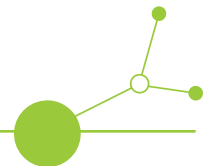


ZEB4ZEN

D.4.1.2. Development of Green and Digital Energy Action Plan



Version 1

07 2026





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DEVELOPMENT OF GREEN AND DIGITAL ENERGY ACTION PLAN

A. INTRODUCTION

The transition to a sustainable, resilient, and climate-neutral society requires cities and communities to fundamentally rethink the way they plan, produce, distribute, and consume energy. The development of Green and Digital Energy Action Plans represents a cornerstone of this transformation. These strategic documents are designed to provide a long-term framework for reducing greenhouse gas emissions, increasing energy efficiency, and integrating renewable energy, while simultaneously leveraging digital technologies to enable transparency, optimization, and citizen engagement.

The “green” dimension of the Action Plan focuses on:

- Decarbonising the built environment by improving the energy performance of buildings through deep renovation.
- Promoting clean heating and cooling solutions, such as heat pumps, district heating from renewable sources (e.g. geothermal).
- Expanding local renewable energy production, including photovoltaic installations on rooftops and the development of photovoltaic energy communities.
- Modernising infrastructure—such as public lighting, transport systems, and energy networks—to become more efficient and climate-friendly.
- Ensuring the alignment of urban energy strategies with broader frameworks like the EU Green Deal, Fit for 55, and REPowerEU.

These goals are achieved through scenario-based planning, cost-benefit analysis, and alignment with environmental protection and architectural conservation.

The “digital” dimension of the Action Plan focuses on:

- Digital mapping and GIS-based building stock models that provide granular data on energy consumption, emissions, building types, and renovation potential.
- Simulation and modelling tools to test decarbonisation scenarios under different economic, technical, and policy assumptions.
- Data-driven solutions, ensuring that public investments deliver measurable energy and emissions savings.
- Digital platforms for participation, allowing stakeholders to visualize plans, to upgrade and update data, co-design measures, and track progress in transparent ways.



The plan provides a clear roadmap for action, identifying:

Detailed analysis and proposal of energy efficiency (EE) and decarbonisation measures, that include building envelope upgrades, transition to renewable-based heating and cooling systems, electrification of end uses, public infrastructure modernization, and integration of local renewable generation.

Decarbonisation roadmap, recommending trajectory for measures implementation grouped into logical timeline phases.

Investment estimation, providing a quantified forecast of total capital needs across the roadmap horizon. Each group of measures (e.g., building renovation, RES installation, lighting retrofit) is costed based on unit benchmarks and scaled across the building stock and infrastructure assets.

Implementation timeline (until 2050), structured into gradually long-term (2050) milestones, aligning with EU climate neutrality objectives.

Savings calculations in primary energy and CO₂ emissions, calculated for each scenario and project graduation period.

Key Performance Indicators (KPIs), clearly defined and measurable. KPIs cover:

- Reduction in final and primary energy use (kWh/m²),
- Decrease in CO₂ emissions (tons/year),
- Share of renewable energy in final consumption (%),
- Renovated floor area (m²),
- Installed RES capacity (kWp),
- Payback period.

Digital visualisation and spatial planning framework, enabling the structured representation of the building stock, current energy performance, and planned interventions in digital and georeferenced form.

The plan includes GIS-based layers that map:

- Buildings and blocks spatial presentation,
- Data of buildings,
- Energy and emissions data on buildings block level,
- Potential and simulated effects of measures implementation on buildings block level,
- ...



B. GREEN AND DIGITAL ENERGY ACTION PLAN FOR ZVIJEZDA, CROATIA

1. Existing Conditions and Baseline Assessment

1.1. Urban and Heritage Context

The Zvijezda district, the historic core of the city of Karlovac, is a rare example of Renaissance star-shaped urban planning, originally constructed as a military fortress in the 16th century. It retains its geometric block structure and contains a diverse range of buildings, including residential units, civic and cultural institutions, and administrative premises. The area is under cultural protection, imposing strict conditions for physical interventions.

1.2. Building Stock Characteristics

- Majority of buildings are over 100 years old, with limited or no thermal insulation.
- High heat loss due to poor envelope performance.
- Dominance of outdated heating systems: wood stoves, gas boilers, electric heaters.
- Lack of unified energy infrastructure - fragmented, building-level energy management.

1.3. Energy and Emissions Baseline

- Primary Energy Consumption: kWh/year
- CO₂ Emissions: tons/year
- Heating Energy Demand: accounts for ~50% of total energy use
- Main fuels: biomass (firewood), natural gas, fuel oil, electricity (resistive heating)

1.4. GIS Representation

A geospatial model was developed for the entire district, identifying:

- 29 urban blocks
- 235 buildings (residential and public use)
- Zoning layers, energy infrastructure, cultural status tags



Figure 1: Buildings blocks CO₂ emissions [tCO₂/year] – Baseline Scenario

1.5. KPIs and Impact Summary

Table 1: KPIs and Impact Summary (Baseline Scenario) – year 2020

INDICATOR	VALUE
Primary Energy Needs [kWh/y]	44.596.444
Specific Primary Energy Needs [kWh/m ² /y]	336,85
Final Energy Needs [kWh/y]	36.878.376
Specific Final Energy Needs [kWh/m ² /y]	278,55
CO ₂ Emissions [tCO ₂ /y]	5.247
Specific CO ₂ Emissions [kgCO ₂ /m ² /y]	39,63
OPEX [€/m ² /y]	3.028.662



2. Integration of Existing City Strategies into the Zvijezda Green and Digital Energy Action Plan

This chapter outlines the alignment between proposed measures for the Zvijezda district and the broader energy and climate objectives defined in the following official city documents:

- Action Plan for Green Karlovac
- Sustainable Energy and Climate Action Plan (SECAP) of Karlovac
- Development Plan of the City of Karlovac 2021-2030
- Guidelines for Integrating Sustainable Energy and Climate Planning into the City's Urban Plans (EKPP Guidelines)

The following thematic areas have been identified as priorities, and are fully consistent with measures included in the Green and Digital Energy Action Plan for Zvijezda under the ZEB4ZEN framework:

1. Energy-Climate Zoning

As part of the “Guidelines for Integrating Sustainable Energy and Climate Planning into the Urban Plan of the City of Karlovac”, a spatial framework for energy-climate zoning was proposed. This zoning aims to tailor energy efficiency and climate resilience measures to the specific urban morphology, heritage constraints, and energy infrastructure of each part of the city.

The Zvijezda district — the historic star-shaped core of Karlovac—is explicitly designated as Zone Z1 (Z1-01), a priority area under conservation protection.

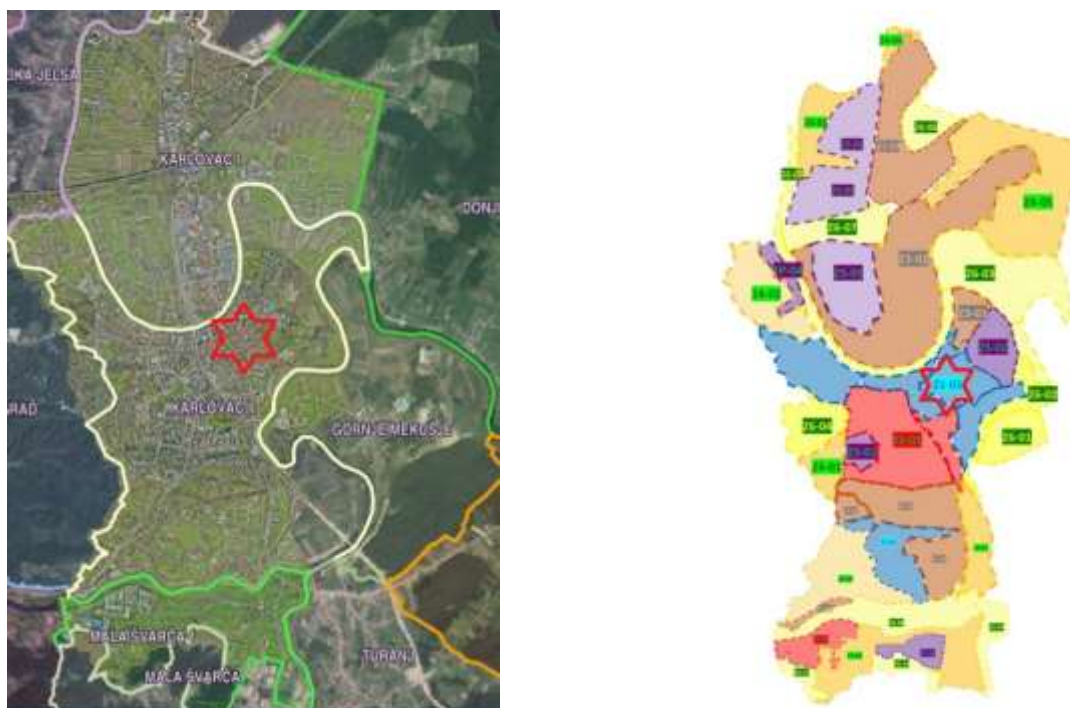


Figure 2: Overview of the recommended areas of energy and climate zones within the scope of the GUP, (Sources: GIS Karlovac, REGEA)

Key characteristics of Zone Z1 (Zvijezda and surroundings):

- Includes the core urban structure of Zvijezda, its green buffer zones, the old town centre, and historically significant areas along the Korana and Kupa rivers.



- Subject to strict heritage protection regulations under the Urban Development Plan (UPU).
- Recognised as a strategic site for energy transition and climate neutrality.

Strategic Recommendations for Zone Z1:

- Mandatory connection to the district heating system or the use of a central renewable-based heating/cooling system (e.g. geothermal).
- Obligation to achieve climate neutrality upon adoption of amendments to the General Urban Plan (GUP).
- Application of integrated planning principles, in accordance with the city's Sustainable Energy and Climate Action Plan (SECAP) and specifically:
 - **Measure 3:** Introduction of integrated energy and climate planning.
 - **Measure 26:** Establishment of energy zoning in the urban planning framework.

By designating Zvijezda as Zone Z1, the City of Karlovac reinforces its intention to preserve architectural heritage while also pursuing an ambitious climate and energy transition agenda. This zoning recommendation directly supports the goals and structure of the Zvijezda Green and Digital Energy Action Plan, ensuring that proposed building renovations and energy system upgrades are consistent with long-term urban and environmental strategies.

2. Geothermal and District Heating System

Karlovac Development Plan and SECAP propose the transition to low-carbon district heating, with emphasis on future integration of geothermal sources to reduce dependence on fossil fuels and improve air quality.

Zvijezda is identified as a strategic location for connection to a modernised district heating system, particularly through potential geothermal energy infrastructure already under study.

Linked measure in Zvijezda Green and Energy Action Plan:

Full conversion of heating systems to geothermal-powered district heating, combined with thermal retrofitting of buildings.

