACE

To validate laboratory findings under real historic conditions, the team built research stations in the northern annex of the Zamoyski Palace, also within the UNESCO zone.

Tests included:

- installation of 3 internal wall insulation systems
- installation of 4 ceiling insulation systems
- continuous monitoring of temperature, humidity and heat flux over 7 days
- 567 measurement cycles, producing >2,200 heat flux readings
- detailed thermal imaging with FLIR B365 cameras

Results showed that:

- insulated surfaces reached 23.8°C, while uninsulated masonry remained at 16.3°C, confirming large heat-loss reductions
- Material 1 again demonstrated the lowest U-value, confirming its superior real-world performance
- ceiling tests were inconclusive due to weather (too high outdoor temperatures), to be repeated in winter 2024/25.

These results provided a robust scientific foundation for the pilot building design.

DIGITAL TWIN DEVELOPMENT

Before implementation, the selected building — Kamienica Ormiańska 11 — was fully digitised using:

- Laser scanning (FARO) from ~100 scanning positions
- Photogrammetry (~1,500 high-resolution images)
- generation of a unified 3D point cloud
- creation of detailed inventory drawings and a full digital twin model used for design and procurement.

This ensured high accuracy in design and conservation compliance.

PILOT IMPLEMENTATION – ORMIAŃSKA 11

The implementation target was a three-storey 19th-century tenement building located in the UNESCO-listed Old Town of Zamość. Due to financial and conservation constraints, the pilot focused on the thermal modernisation of the attic, which represented the building's most significant heat-loss area.

Investment components included:

- installation of Ytong Multipor mineral boards (λ = 0.040 W/mK)
- installation of PUR foam insulation (λ = 0.030 W/mK)
- addition of triple-glazed wooden windows (92 mm profile)
- complementary preparatory works (surface repair, levelling, finishing)

All materials were chosen for:

- compatibility with historic structures
- vapour permeability
- low impact on protected interiors
- proven thermal performance from laboratory and palace tests.

Permits were obtained from the conservation office, and the works were executed using non-invasive, reversible methods required in historic buildings.

OVERVIEW & CONCLUSION

The Zamość pilot within the ZEB4ZEN project addressed one of the most challenging energy-efficiency contexts in Central Europe: improving thermal performance in UNESCO-protected historic buildings where external insulation is prohibited. To meet this challenge, the pilot followed a multi-stage, science-driven approach combining laboratory testing, in-situ measurements, digital modelling, and targeted onsite implementation. The preparation phase began with an extensive laboratory analysis of nine insulation materials, performed at the Lublin University of Technology, where thermal conductivity (λ) was measured under varying temperature (−20°C to +50°C) and humidity conditions (0–90% RH) to understand each material's behaviour in real historic environments. These tests generated over 180 measurements and revealed large performance differences, with Material 1 (mineral board) consistently achieving the lowest λ values and highest stability, making it the top candidate for use in historic masonry structures.

To validate the laboratory findings, the team established a research station in the Zamoyski Palace, installing three types of internal wall insulation and four ceiling insulation systems. Over seven days, more than 2,200 heat-flux readings and 1,100 temperature readings were collected using an ALMEMO 2890-9 recorder, alongside detailed thermal imaging using a FLIR B365 camera. The results confirmed the superior performance of the selected mineral board, which demonstrated the lowest U-values and increased interior

surface temperatures up to 23.8°C, compared to only 16.3°C on uninsulated masonry. These findings provided solid empirical evidence for selecting the final insulation system for pilot implementation.

The actual pilot works were executed in Kamienica Ormiańska 11, a 19th-century public building located in the UNESCO-listed Old Town. Prior to construction, the building was fully digitised using laser scanning and photogrammetry (approximately 1,500 high-resolution photographs and ~100 FARO scans), enabling the creation of a precise 3D digital twin to support design, procurement and conservation compliance. Based on laboratory and in-situ tests, the attic—identified as the building's most significant thermal loss area—was thermally modernised using Ytong Multipor mineral boards, PUR foam insulation, and a triple-glazed wooden window package, all selected for compatibility with historic materials and proven insulation performance.