3. Heat Pumps as Decentralised Low-Carbon Technology

The EKPP Guidelines support the application of heat pumps in buildings that are not suitable for district heating, especially in heritage zones where invasive interventions are limited.

SECAP includes the use of high-efficiency heating and cooling systems, explicitly naming heat pumps as a priority solution for decarbonisation in residential buildings.

Linked measure in Zvijezda Green and Energy Action Plan:

Building-level implementation of air-to-water or ground-source heat pumps, where connection to district heating system is not viable.

4. Photovoltaics on Buildings

All three documents encourage the deployment of solar PV systems on rooftops, with SECAP targeting significant increases in the share of renewable energy in the building sector.

The Karlovac Development Plan promotes the creation of energy self-sufficient public buildings through PV installations.

Linked measure in Zvijezda Green and Energy Action Plan:

Installation of building-integrated PV systems on suitable residential and public buildings in Zvijezda.

5. Energy Communities and Off-Site PV Systems



The EKPP Guidelines support the formation of renewable energy communities as a model for collective investment in PV systems.

SECAP calls for citizen engagement in clean energy generation and for exploring municipal land as potential locations for PV plants linked to urban districts.

Linked measure in Zvijezda Green and Energy Action Plan:

Establishment of an energy community for Zvijezda, enabling local residents and institutions to benefit from off-site solar production.

6. Public Lighting Modernisation

SECAP includes the objective of full LED conversion of the public lighting network, with smart controls to reduce consumption and light pollution.

Ongoing public lighting replacement programmes in Karlovac have already targeted thousands of luminaires.

Linked measure in Zvijezda Green and Energy Action Plan:

Replacement of all public lighting in Zvijezda with heritage-appropriate LED systems and smart dimming technologies.

7. Sustainable Mobility and Transport Electrification

The Karlovac Development Plan promotes an integrated urban mobility approach, including public transport electrification, cycling infrastructure, and pedestrian zones.

SECAP supports the development of EV charging infrastructure and low-emission zones in the city centre.

Linked measure in Zvijezda Green and Energy Action Plan:

Installation of EV chargers at district entry points, promotion of e-bikes, and gradual limitation of fossil-fuel vehicles in the historic core.

3. Analysis Limitations and Assumptions

The energy modelling and scenario analysis presented in this Action Plan are based on the best available data at the time of preparation. However, several limitations must be acknowledged, particularly considering the complex historical and cultural nature of the Zvijezda district and the challenges associated with data availability and quality:

- **Incomplete and inconsistent data**

For many buildings, especially those without energy performance certificates, information regarding heating systems, floor area, usage patterns, and renovation status was either unavailable or incomplete. In such cases, reasoned assumptions were made based on typologies, visual inspections, and statistical averages.

- **Use of generalized values**

In the absence of building-specific data, average specific energy demand values (e.g., 350-380 kWh/m²) and heating demand factors were applied. This approach introduces a level of uncertainty at the individual building level, though the methodology is more reliable when assessed at the district scale.

- **Heritage constraints and structural condition**

Many buildings in Zvijezda are protected cultural assets and/or damaged by recent earthquakes. Their structural condition and architectural restrictions significantly affect the feasibility and applicability of certain renovation measures. This affects the energy modelling assumptions and must be considered when interpreting the results.



- **Diversity and overlap of energy sources**

Survey results and historical data indicate that multiple energy sources are often used in parallel (e.g., firewood and electric heaters). The modelling approach distributes heating energy demand among different carriers using proxy data and assumptions, which may not reflect actual usage precisely.

- **Limitations Related to Buildings Use and Resident Behaviour**

Another limitation affecting the reliability of the model is the **lack of complete and up-to-date information on the actual use of residential and non-residential units within buildings**. Due to ongoing infrastructure works in the district (e.g., the Agglomeration project), as well as demographic and economic shifts, the occupancy status of many buildings is uncertain. Some units may be temporarily vacant, under renovation, or partially in use. Furthermore, a notable portion of the building stock is in **poor structural condition**, and a significant share of residents could be affected by energy poverty. This results in a behavioural pattern where living spaces are underheated or not heated at all during winter months, and cooling is entirely absent in summer, leading to significantly lower real energy consumption than expected under normative conditions. These factors are not fully captured in the model, which assumes standardised usage profiles and heating demand, and thus may overestimate actual energy needs in some cases.

- **Calibration challenges**

While the model was calibrated using real energy consumption data where available (especially for public buildings and electricity), no comprehensive consumption datasets exist for natural gas, heating oil, or firewood. This impacts the precision of fuel-specific projections and investment estimates.

- **Temporal evolution of the district**

Ongoing infrastructure works (e.g., Agglomeration project) and potential changes in building usage or ownership mean that the current energy model represents a snapshot in time, and will need to be updated regularly to remain relevant and accurate.

- **Conservation Constraints and Compatibility with Decarbonisation Goals**

An additional limitation specific to the Zvijezda district is its protected cultural heritage status, which imposes strict regulations on any physical interventions. Measures such as thermal insulation of facades, replacement of windows, installation of solar panels, or placement of external heat pump units are often restricted or prohibited under conservation guidelines. These constraints can significantly limit the technical feasibility or cost-effectiveness of standard energy renovation approaches. As a result, certain assumptions made in the modelling (e.g. insulation thickness, PV installation, mechanical system replacement) may not be permitted or only partially implementable without specific waivers or alternative technical solutions. The Action Plan aims to identify viable decarbonisation strategies that are technically flexible, visually unobtrusive, and culturally respectful, but acknowledges that full harmonisation between heritage protection and climate targets remains a complex, case-by-case challenge.

As a result, all projections and scenario-based evaluations in this Plan should be interpreted as indicative and subject to refinement as more precise or updated data become available. The methodology prioritises transparency, replicability, and strategic insight over building-level precision.



4. Decarbonisation Strategy Scenario 1: Block-Level Buildings Renovation with Centralised Heating, Smart Lighting and E-Mobility

4.1. Scenario Overview

This scenario proposes a neighbourhood-scale renovation approach based on the deployment of a modern, low-emission centralised District Heating System (DHS) powered by geothermal energy. It is accompanied by a set of supporting measures aimed at improving building performance and increasing local renewable energy production.

4.2. Technical Measures

1. Thermal Envelope Refurbishment

- Exterior wall insulation using mineral wool (where permitted)
- Roof/attic insulation
- Window replacement with heritage-compatible triple-glazed units
- Floor insulation from basement/cellar side

2. Heating System Shift

- Full replacement of individual heating systems with district heating substations (hydraulic interface units)
- Geothermal heat source located outside the district and piped in via pre-insulated distribution network

3. On-Site Renewable Energy

- Rooftop photovoltaic (PV) systems on suitable public and private buildings
- Average size: 3-10 kWp per building (subject to roof orientation, shading, and structural limits)

4. Off-Site RES via Energy Communities

- Participation of Zvijezda residents in solar farms located on municipal land outside the heritage zone
- Virtual net metering and prosumer rights enabled

5. Public Lighting Retrofit

- Replacing all existing sodium/fluorescent lamps with LED fixtures
- Adding smart controls (dimming, motion sensors)



Table 2: Key Performance Indicators - public lightning retrofit in Zvijezda neighbourhood (Phase 1- 2025)

Parameter:	Value:
Energy consumption before [kWh/y]:	151.571,88
Installed power before [kW]:	30,58
Unit price of electricity [€/kWh]:	0,105
CO ₂ factor for electricity [kgCO ₂ /kWh]:	0,159
OPEX before [€/y]:	15.859,17
CO ₂ emissions before [tCO ₂ /kWh]:	24,10
Energy consumption after [kWh/y]:	25.770,96
Installed power after [kW]:	8,64
OPEX after [€/y]:	2.696,45
CO ₂ emissions after [tCO ₂ /kWh]:	4,10
Final Energy savings [kWh/y]:	125.800,92
Primary Energy savings [kWh/y]:	188.450,78
Installed power reduction [kW]:	21,94
OPEX savings [€/y]:	13.162,72
CO₂ emission reduction [tCO₂/kWh]:	20,00
Number of public lighting fixtures in Zvijezda:	194
Unit price [€/piece]:	465,65
Investment [€]:	90.335,27
Investment quality [€/kW]:	4.118,32
Investment quality [€/kWh]:	0,72
Investment quality [€/tCO ₂]:	4.516,23
Simple Payback Period [years]:	6,86

Table 3: Key Performance Indicators - public lightning retrofit in Zvijezda neighbourhood (Phase 2 - 2038)

Parameter:	Value:
Energy consumption before [kWh/y]:	25.770,96
Installed power before [kW]:	8,64
Unit price of electricity [€/kWh]:	0,105
CO ₂ factor for electricity [kgCO ₂ /kWh]:	0,159
OPEX before [€/y]:	2.705,95
CO ₂ emissions before [tCO ₂ /kWh]:	8,64
Energy consumption after [kWh/y]:	16.285,82
Installed power after [kW]:	6,05
OPEX after [€/y]:	1.704,01
CO ₂ emissions after [tCO ₂ /kWh]:	2,59
Final Energy savings [kWh/y]:	9.485,14
Primary Energy savings [kWh/y]:	14.208,74
Installed power reduction [kW]:	2,59
OPEX savings [€/y]:	992,44
CO₂ emission reduction [tCO₂/kWh]:	1,51
Number of public lighting fixtures in Zvijezda:	194
Unit price [€/piece]:	100,00
Investment [€]:	19.400,00
Investment quality [€/kW]:	7.484,57
Investment quality [€/kWh]:	2,05
Investment quality [€/tCO ₂]:	12.863,54
Simple Payback Period [years]:	19,55



6. Traffic shutdown (except for residents) & electrification of transport

- Introduction of e-vehicle charging stations on the perimeter of Zvijezda
- Incentives for e-bike sharing and electric minibuses

Table 4: Indicative energy reduction in transport

Year	Transport Measures in Zvijezda	Traffic Reduction [%]	Energy consumption [kWh/y]	Energy reduction [kWh/y]	CO2 emissions [tCO2/y]	CO2 emission savings [tCO2/y]
2025	No measures	0%	1.090.788	0	305,89	0
2030	Traffic ban for trucks	30%	763.552	327.236	214,12	91,77
2040	Traffic ban for petrol, diesel and LPG vehicles	80%	152.710	610.841	42,82	171,30
2050	Pedestrian-priority zone	100%	0	152.710	0,00	42,82

4.3. KPIs and Impact Summary (Scenario 1)

Table 5: KPIs and Impact Summary (Scenario 1) - year 2050.