The temperature difference observed in the Zamoyski Palace tests, 23.8°C on insulated vs. 16.3°C on uninsulated walls indicates a 30 – 35% reduction in conductive heat loss through insulated partitions under comparable winter conditions. Since the attic was the building's largest heat-loss area, applying similar insulation measures is expected to yield proportional savings.Based on typical thermal loss profiles of similar masonry tenements and the measured performance improvement in **15 - 20% reduction in annual heating demand is expected for the top floor of Ormiańska 11**. At the whole-building level, this translates into an approximate **8 - 12% reduction in total heating energy consumption**, depending on occupancy, heating schedule and internal loads.

Zamość's role in ZEB4ZEN is the testing and implementation of internal insulation for historic tenement houses, forming one of the project's key replicable solutions for energy-intensive heritage buildings. In conclusion, the Zamość pilot successfully demonstrated a technically rigorous and conservation-appropriate pathway for improving energy efficiency in historic buildings. By combining laboratory research, controlled field testing, digital twin modelling, and a carefully curated attic insulation retrofit, the city created a validated methodology for reducing heat losses while respecting UNESCO heritage constraints. Early measurements show substantial improvements in wall and ceiling thermal performance, with expected reductions in heating demand and significant enhancements to indoor comfort. Most importantly, the solutions and methods tested in Zamość are scalable and replicable, offering a robust blueprint for modernising other historic buildings across the Old Town and similar heritage districts throughout Central Europe.

4.3 Pilot Investments in Palmanova

Palmanova, a Renaissance star-shaped fortified city and UNESCO World Heritage Site, faces extremely strict cultural and landscape protection rules that limit the installation of renewable energy infrastructure within the historic walls. As part of the ZEB4ZEN project, the city is testing a highly replicable solution: the establishment of a Renewable Energy Community (REC) supported by a new 60 kWp photovoltaic (PV) plant located outside the UNESCO perimeter. This pilot differs from Karlovac and Zamość because it does not intervene directly on a building. Instead, it deploys an energy governance and shared-generation model that allows households, SMEs and municipal users in a historic insula to collectively benefit from renewable energy without compromising the city's protected landscape. At EU level, RECs are recognised under the RED II Directive as instruments that empower citizens, reduce energy poverty, and accelerate decarbonisation. Palmanova pilot is the application of shared solar generation for a heritage-sensitive neighbourhood, showing how collective solutions can overcome heritage-related constraints. The pilot consists of:

- Creation of a Renewable Energy Community (REC) with voluntary participation of residents, SMEs and municipal entities within the fortified city center.
- Installation of a 60 kWp PV system on municipal land outside the UNESCO-protected area, in compliance with conservation rules.
- Legal, technical and administrative setup of the REC, including the drafting of the founding documents (Statute, internal regulation, governance rules).
- Engagement activities with citizens, SMEs, municipal councillors and the wider local community.
- Alignment with new Italian national regulations governing RECs.

These components allow Palmanova to demonstrate a scalable model for achieving renewable energy uptake in urban heritage settings where direct PV installation is restricted.

PREPARATORY PHASE ACTIVITIES

Legal Framework and Delays

The preparatory phase experienced delays due to the late publication of the Italian national implementing rules (Decreto CACER and GSE Operational Rules), published only in February 2024, far behind the original 2021 schedule.

These rules define:

- who can establish a REC,
- technical, legal and administrative requirements
- regulations and procedures defined by GSE (Italian Energy Services Operator)

Because these regulations were a prerequisite to proceed, Palmanova could not begin implementation activities until they were released.

Identification of the Pilot Area

The selected pilot concerns:

- the fortified city area, whose consumers will form the user base of the REC;
- a PV installation area outside the fortifications, chosen because internal roofs are protected under cultural heritage law.

Maps prepared with GSE data confirm that both production and consumption points lie under the same primary substation (cabina primaria), fulfilling CER requirements.

Regulatory and Landscape Constraints

Because Palmanova is UNESCO-listed, installation of solar PV inside the fortifications is severely restricted by:

- Italian Cultural Heritage Code (D.Lgs 42/2004),
- Landscape buffer of 500 m around protected perimeters, applied through "Decreto PNRR3",
- Additional hydrological and landscape restrictions related to the Brentane watercourse (L. 431/85).

The pilot therefore selected a degraded peripheral area where PV is acceptable, subject to environmental mitigation measures (green buffers, reversible foundations, dark-green equipment colouring).

Permitting Activities

The municipality has:

- defined the PV area and prepared the landscape compatibility dossier,
- begun consultations with the Soprintendenza (heritage authority),
- stated the technical justification and visual mitigation measures required for approval.

Community Engagement

A structured engagement campaign was launched by the city and APE FVG:

- meetings with local SMEs (16 Jan, 23 Jan, 29 Jan 2025)
- meeting with city councillors (11 Mar 2025)
- two public events for citizens scheduled for 3 April 2025

These activities aimed to collect expressions of interest, share energy consumption data, and introduce the benefits and governance of the CER.

Legal Support

The municipality commissioned legal assistance for:

- review of the CER's Founding Act, Statute, Internal Regulation,
- analysis of governance options,
- compliance with GSE rules and public-sector participation requirements.

Technical Characteristics of the Pilot PV System

The ZEB4ZEN proposal defines:

- 60 kWp peak power,
- final detailed design to be prepared in the feasibility and executive design phase,
- system sited externally to the historic core, on municipal service land with optimal solar exposure and minimal shading.

Additional specifications (inclination, support structure, inverter typology) will be defined during the technical-economic feasibility study, incorporating:

- optimisation of solar capture;
- compliance with CEI norms for CER-eligible PV;
- landscape integration measures.

CER STRUCTURE AND GOVERNANCE

CER Characteristics

The Renewable Energy Community will:

- consist of municipal consumers, residents and SMEs;
- share PV-generated energy through Italy's "autoconsumo diffuso" framework;
- be structured as a not-for-profit collective legal entity;
- operate under the governance rules defined by the Statute and national CER legislation;
- be managed by a Referente (CER Manager) responsible for GSE communication and administrative operations.

Stakeholders

Key stakeholders include:

- Municipality of Palmanova (promoter, landowner, contracting authority);
- APE FVG (technical partner);
- SMEs and residents (CER members);
- Legal advisor (Statute drafting and compliance);
- GSE (Italian Energy Services Operator)
- Heritage authorities (Soprintendenza);
- e-distribuzione (DSO).

Implementation Pathway

Following completion of the regulatory framework, the city will perform:

- Feasibility study (technical, economic, organisational).
- Recruitment of CER members + collection of consumption data.
- Finalisation of Statute, internal rules, governance and legal registration.
- Public procurement for PV design and construction.
- Construction, grid connection and commissioning.
- Activation of CER with GSE and start of compensated shared generation.

The Interreg timeline foresees implementation throughout 2024–2026 with final evaluation in 2026.

OVERVIEW & CONCLUSION

The Palmanova pilot showcases an innovative, heritage-sensitive pathway for integrating renewable energy into a UNESCO-protected urban fabric. Instead of modifying historic buildings, the project strategically locates a 60 kWp PV facility outside the fortified area and uses a Renewable Energy Community (CER) to distribute clean energy to consumers within the old city. This approach overcomes long-standing conservation constraints while enabling residents and SMEs to benefit from modern energy solutions.

The preparatory phase focused on interpreting and aligning with Italy's newly finalised CER regulatory framework, conducting early-stage community engagement, selecting appropriate PV siting, and initiating legal and administrative processes for CER creation. These steps were necessary given the regulatory delays

that postponed implementation until 2024. Alongside permitting and legal structuring, Palmanova developed a detailed roadmap for designing, building and activating the PV plant and CER.

Once implemented, the pilot is expected to generate 87.000 kWh of renewable electricity annually, reduce dependence on grid energy for participating users, lower energy bills through national incentives, improve resilience to energy price shocks, and **avoid 17-23 tCO_2** emissions per year. Socially, it will strengthen local engagement, support vulnerable consumers, and provide equitable access to clean energy. Importantly, it will do so without any alteration of Palmanova's protected heritage assets.