INDICATOR	VALUE
Primary Energy Needs [kWh/y]:	21.380.712
Final Energy Needs [kWh/y]:	17.684.496
CO ₂ Emissions [t CO ₂ /y]:	339
Specific Primary Energy Needs [kWh/m ² /y]:	161,50
Specific Final Energy Needs [kWh/m ² /y]:	133,58
Specific CO ₂ Emissions [kgCO ₂ /m ² /y]:	2,56
Primary Energy Reduction [kWh/y]:	23.215.732
Final Energy Reduction [kWh/y]:	19.193.880
CO ₂ Emissions Reduction [t CO ₂ /y]:	4.908
OPEX Savings [€/year]:	1.095.560
Total Investment [€]:	43.839.021 €
Payback Period (average) [years]:	51,53
RES Share in Final Energy [%]:	14,77
Heating Supply Type:	Geothermal District Heating
Installed PV Capacity [kW]:	2.577



4.4. Action plan (Scenario 1)

Table 6: Action plan for Scenario 1 (2025 - 2050)

SEGMENT	Year	CAPEX [€]	OPEX savings [€/year]	Final energy savings [kWh/year]	Primary energy savings [kWh/year]	Production [kWh/year]	CO2 savings [t/year]	Simple payback period [years]
BLOCK 1	2025	4.543.291	70.909	1.492.853	1.829.434	281.065	370	65,56
BLOCK 2	2025	1.271.855	16.044	375.680	462.198	111.078	86	75,38
BLOCK 3	2025	1.248.307	21.816	385.440	504.523	209.105	119	85,00
BLOCK 4	2025	288.208	3.767	166.290	202.842	39.853	10	77,00
BLOCK 5	2030	2.619.134	35.597	485.815	611.798	73.524	237	77,00
BLOCK 6	2030	1.270.268	21.620	521.566	694.367	46.569	120	62,38
BLOCK 7	2030	1.113.350	25.649	440.018	733.733	63.789	204	54,57
BLOCK 8	2030	1.519.281	35.822	521.887	649.299	166.254	183	53,00
BLOCK 9	2030	1.008.996	28.503	414.656	541.849	99.230	105	76,33
BLOCK 10	2035	1.522.257	46.178	667.058	921.273	120.491	121	68,91
BLOCK 11	2035	1.258.540	20.090	559.904	682.609	68.776	100	69,90
BLOCK 12	2035	734.596	18.680	365.976	468.604	26.528	63	49,70
BLOCK 13	2040	5.302.703	128.544	2.150.737	2.891.452	255.035	409	45,52
BLOCK 14	2040	1.953.633	53.952	633.339	945.915	169.018	223	34,14
BLOCK 15	2040	1.193.889	50.037	510.016	712.761	91.495	165	23,00
BLOCK 16	2040	249.744	1.854	-85.220	-56.416	0	9	135,00
BLOCK 17	2040	1.025.280	24.885	462.369	608.260	75.702	69	47,79
BLOCK 18	2040	1.642.766	63.299	718.768	1.016.030	145.494	174	26,67
BLOCK 19	2045	1.951.084	90.368	857.113	1.193.248	161.955	314	24,33
BLOCK 20	2045	1.811.101	71.565	790.697	1.075.346	167.642	251	25,00
BLOCK 21	2045	1.034.313	25.914	431.823	567.790	57.533	91	48,00
BLOCK 22	2045	518.711	14.254	248.787	333.042	17.508	35	48,00
BLOCK 23	2045	2.824.082	65.204	960.772	1.336.271	85.825	197	54,06
BLOCK 24	2045	135.550	4.595	64.974	89.213	0	12	29,00
BLOCK 25	2045	712.493	22.909	253.907	342.007	37.028	90	39,86
BLOCK 26	2050	1.270.735	16.265	290.076	335.311	130.358	118	78,00
BLOCK 27	2050	2.118.509	54.155	920.404	1.077.852	0	379	39,00
BLOCK 28	2050	759.078	26.050	344.197	476.895	28.660	73	31,38
BLOCK 29	2050	937.267	37.035	409.195	556.504	105.268	130	25,00
PUBLIC LIGHTNING 1. phase	2025	90.335	13.163	125.801	188.450	0	20	6,86
PUBLIC LIGHTNING 2. phase	2038	19.400	992	9.485	14.209	0	2	19,55
TRANSPORT 1. phase	2030	-	116.368	763.552	889.988	0	214	-
TRANSPORT 2. phase	2040	-	23.274	152.710	177.998	0	43	-
TOTAL:		43.948.756	1.249.356	17.410.645	23.074.654	2.834.783	4.735	51,45

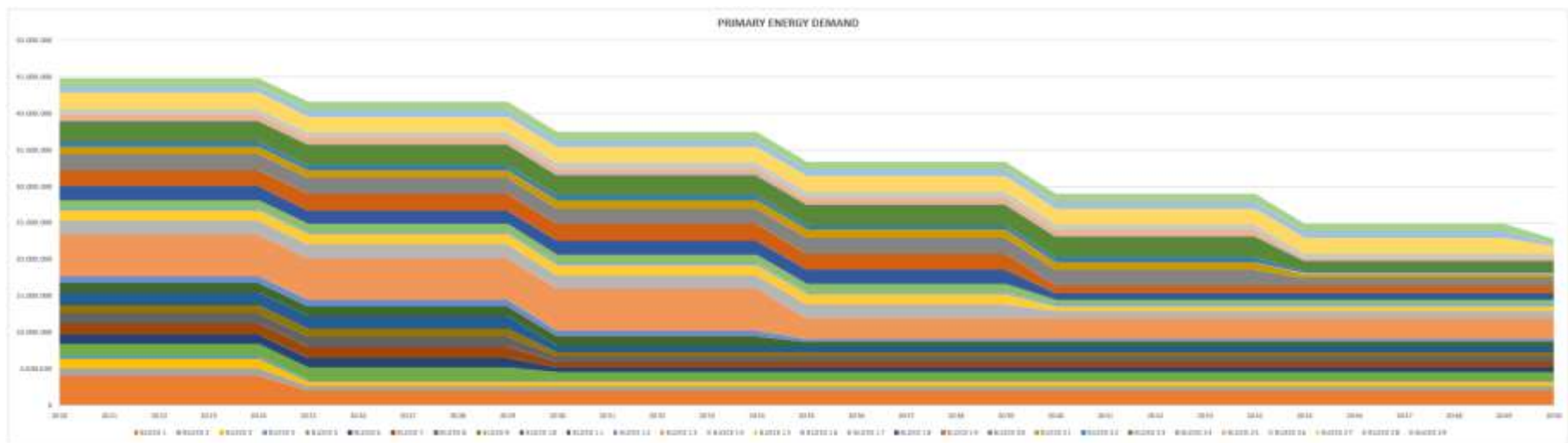


Figure 3: Scenario 1 - Primary energy demand reduction (2025 - 2050)

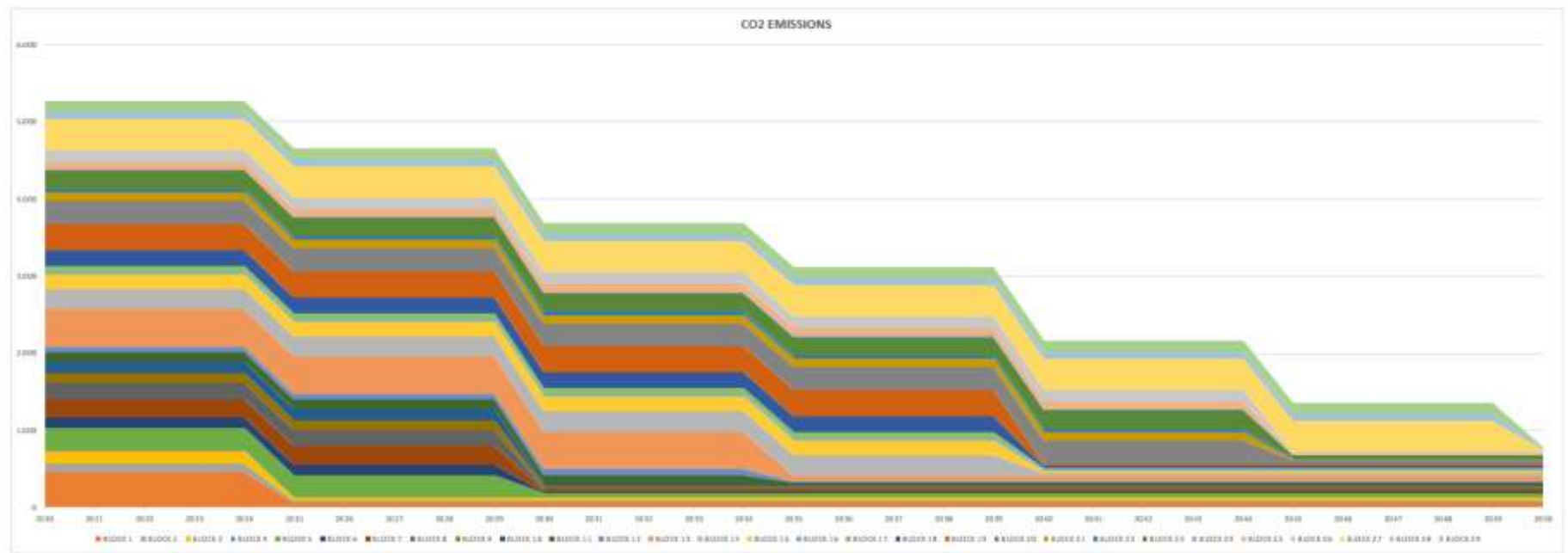


Figure 4: Scenario 1 - CO₂ emissions reduction (2025 - 2050)

5. Decarbonisation Strategy Scenario 2: Block-Level Buildings Renovation with Heat Pumps, Smart Lighting and E-Mobility

5.1. Scenario Overview

This alternative approach focuses on building-level heating solutions, replacing fossil fuel systems with electric air-to-water or ground-source heat pumps, while maintaining all other renovation and energy production measures from Scenario 1.

5.2. Technical Measures

1. Thermal Insulation and Windows

- Identical to Scenario 1 (with special attention to façade-integrated insulation where heritage allows)

2. Heat Pump Implementation

- Individual units sized per building heat demand
- SCOP assumed: 4.3 (annual performance)
- Some buildings may require hybrid systems (e.g., HP + auxiliary electric heater for peak loads)

3. Same RES Measures

- On-site PV for electricity production (self-consumption model)
- Off-site PV through energy community participation

4. Public Infrastructure Improvements

- Same LED street lighting upgrade and smart controls
- Electrification of transport as in Scenario 1

5.3. KPIs and Impact Summary (Scenario 2)

Table 7: KPIs and Impact Summary (Scenario 2) - year 2050.