Overall, the Palmanova pilot delivers a replicable model for heritage-led renewable integration, demonstrating how Renewable Energy Communities can unlock decarbonisation potential even in the most constrained historic centres. The investment will offer valuable lessons for other European star-shaped fortified towns and heritage sites facing the dual challenge of conservation and climate neutrality.

E. COMPARATIVE SUMMARY OF PILOT RESULTS

This concluding chapter provides a harmonised comparison of the three ZEB4ZEN pilot location:

- Energy Flow Results (energy and CO_2 baseline in the pilot districts), and
- Pilot Investment Results (solutions implemented / prepared under WP2).

The tables below synthesise the pilots into a single cross-project overview, enabling easy comparison of scale, technologies, impacts and replicability.

Pilots Energy Flow Results - Comparative Table

Table 5: Pilots Energy Flow Results - Comparative Table

Parameter	Karlovac - Zvijezda	Quedlinburg	Zamość - Old Town Zone	Palmanova - Selected Insula
Overall Final Energy [GWh/y]	31.02	5.67	3.04	1.17
Overall Primary Energy [GWh/y]	36.26	6.55	4.43	1.63
Overall CO_2 Emissions [t/y]	6,534	1,367	1,169	384.58
Usefull Area [m^2]	151,923	24,718	7,940	9,782
Buildings Final Energy [GWh/y]	29.59	4.85	2.33	0.83
Public Lighting Final Energy [GWh/y]	0.15	0.025	0.010	0.015
Transport Final Energy [GWh/y]	1.28	0.08	0.71	0.33
Specific Final Energy [kWh/m^2/y]	194,75	196,36	293,19	84,80
Specific Primary Energy [kWh/m^2/y]	223,17	227,34	458,12	126,20
Specific CO2 Emissions [kg/m^2/y]	39,16	45,01	120,09	24,80

Pilots Investment Results - Comparative Table

Table 6: Pilots Investment Results - Comparative Table

Category	Karlovac - City Hall Pilot	Zamość - Ormiańska 11 Pilot	Palmanova - CER & PV Pilot
Pilot Focus	PV + V2G + EV + Digital EMS	Internal insulation + digital twin	Renewable Energy Community + external PV
Main Technologies Installed	- 10 kW AC PV (11.7 kWp DC)	- Internal wall insulation (3 systems tested)	- 60 kWp PV outside city walls
	- Bidirectional V2G charger (11-22 kW)	- Ceiling insulation (4 systems tested)	- Full CER legal/organisational setup
	- BYD SEAL U EV with V2L/V2G	- PUR foam, Multipor, mineral boards	- Founding Act, Statute, rules
	- Končar Digital EMS platform	- Triple-glazed wooden windows	- Engagement with SMEs & citizens
		- Building digital twin (LiDAR + photogrammetry)	
Investment Value	PV: **€9,688**	Construction cost included in pilot budget (various components)	Legal services:
	V2G charger: **€16,540**	Full digital-twin + lab testing funded by project	PV CAPEX TBD after feasibility
	EMS software: **€15,890**		
Measured / Expected Impact	- ~14 MWh/y renewable generation	- 30-35% reduction in heat-loss on insulated partitions	- 87 MWh/y PV generation expected
	- Reduced grid imports	- 15-20% heating savings top floor	- 17-23 tCO_2 avoided annually
	- EV battery as flexible storage	- 8-12% whole-building heating reduction	- Reduction in electricity purchases for members
	- Peak shaving, improved resilience		
Heritage Compatibility	Fully reversible; rooftop PV allowed; V2G/EV non-intrusive	100% internal; reversible; conservation-approved	PV placed outside city walls; no impact on UNESCO fabric
Digitalisation Level	Very high (real-time energy + V2G optim.)	Very high (complete digital twin)	Medium (CER data platform + GSE systems)
Replicability	High - compact PV+V2G package	Very high - validated internal insulation systems	Very high - CER model ideal for