INDICATOR	VALUE
Primary Energy Needs [kWh/y]:	10.888.797
Final Energy Needs [kWh/y]:	5.475.449
CO ₂ Emissions [t CO ₂ /y]:	897
Specific Primary Energy Needs [kWh/m ² /y]:	82,25
Specific Final Energy Needs [kWh/m ² /y]:	41,36
Specific CO ₂ Emissions [kg CO ₂ /m ² /y]:	6,78
Primary Energy Reduction [kWh/y]:	33.707.647



Final Energy Reduction [kWh/y]:	31.402.927
CO ₂ Emissions Reduction [t CO ₂ /y]:	4.350
OPEX Savings [€/year]:	1.270.346
Total Investment [€]:	55.889.721
Payback Period (average) [years]:	52,56
RES Share in Final Energy [%]:	51,77
Heating Supply Type:	Shallow ground-source heat pumps
Installed PV Capacity [kW]:	2.577



5.4. Action plan (Scenario 2)

Table 8: Action plan for Scenario 2 (2025 - 2050)

SEGMENT	Year	CAPEX [€]	OPEX savings [€/year]	Final energy savings [kWh/year]	Primary energy savings [kWh/year]	Production [kWh/year]	CO2 savings [t/year]	Simple payback period [years]
BLOCK 1	2025	5.737.364	85.501	2.535.015	2.723.321	281.065	324	66,56
BLOCK 2	2025	1.606.127	20.290	651.407	700.628	111.078	73	69,88
BLOCK 3	2025	1.758.006	26.304	707.729	780.829	209.105	104	89,14
BLOCK 4	2025	363.954	5.080	259.648	282.950	39.853	6	72,00
BLOCK 5	2030	3.307.498	41.937	998.098	1.047.005	73.524	215	81,00
BLOCK 6	2030	1.604.119	27.551	898.621	1.021.071	46.569	102	61,38
BLOCK 7	2030	1.405.961	30.696	781.765	1.028.198	63.789	188	53,86
BLOCK 8	2030	1.918.579	41.119	895.779	970.331	166.254	165	55,57
BLOCK 9	2030	1.274.181	32.654	691.818	780.975	99.230	93	71,00
BLOCK 10	2035	1.941.302	53.220	1.148.374	1.335.639	120.491	100	66,55
BLOCK 11	2035	1.589.311	26.035	931.126	1.004.777	68.776	83	64,90
BLOCK 12	2035	927.665	21.928	597.305	667.077	26.528	52	49,60
BLOCK 13	2040	6.808.707	152.762	3.818.835	4.326.570	255.035	329	46,75
BLOCK 14	2040	2.467.087	60.362	1.082.753	1.332.034	169.018	204	38,57
BLOCK 15	2040	1.507.668	55.191	867.188	1.019.948	91.495	147	26,83
BLOCK 16	2040	531.357	3.401	25.959	38.887	0	4	156,00
BLOCK 17	2040	1.294.745	29.036	759.112	862.763	75.702	54	49,93
BLOCK 18	2040	2.074.519	70.422	1.221.276	1.447.508	145.494	151	30,33
BLOCK 19	2045	2.463.869	99.125	1.475.504	1.724.195	161.955	286	27,67
BLOCK 20	2045	2.287.096	79.383	1.332.516	1.541.343	167.642	227	29,00
BLOCK 21	2045	1.306.151	30.372	746.041	837.625	57.533	76	49,25
BLOCK 22	2045	655.039	16.520	410.355	471.657	17.508	28	48,67
BLOCK 23	2045	3.566.310	76.844	1.783.591	2.042.675	85.825	160	55,00
BLOCK 24	2045	171.175	5.213	108.883	126.889	0	10	33,00
BLOCK 25	2045	899.747	25.807	458.246	517.470	37.028	82	42,00
BLOCK 26	2050	1.604.710	19.244	499.747	515.382	130.358	109	83,00
BLOCK 27	2050	2.675.296	63.807	1.606.649	1.666.698	0	348	42,00
BLOCK 28	2050	958.579	29.461	585.210	683.817	28.660	62	34,63
BLOCK 29	2050	1.183.599	41.081	689.594	797.663	105.268	117	29,00
PUBLIC LIGHTNING 1. phase	2025	90.335	13.163	125.801	188.450	0	20	6,86
PUBLIC LIGHTNING 2. phase	2038	19.400	992	9.485	14.209	0	2	19,55
TRANSPORT 1. phase	2030	-	116.368	763.552	889.988	0	214	-
TRANSPORT 2. phase	2040	-	23.274	152.710	177.998	0	43	-
TOTAL:		55.999.456	1.424.142	29.619.692	33.566.569	2.834.783	4.177	53,21

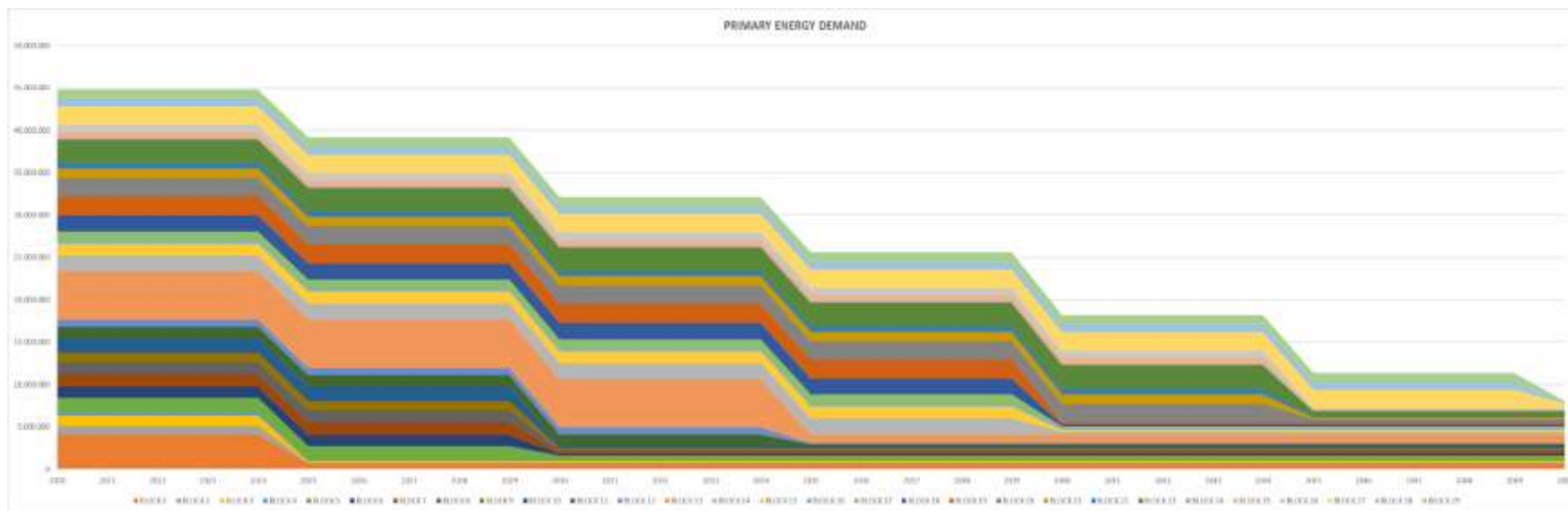


Figure 5: Scenario 2 - Primary energy demand reduction (2025 - 2050)

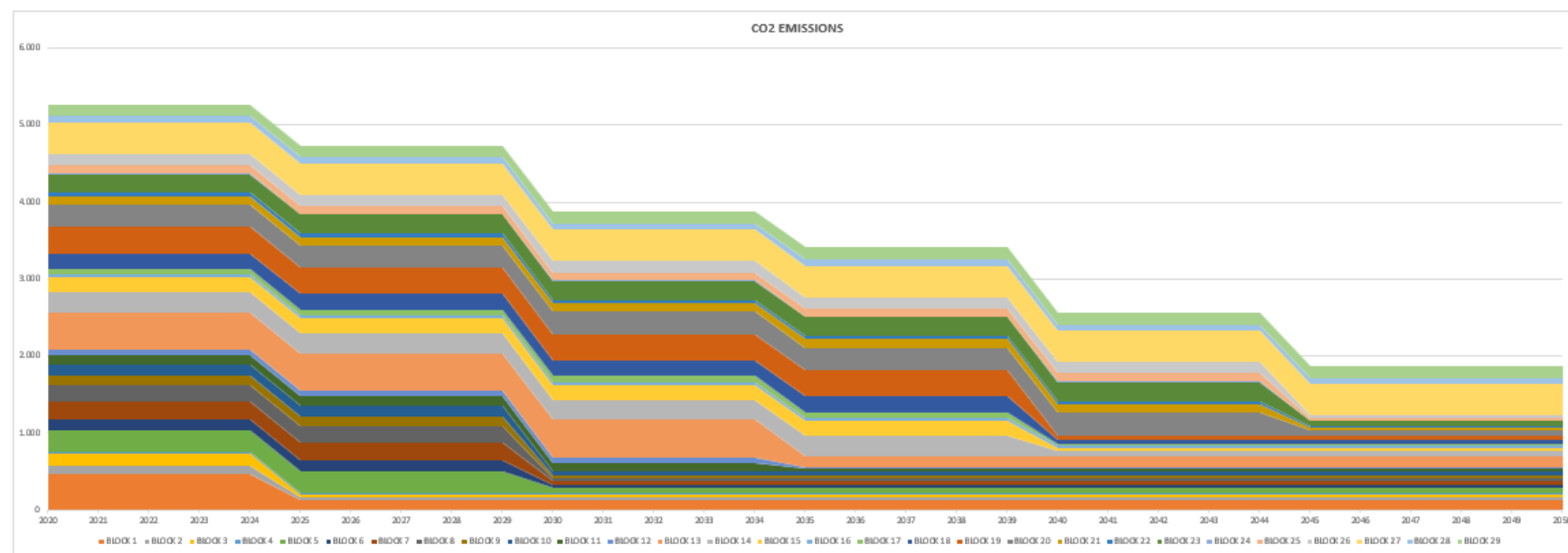


Figure 6: Scenario 2 - CO₂ reduction (2025 - 2050)

6. Implementation Roadmap and Milestones

Outlines the proposed timeline for implementing renovation measures, including phased actions from short-term (2025) to long-term (2050). Defines project stages, responsible entities, and key deadlines to ensure structured deployment of technologies, building upgrades, and infrastructure improvements.

7. Scenario Calculations and GIS Integration Overview

7.1. Energy Modelling and Scenario Tables

The core of the analytical work for the Zvijezda Green and Digital Energy Action Plan was carried out through a dedicated Excel-based model. This tool was developed to calculate baseline energy demand and simulate the effects of different renovation and decarbonisation scenarios.

Key features of the modelling approach include:

- Building-by-building data structure: Each of the 235 buildings in the district is represented with attributes such as use type, floor area, conservation status, heating system, and energy demand (derived or assumed).
- Energy flow calculations: Final and primary energy demand were computed by end-use (heating, DHW, lighting, appliances) and by fuel type, with energy conversion factors taken from the national 2021 methodology for building energy audits.
- Scenario differentiation: For each decarbonisation strategy, the model applied specific technical measures, e.g. heat pump SCOP, CTS supply efficiency, PV sizing, and RES shares.

Impact estimates: The model outputs included reductions in primary/final energy, CO₂ emissions, estimated investment costs, and calculated payback periods.

The model was calibrated using available consumption data, certificates, and survey inputs. Due to data limitations, some values are based on reasonable assumptions and averages, as documented in the methodology section of this report.

7.2. GIS Integration

To support spatial visualisation, communication, and cross-sectoral planning, a QGIS-based geospatial platform was used to represent energy data and simulate the impact of proposed measures.

Main steps in GIS integration included:

- Importing building-blocks-level data from Excel to QGIS using georeferenced block and parcel layers.
- Assigning attributes: Each building-block polygon was linked to calculated energy and emissions values, baseline and scenario data, and technical renovation indicators (e.g. insulation applied, PV installed, heating type changed).
- Creating thematic layers for:
 - CO₂ emissions per building block
 - Energy use intensity (kWh/m²)
 - Heating system types (current vs. scenario)
 - PV capacity (on-site and virtual)



This combined Excel-GIS workflow ensures that all scenarios are spatially explicit, analytically traceable, and digitally reproducible. It also provides a strong basis for future updates as better data become available and as implementation progresses.

8. Governance and Institutional Framework

Defines the roles and responsibilities of stakeholders involved in the planning, coordination, financing, and execution of the action plan. Includes municipal departments, utilities, private sector partners, and community actors. Aligns implementation with local urban and regulatory plans (e.g. GUP, UPU, conservation rules).

9. Conclusion and Strategic Outlook

The transformation of Zvijezda into a low-carbon, energy-efficient neighbourhood is both feasible and desirable, given the maturity of available technologies and the alignment with EU and national climate objectives. Both scenarios lead to substantial decarbonisation, but the decision between centralised and decentralised approaches depends on factors such as funding model, technical capacity, community preferences, and long-term urban energy vision.



C. GREEN AND DIGITAL ENERGY ACTION PLAN FOR QUEDLINBURG, GERMANY

1. Decarbonisation Strategy Scenario: Building Renovation with Heat Pumps

1.1. Scenario Overview

This scenario for Quedlinburg focuses on a decentralised approach to decarbonisation, based on deep energy renovation of buildings combined with the introduction of high-efficiency heat pumps as the primary heating technology. The strategy targets residential building blocks and aims to significantly reduce energy demand, greenhouse gas emissions, and operational costs, while increasing the share of renewable energy in final consumption. The approach is based on building-level interventions, allowing flexibility in implementation and adaptation to the specific technical and ownership conditions of the building stock. This makes it particularly suitable for heterogeneous urban areas with varying building typologies and renovation states.

1.2. Technical Measures

THERMAL ENVELOPE REFURBISHMENT

The renovation of the building envelope represents the foundation of the scenario. Measures include:

- External wall insulation (according to structural and architectural feasibility)
- Roof and attic insulation to reduce heat losses
- Replacement of windows with high-efficiency glazing systems
- Floor or basement ceiling insulation

These interventions significantly reduce heating demand and improve indoor thermal comfort, while also enabling more efficient operation of heat pumps.

HEAT PUMP SYSTEMS IMPLEMENTATION

Existing fossil fuel-based heating systems are replaced with electric heat pumps (air-to-water or ground-source, depending on site conditions).

- Systems are dimensioned according to reduced building heat demand after renovation
- Average seasonal performance (SCOP) assumed at high efficiency levels
- In some cases, hybrid systems may be used to cover peak loads

The electrification of heating is a key element of the decarbonisation pathway, particularly when combined with renewable electricity sources.

RENEWABLE ENERGY INTEGRATION

The scenario assumes the integration of renewable electricity, primarily through:



- On-site photovoltaic systems (where applicable)
- Potential participation in local or regional renewable energy schemes

This enables partial self-consumption of electricity used by heat pumps, further reducing operational costs and emissions.

1.3. Phasing and Implementation Timeline

The implementation is structured in phases aligned with investment cycles and renovation priorities:

PHASE 1 (2025-2030):

Focus on priority buildings (mainly Block 1), achieving:

- ~754,623 kWh/year final energy savings
- ~129 tCO₂/year emissions reduction

PHASE 2 (2030-2040):

Expansion to additional buildings, continuing energy demand reduction across the stock.

PHASE 3 (2040-2050):

Completion of renovation and full deployment of heat pump systems across Blocks 16 and 17, delivering the largest cumulative savings. This gradual rollout enables balanced investment planning and alignment with building renovation cycles.

1.4. Strategic Impact

The proposed scenario transforms the Quedlinburg building stock towards a low-carbon, energy-efficient system by:

- Eliminating fossil fuel-based heating at building level
- Reducing dependence on external energy sources
- Increasing resilience through electrification and efficiency
- Contributing to EU climate neutrality objectives

The combination of thermal insulation and heat pumps proves to be a robust and scalable solution, applicable across different building types and adaptable to local constraints.

1.5. Phasing and Implementation Timeline

The implementation is structured in phases aligned with investment cycles and renovation priorities:

PHASE 1 (2025-2030)

The first phase focuses on the most suitable and priority buildings, primarily located in Block 1. These buildings are characterised by relatively favourable technical conditions for renovation and early adoption of heat pump systems. During this phase, the emphasis is on achieving quick wins in energy savings while establishing the technical and organisational framework for broader implementation. Early investments



enable a reduction in energy demand and emissions, while also providing practical experience for scaling up the measures in later phases.

PHASE 2 (2030-2040)

In the second phase, the renovation programme expands to a larger share of the building stock, including additional buildings within Block 1 and gradually extending to other blocks. This phase represents the core period of implementation, where the majority of thermal insulation measures are applied and heat pump systems are installed at scale. The focus is on maximising cumulative energy savings and reducing emissions through systematic renovation. At the same time, lessons learned from the initial phase contribute to improved efficiency in project delivery and cost optimisation.

PHASE 3 (2040-2050)

The final phase completes the transformation of the building stock, with a particular focus on Blocks 16 and 17, which are implemented later due to technical, financial, or organisational constraints. This phase ensures full coverage of the planned measures, optimising system performance and achieving the highest levels of energy efficiency and decarbonisation. By the end of the period, the majority of buildings are expected to operate with significantly reduced energy demand and fully electrified heating systems based on heat pumps.

BLOCK / Year of EE measures implementation	No. of Buildings	Useful Area [m2]	CAPEX [€/year]	OPEX savings [€/year]	Final energy savings [kWh/year]	Primary energy savings [kWh/year]	CO2 savings [t/year]	Simple payback period [years]
BLOCK 1	37	15.818	6.916.770	126.513	1.199.221	1.201.963	204	53,49
2025	18	10.333	4.518.047	80.188	754.623	759.171	129	55,56
2030	19	5.485	2.398.723	46.325	444.598	442.792	75	51,53
BLOCK 16	31	13.821	5.723.925	140.775	1.316.041	1.328.512	222	41,84
2040	20	10.008	4.378.124	116.681	1.078.376	1.095.088	182	36,35
2045	11	3.813	1.345.801	24.094	237.665	233.424	40	51,82
BLOCK 17	29	14.807	3.454.442	103.800	1.064.505	1.025.406	165	36,97
2045	11	5.521	948.278	24.503	268.379	250.379	39	38,09
2050	18	9.286	2.506.164	79.297	796.126	775.027	126	36,28
TOTAL:	97	44.446	16.095.137	371.088	3.579.767	3.555.881	591	44,82



GREEN AND DIGITAL ENERGY ACTION PLAN FOR ZAMOŚĆ, POLAND

1. Decarbonisation Strategy Scenario 1: Building Renovation and Geothermal District Heating

1.1. Scenario Overview

The proposed decarbonisation strategy for the pilot site in historic centre of Zamość combines energy renovation of buildings with the gradual transition to a renewable-based district heating system supplied by geothermal energy. The scenario has been developed for urban fabric, where interventions must preserve the historical and architectural value of buildings while significantly reducing energy consumption and greenhouse gas emissions.

The strategy builds upon the building-level analyses carried out within Deliverables D.1.2.1 and D.1.2.2 and integrates them into a neighbourhood-scale approach. Priority is given to improving the thermal performance of building envelopes, followed by the replacement of fossil-fuel heating systems through connection to a geothermal district heating network. The proposed solution enables substantial decarbonisation while minimising visible interventions on protected buildings and reducing the need for individual heating installations. The scenario supports the long-term objective of transforming the historic centre into a low-carbon heritage district that combines cultural preservation with modern renewable energy infrastructure.

1.2. Technical Measures

The scenario consists of the following EE measures:

- Deep renovation of residential and public buildings using heritage-compatible insulation solutions, improved windows where conservation regulations permit, and optimisation of building envelopes.
- Gradual connection of renovated buildings to a geothermal district heating network replacing existing natural gas and other fossil-fuel based heating systems.
- Installation of modern district heating substations with smart metering and energy management functions.
- Modernisation of internal heating installations to improve distribution efficiency and compatibility with lower supply temperatures.

The district heating system provides a centralised renewable heat source that significantly simplifies operation and maintenance while improving energy security and reducing local air pollution.

Table 9: Decarbonisation Strategy Scenario 1: Building Renovation with Geothermal District Heating

Building ID	Year	CAPEX [€]	OPEX savings [€/year]	Final energy savings [kWh/year]	Primary energy savings [kWh/year]	Production [kWh/year]	CO2 savings [t/year]	Simple payback period [years]
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1	2030	978.354	31.227	350.862	496.542	0	145	31
2	2030	56.104	1.956	21.976	30.702	0	9	29
3	2030	54.026	1.724	19.375	27.420	0	9	31
4	2030	78.961	2.753	30.930	43.208	0	13	29
5	2030	286.753	9.153	102.836	145.535	0	42	31
6	2030	27.013	862	9.687	13.710	0	4	31
7	2030	27.013	942	10.581	14.782	0	4	29
8	2030	47.792	1.666	18.721	26.153	0	7	29
9	2030	162.078	5.650	63.487	88.691	0	25	29
10	2030	96.970	3.380	37.984	53.063	0	15	29
11	2030	58.611	2.044	22.958	32.073	0	10	29
12	2030	207.792	7.244	81.394	113.707	0	32	29
13	2030	173.160	5.527	62.100	87.884	0	26	31
14	2030	169.697	5.416	60.857	86.126	0	25	31
15	2030	155.844	5.433	61.046	85.280	0	24	29
16	2030	169.697	5.916	66.472	92.861	0	27	29
TOTAL:		2.749.864	90.892	1.021.266	1.437.738	0	416	30

Table 10: Scenario 1: KPI's

INDICATOR	VALUE
Heating Supply Type:	Geothermal District Heating
Primary Energy Needs [kWh/y]:	3.295.969
Final Energy Needs [kWh/y]:	2.398.742
CO ₂ Emissions [t CO ₂ /y]:	600
Useful Area [m ²]	7.940
Specific Primary Energy Needs [kWh/m ² /y]:	415,11
Specific Final Energy Needs [kWh/m ² /y]:	302,11
Specific CO ₂ Emissions [kg CO ₂ /m ² /y]:	75,57
Primary Energy Savings [kWh/y]:	1.437.738
Final Energy Savings[kWh/y]:	1.021.266
CO ₂ Emissions Savings [t CO ₂ /y]:	416
OPEX Savings [€/year]:	90.892
Investment (TI, Geoth) (2024) [€]:	2.749.864
Simple Payback Period [years]:	30,25

1.3. Phasing and Implementation Timeline

Implementation is proposed through several coordinated phases:

PHASE 1



Detailed engineering studies and permitting.

Preparation of district heating infrastructure.

Renovation of priority public buildings.

Pilot connection of selected buildings to the geothermal network.

PHASE 2

Extension of district heating infrastructure throughout the historic centre.

Large-scale renovation of residential buildings.

Progressive replacement of existing fossil-fuel heating systems.

PHASE 3

Completion of network expansion.

Optimisation of system operation using digital monitoring.

Integration with additional renewable electricity sources where feasible.

This phased implementation reduces investment risks while allowing gradual adaptation of residents and public institutions.

Table 11: Scenario 1: Decarbonization Roadmap 2020 - 2050

Year	Primary Energy Needs	Final Energy Needs	CO2 Emissions
2020	3.295.969	2.398.742	600
2030	2.698.097	1.975.599	425
2035	2.497.917	1.833.773	368
2040	2.210.383	1.627.950	286
2045	1.858.231	1.377.476	184

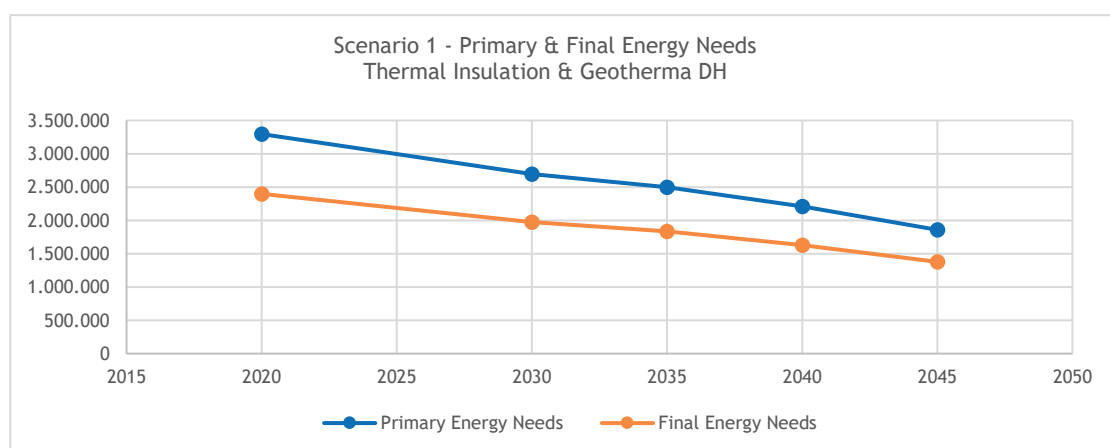


Figure 7: Scenario 1: Primary & Final Energy Needs

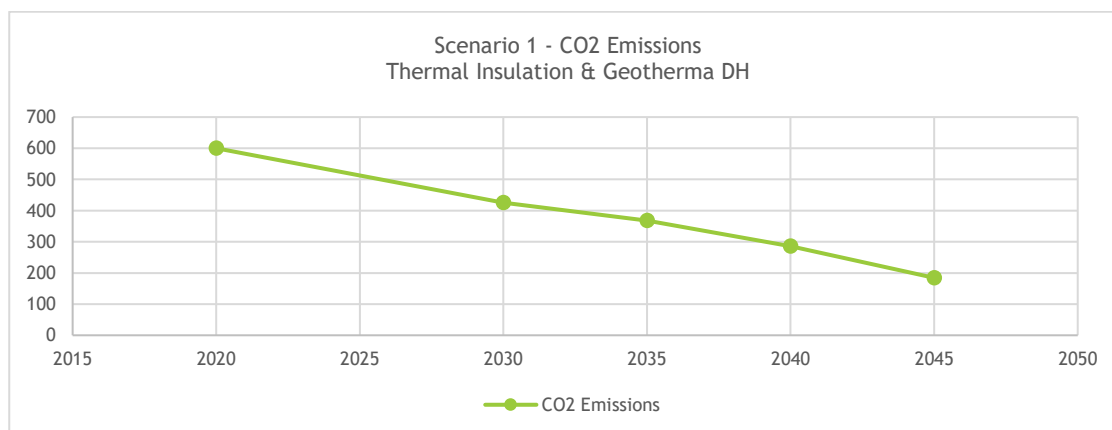


Figure 8: Scenario 1: CO2 Emissions

Table 12: Scenario 1: Primary / Final Energy & CO2 Savings

Year:	Primary Energy Savings [kWh/y]	Final Energy Savings [kWh/y]	CO2 Emissions Savings [t/y]
2030	597.872	423.143	175
2035	200.180	141.825	57
2040	287.535	205.823	82
2045	352.152	250.474	102
TOTAL:	1.437.738	1.021.266	416

1.4. Strategic Impact

The proposed scenario contributes simultaneously to climate neutrality, heritage preservation and urban resilience.

Expected strategic benefits include:

- significant reduction of final and primary energy demand;
- reduction of CO₂ emissions;
- replacement of fossil fuels with renewable geothermal energy;
- improved indoor comfort and building durability;
- reduced local air pollution;
- increased energy security through centralised renewable heating;



2. Decarbonisation Strategy Scenario 2: Building Renovation and Shallow ground-source heat pumps

2.1. Scenario Overview

The second scenario represents a decentralised decarbonisation pathway based on building renovation combined with shallow ground-source heat pump systems. This option is intended for buildings or areas where connection to a district heating network may not be technically or economically feasible.

Following improvements to the thermal performance of buildings, heating demand is reduced sufficiently to enable efficient operation of high-performance ground-source heat pumps. The scenario allows each building to operate independently while maintaining compatibility with strict heritage protection requirements. The approach provides flexibility for phased implementation and enables gradual replacement of conventional heating systems without requiring large-scale energy infrastructure investments.

2.2. Technical Measures

The scenario includes:

- Deep renovation of building envelopes using conservation-compatible solutions.
- Installation of vertical borehole heat exchangers where geological conditions permit.
- Deployment of high-efficiency ground-source heat pumps for space heating and domestic hot water preparation.
- Modernisation of internal heating systems to low-temperature operation.

Where possible, borehole fields may be shared between neighbouring buildings to optimise land use and reduce installation costs.

Table 13: Decarbonisation Strategy Scenario 1: Building Renovation and Shallow ground-source heat pumps

Building ID	Year	CAPEX [€]	OPEX savings [€/year]	Final energy savings [kWh/year]	Primary energy savings [kWh/year]	Production [kWh/year]	CO2 savings [t/year]	Simple payback period [years]
1	2030	485.166	47.291	638.468	649.247	0	92	10
2	2030	27.822	2.873	38.443	39.399	0	6	10
3	2030	26.791	2.611	35.257	35.852	0	6	10
4	2030	39.157	4.043	54.105	55.449	0	8	10
5	2035	142.201	13.861	187.133	190.293	0	27	10
6	2035	13.396	1.306	17.628	17.927	0	2	10
7	2035	13.396	1.383	18.510	18.969	0	2	10
8	2035	23.700	2.447	32.748	33.562	0	4	10
9	2040	80.374	8.298	111.058	113.817	0	16	10
10	2040	48.087	4.965	66.445	68.096	0	10	10
11	2040	29.065	3.001	40.161	41.159	0	6	10
12	2040	103.044	10.638	142.382	145.920	0	21	10
13	2045	85.870	8.370	113.003	114.911	0	16	10
14	2045	84.153	8.202	110.743	112.613	0	16	10
15	2045	77.283	7.979	106.787	109.440	0	16	10
16	2045	84.153	8.688	116.278	119.168	0	17	10
TOTAL:		1.363.657	135.954	1.829.149	1.865.822	0	264	10



Table 14: Scenario 2: KPI's

INDICATOR	VALUE
Heating Supply Type:	Shallow ground-source heat pumps
Primary Energy Needs [kWh/y]:	3.295.969
Final Energy Needs [kWh/y]:	2.398.742
CO ₂ Emissions [t CO ₂ /y]:	600
Useful Area [m ²]	7.940
Specific Primary Energy Needs [kWh/m ² /y]:	415,11
Specific Final Energy Needs [kWh/m ² /y]:	302,11
Specific CO ₂ Emissions [kg CO ₂ /m ² /y]:	75,57
Primary Energy Savings [kWh/y]:	1.865.822
Final Energy Savings[kWh/y]:	1.829.149
CO ₂ Emissions Savings [t CO ₂ /y]:	264
OPEX Savings [€/year]:	135.954
Investment (TI, HP) (2024) [€]:	1.363.657
Simple Payback Period [years]:	10,03

2.3. Phasing and Implementation Timeline

Implementation is foreseen in three consecutive phases:

PHASE 1

Geological investigations.

Feasibility studies.

Demonstration installations on representative pilot buildings.

PHASE 2

Progressive installation of ground-source heat pump systems in suitable residential and public buildings.

Optimisation of internal heating systems.

PHASE 3

Large-scale deployment across the historic district.

Digital optimisation of system operation.

Integration with future renewable electricity generation and energy communities where appropriate.

Table 15: Scenario 2: Decarbonization Roadmap 2020 - 2050

Year	Primary Energy Needs	Final Energy Needs	CO ₂ Emissions
2020	3.295.969	2.398.742	600
2030	2.516.022	1.632.468	489
2035	2.255.271	1.376.450	453
2040	1.886.279	1.016.404	401
2045	1.430.147	569.593	336

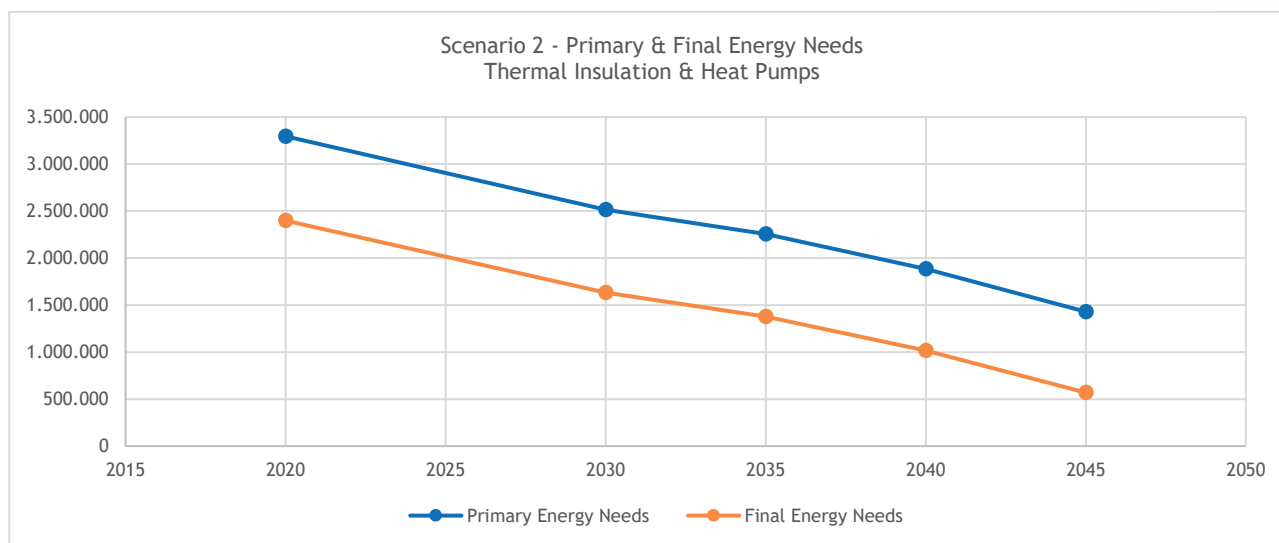


Figure 9: Scenario 2: Primary & Final Energy Needs

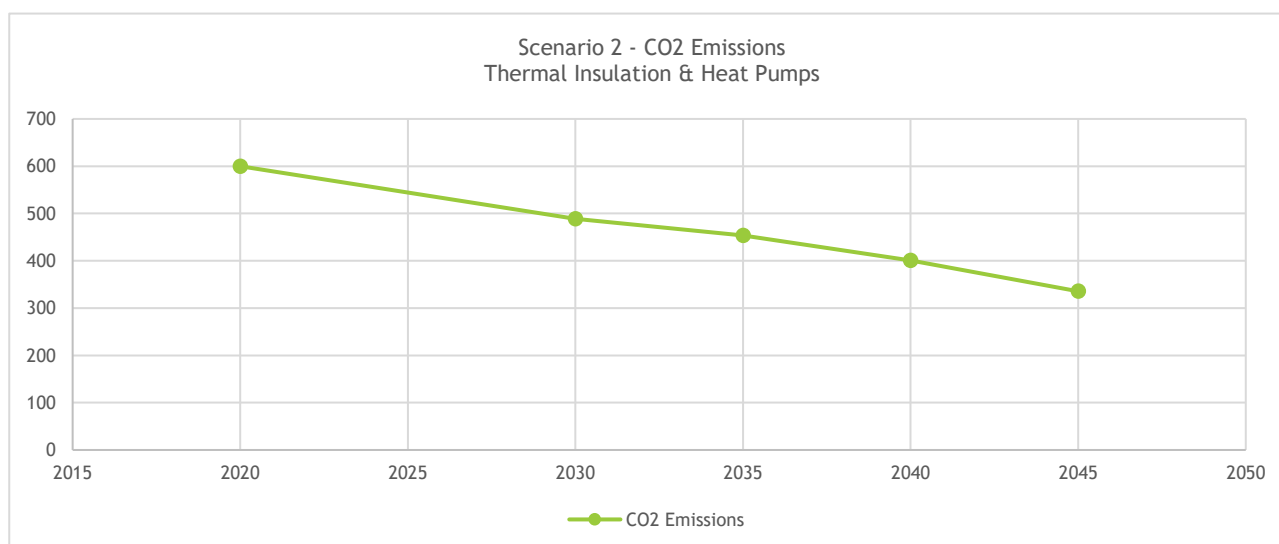


Figure 10: Scenario 2: CO₂ Emissions

Table 16: Scenario 2: Primary / Final Energy & CO₂ Savings

Year:	Primary Energy Savings [kWh/y]	Final Energy Savings [kWh/y]	CO ₂ Emissions Savings [t/y]
2030	779.947	766.274	111
2035	260.750	256.019	36
2040	368.992	360.045	53
2045	456.132	446.811	65
TOTAL:	1.865.822	1.829.149	264



2.4. Strategic Impact

The decentralised scenario provides an alternative pathway towards climate neutrality while preserving the historical character of Zamość pilot.

Its principal benefits include:

- high energy efficiency through ground-source heat pumps;
- major reductions in greenhouse gas emissions;
- elimination of fossil-fuel heating systems;
- flexible implementation adapted to individual buildings;
- compatibility with heritage conservation requirements;
- improved resilience through distributed energy systems;
- creation of a scalable model for historic urban districts lacking district heating infrastructure.

3. Public Lighting

The public lighting system in Zamość pilot has already undergone significant modernisation through the replacement of conventional luminaires with energy-efficient LED technology. As a result, the system already achieves substantially lower electricity consumption and maintenance requirements compared to traditional lighting solutions.

Based on the available information, no additional public lighting measures are proposed within this Energy Action Plan. Further optimisation, such as the implementation of adaptive lighting controls, smart lighting management systems or additional efficiency improvements, would require more detailed technical information on the existing infrastructure, operational profiles and control systems, which is currently not available.

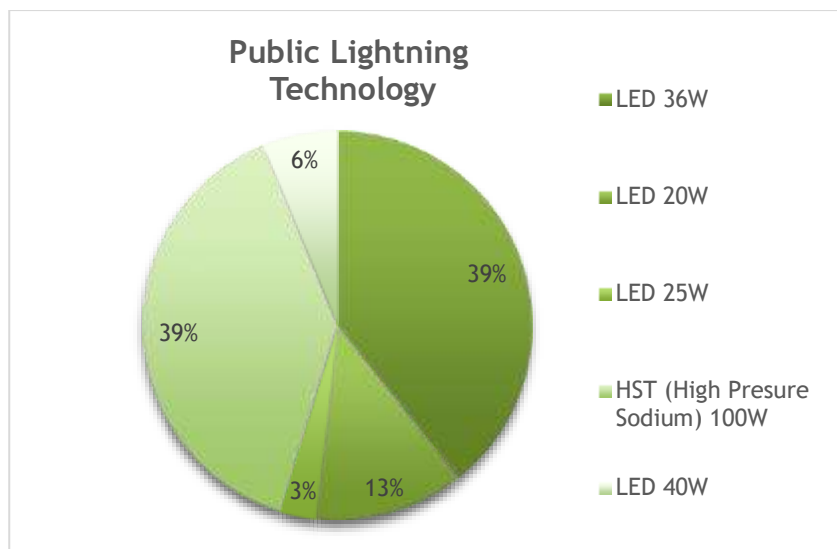
Consequently, public lighting is not considered a priority intervention within the present Action Plan. Nevertheless, future updates of the plan may include additional measures once more comprehensive technical data become available and opportunities for further digitalisation and optimisation can be assessed.

Table 1: Public Lighting - Electricity consumption, Zamość

No	TECHNOLOGY	Lamp Power [W]	No. of Lamps	Installed Power [W]	Share	Installed Power [kW]	Working Hours [h/y]	Electricity Consumption [kWh/y]
1	LED 36W	36	28	1.008,00	39,33%	1,008	4100	4.132,80
2	LED 20W	20	16	320,00	12,49%	0,32	4100	1.312,00
3	LED 25W	25	3	75,00	2,93%	0,075	4100	307,50
4	HST (High Pressure Sodium) 100W	100	10	1.000,00	39,02%	1	4100	4.100,00
5	LED 40W	40	4	160,00	6,24%	0,16	4100	656,00
TOTAL:			61	2.563,00	100,00%	2,563		10.508,30



Figure 11: Public Lightning - technology, Zamość



4. Transportation

The transport sector represents an important component of neighbourhood decarbonisation due to its contribution to overall energy consumption and greenhouse gas emissions. However, detailed local transport data for the Zamość pilot area, such as traffic counts, vehicle kilometres travelled and modal split, are currently not available. Therefore, the proposed transport measures should be considered indicative and primarily intended to demonstrate the potential contribution of sustainable mobility measures to achieving a zero-emission neighbourhood.

Table 2: Fuel consumption, Zamość

FUEL	Share	Fuel Consumption [kWh/y]	Assumed number of vehicles
Gasoline	53,20%	425.295,57	56
Diesel	38,70%	309.378,54	41
LPG	1,10%	8.793,71	1
Electricity	7,00%	55.959,94	7
TOTAL:	100,00%	799.427,76	105

According to the available baseline assessment, approximately 7% of the vehicle fleet is already electrified, while the remaining energy consumption is associated with conventional gasoline, diesel and LPG vehicles. Since electric vehicles do not contribute to direct fossil fuel consumption within the transport sector, only conventional vehicles are considered when estimating the effects of the proposed transport measures.

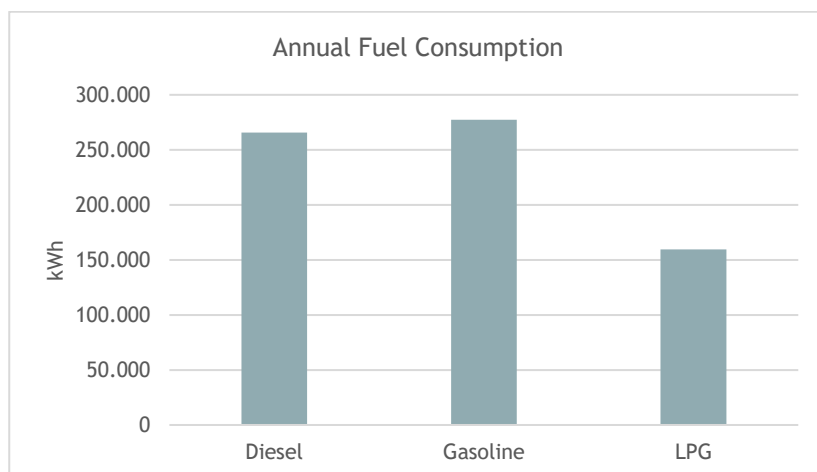


Figure 12: Estimation of fossil fuel consumption in traffic, Zamość pilot

For the purpose of estimating future energy savings and CO₂ emission reductions, the same calculation methodology applied for the Karlovac pilot will be used. The assessment assumes progressive reductions in fossil-fuel vehicle traffic resulting from the implementation of sustainable mobility measures, while maintaining a transparent and comparable approach across all pilot sites.

The indicative transport transition foresees a gradual introduction of traffic management measures. In the medium term, restrictions on heavy goods vehicles can reduce traffic-related energy consumption and emissions while improving environmental quality within the historic centre. In the longer term, access restrictions for conventional petrol, diesel and LPG vehicles could further accelerate decarbonisation, complemented by increased use of public transport, walking and cycling.

The long-term vision is the establishment of a pedestrian-priority historic centre with limited access for motorised traffic, preserving accessibility for residents, emergency services and other authorised users. These measures are expected to improve air quality, reduce noise levels, enhance the attractiveness of public spaces and contribute to the overall climate neutrality objectives of the Zamość neighbourhood.

Table 17: Indicative energy reduction in transport

Year	Transport Measure in Zvijezda	Traffic Reduction [%]	Energy consumption [kWh/y]	Energy reduction [kWh/y]	CO ₂ emissions [tCO ₂ /y]	CO ₂ emission savings [tCO ₂ /y]
2025	No measures	0%	702.617	0	192,61	0
2030	Traffic ban for trucks	30%	491.832	210.785	135,11	57,50
2040	Traffic ban for petrol, diesel and LPG vehicles	80%	98.366	393.466	27,02	108,09
2050	Pedestrian-priority zone	100%	0	98.366	0,00	27,02



D. GREEN AND DIGITAL ENERGY ACTION PLAN FOR PALMANOVA, ITALY

1. Existing Conditions and Baseline Assessment

1.1. Urban and Heritage Context

Palmanova is a UNESCO Renaissance fortress city located in the Friuli Venezia Giulia Region, Italy. Its unique nine-pointed star-shaped urban layout represents one of the most significant examples of military urban planning in Europe. The historic insula analysed within the ZEB4ZEN project contains municipal buildings, educational facilities, administrative premises and cultural heritage assets that require careful balancing between energy efficiency improvements and heritage conservation requirements.

The Municipality has committed to reducing greenhouse gas emissions and improving the energy performance of public assets in line with European climate objectives, regional energy policies and local sustainability strategies.

Due to its unique Renaissance urban structure and heritage value, energy renovation measures must be carefully designed to preserve architectural integrity while improving energy performance. The proposed approach prioritises non-invasive solutions and compatible technologies, ensuring consistency with heritage conservation requirements.



Figure 13: Map of Palmanova with the analysed insula



1.2. Building Stock Characteristics

The analysed building stock consists of six private and public buildings with a total conditioned floor area of 8,171 m². Main characteristics include:

- Ageing building envelopes with limited thermal insulation.
- Conventional heating systems with relatively low efficiency.
- High heating energy demand.
- Significant opportunities for electrification and energy performance improvement.
- Absence of integrated digital energy monitoring systems.

1.3. Energy and Emissions Baseline

The baseline assessment identified the following annual performance indicators:

INDICATOR	BASELINE
Final Energy Consumption [kWh/year]	1.365.785
Primary Energy Consumption [kWh/year]	1.951.325
Energy Costs [€/year]	575,273
CO ₂ Emissions [tCO ₂ /year]	293

Heating demand represents the largest share of overall energy consumption.

1.4. Digital Representation and Energy Data Management

The energy assessment was performed using the ZEB4ZEN energy modelling framework, integrating building-level technical data, energy consumption information and decarbonisation calculations.

The proposed digital approach foresees the progressive integration of:

- building energy databases;
- smart metering systems;
- digital monitoring dashboards;
- GIS-based visualization of municipal assets;
- KPI tracking and reporting tools.

1.5. KPIs and Impact Summary

INDICATOR	VALUE
Primary Energy Needs [kWh/y]	1.951.325
Final Energy Needs [kWh/y]	1.365.785
CO ₂ Emissions [tCO ₂ /y]	293
Conditioned floor area [m ²]	8.170,91
OPEX [€/y]	575,273



2. Integration of Existing City Strategies into the Palmanova Green and Digital Energy Action Plan

The proposed measures for Palmanova are consistent with:

- European Green Deal
- Fit for 55 Package
- REPowerEU Strategy
- Italian National Energy and Climate Plan (PNIEC)
- Regional Energy Strategy of Friuli Venezia Giulia
- Local sustainable urban development objectives

The Action Plan contributes to:

Energy Efficiency

Deep renovation of municipal buildings through thermal envelope improvements and reduction of heat losses.

Electrification of Heating

Replacement of conventional heating systems with high-efficiency heat pumps.

Digitalisation

Implementation of digital energy monitoring systems to support data-driven management of municipal assets.

Decarbonisation

Reduction of fossil fuel consumption and greenhouse gas emissions in public buildings.

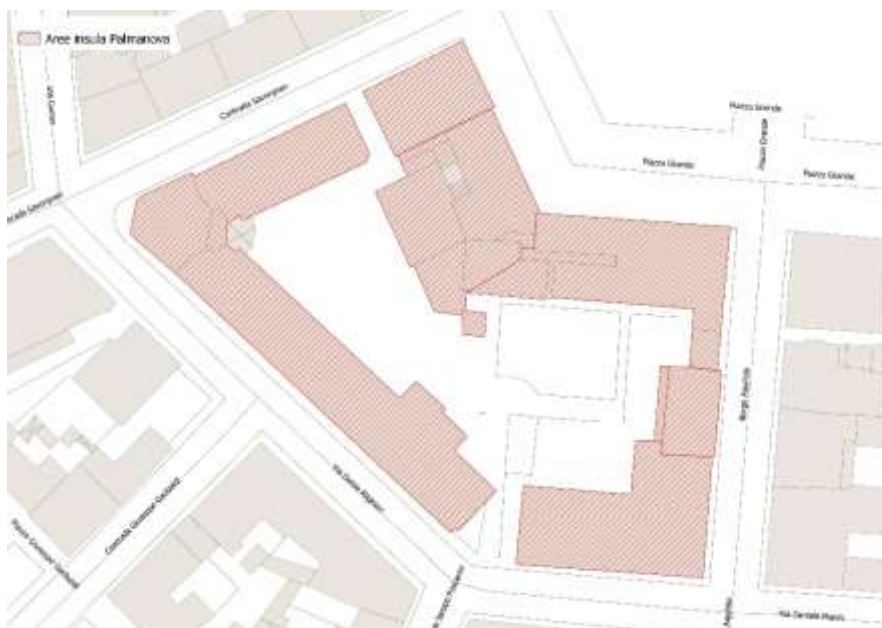


Figure 14: Map detail of Palmanova insula



3. Analysis Limitations and Assumptions

The assessment is based on the best available data at the time of preparation.

Key assumptions include:

- standard operating conditions for public buildings;
- typical occupancy schedules;
- heat pump seasonal performance values according to current technology standards;
- current electricity emission factors;
- average energy price assumptions;

Results should therefore be interpreted as strategic planning values and updated during detailed project design and implementation.

4. Decarbonisation Strategy: Public Buildings Renovation with Heat Pumps and Digital Energy Management

4.1. Scenario Overview

The proposed decarbonisation strategy focuses on the renovation of municipal buildings through a combination of:

- building envelope refurbishment;
- electrification of heating systems;
- deployment of high-efficiency heat pumps;
- digital monitoring and control solutions.

The objective is to create a highly efficient, low-carbon building portfolio while improving indoor comfort and reducing operating costs.

4.2. Technical Measures

Measure 1 - Building Envelope Renovation

- Thermal insulation improvements.
- Roof insulation upgrades.
- High-performance window replacement where applicable.
- Reduction of transmission losses.

Measure 2 - Heat Pump Deployment

- Replacement of conventional heating systems.
- Installation of electric heat pumps.
- Optimisation of heating system efficiency.
- Preparation for future renewable electricity integration.



Measure 3 - Digital Energy Management

- Smart metering.
- Building energy monitoring.
- Energy performance dashboards.
- Continuous KPI tracking.

4.3. KPIs and Impact Summary

Table 18: Target Scenario

INDICATOR	VALUE
Primary Energy Needs [kWh/y]:	1.093.122
Final Energy Needs [kWh/y]:	457.029
CO ₂ Emissions [t CO ₂ /y]:	117
OPEX [€/year]:	180,084

Table 19: Achieved reductions

INDICATOR	REDUCTION
Primary Energy Savings [kWh/y]:	858.203
Final Energy Savings [kWh/y]:	908.756
CO ₂ Reduction [t CO ₂ /y]:	176
OPEX Savings [€/year]:	395,189

Table 20: Percentage Improvement

INDICATOR	REDUCTION
Primary Energy Consumption [kWh/y]:	-44%
Final Energy Consumption [kWh/y]:	-66,5%
CO ₂ Emissions [t CO ₂ /y]:	-60,1%

4.4. Action plan

MEASURE	Year	CAPEX [€]	Annual OPEX Savings [€]	Final energy savings [kWh/year]	Primary energy savings [kWh/year]	CO ₂ savings [t/year]	Simple payback [years]
Building Envelope Renovation	2025	3.573,466	395,189	908.756	858.203	176	From 6 to 16 years, depending on each building
Heat Pump Installation	2025			included	included	included	
Digital Energy Monitoring	2025 - 2026			operational optimisation	operational optimisation	additional monitoring benefits	



5. Implementation Roadmap and Milestones

The roadmap outlines the proposed timeline for implementing renovation measures:

Period	Main Activities
2025	Detailed design and procurement
2025-2026	Building renovation works
2025-2026	Heat pump installation
2026	Digital monitoring deployment
2026 onwards	Monitoring and optimisation

6. Scenario Calculations and GIS Integration Overview

The scenario calculations were performed using the ZEB4ZEN Excel-based energy modelling methodology.

The digital component of the Action Plan should include:

- GIS mapping of municipal buildings.
- Building energy performance database.
- Monitoring of energy consumption and emissions.
- Tracking of renovation measures.
- Reporting of KPIs through digital dashboards.

This approach ensures transparency, replicability and continuous improvement of municipal energy management.

7. Governance and Institutional Framework

The Municipality of Palmanova will act as the coordinating body responsible for planning, procurement, monitoring and reporting activities. Cooperation with regional authorities, energy agencies, technology providers and funding institutions will be essential to ensure successful implementation. Stakeholder engagement activities should accompany the implementation phase in order to increase awareness, promote behavioural change and maximise long-term energy savings. Monitoring and reporting activities should be integrated into regular municipal asset management processes.

8. Conclusion and Strategic Outlook

The proposed Green and Digital Energy Action Plan demonstrates that significant energy and emissions reductions can be achieved through targeted renovation of municipal buildings combined with electrification and digitalisation measures.

The implementation of building envelope improvements, heat pump systems and digital energy management tools is expected to deliver:



- 66,5% reduction in final energy consumption;
- 44% reduction in primary energy consumption;
- 60,1% reduction in CO₂ emissions;
- annual savings of almost € 400 (€ 395,189).

The Action Plan therefore represents a practical and financially viable pathway towards the decarbonisation of Palmanova's building stock and supports the Municipality's contribution to European climate neutrality objectives.