SUMP4Balkans

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SUMP4BALKANS PROJECT | EUROPEAN CLIMATE INITIATIVE (EUKI)

Feasibility study for the transition to electric buses and integration of photovoltaic generation in Ptuj

Final technical and economic feasibility study



Prepared for	City Municipality of Ptuj and the SUMP4Balkans project
Prepared by	Local Energy Agency Spodnje Podravje LEASP
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Document control

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Status and use. This study supports municipal decision-making, funding preparation and concept development. It is not a detailed electrical or civil design, distribution-system connection consent, cadastral survey, environmental permit, final duty schedule, tender specification or binding investment appraisal. Assumptions identified in the study must be replaced with measured interval data, verified duties and supplier or operator quotations before procurement.

Disclaimer. This project is part of the European Climate Initiative (EUKI) of the German Federal Ministry for the Environment, Climate Action, Nature Conservation and Nuclear Safety (BMUKN). It is the overarching goal of the EUKI to foster climate cooperation within the European Union (EU) in order to mitigate greenhouse gas emissions. The opinions put forward in this study are the sole responsibility of the author(s) and do not necessarily reflect the views of the German Federal Ministry for the Environment, Climate Action, Nature Conservation and Nuclear Safety (BMUKN).

1. Executive summary

This feasibility study assesses the technical, economic and environmental feasibility of modernising the public bus transport system in the City Municipality of Ptuj through the introduction of battery-electric buses and the integration of photovoltaic systems into the transport energy supply.

The study is prepared within the framework of the SUMP4Balkans project and follows the common methodological structure applied in the SUMP4Balkans pilot-city feasibility studies. The analysis focuses on the optimisation and electrification of the existing urban bus network in Ptuj, combined with the assessment of suitable locations for charging infrastructure and local renewable electricity generation.

Ptuj currently operates five urban bus lines. The services are provided by Arriva on behalf of the municipality, while public transport is offered free of charge to residents and visitors. The annual municipal cost of operating the service is approximately 1.2 million EUR. One of the strategic options under consideration is the establishment of a municipally operated public transport system, potentially managed through the municipal public service company. This would require the procurement of electric buses, the installation of charging infrastructure, the employment of operational and technical staff, and the use of municipal locations for depot and charging purposes.

The electrification of the bus fleet creates a new electricity demand within the local energy system. This demand can be partially supplied through locally generated solar electricity, particularly if PV systems are installed at municipal-owned locations connected to the public transport system. Three potential charging locations have already been identified: the Recycling Centre CERO Gajke, the Ptuj wastewater treatment plant, and the Ptuj main bus station. CERO Gajke is considered the most suitable main base location, while the wastewater treatment plant and the main bus station could support additional charging functions.

The study therefore treats bus operation, charging infrastructure and municipal PV as one integrated mobility-and-energy system. The upgraded assessment adds an auditable annual and hourly model, reconciles the available PV capacity and consumption figures, quantifies the charging scenarios, compares the candidate locations and tests investment sensitivity. Design-stage inputs are defined as explicit decision gates rather than being hidden inside a single-point forecast.

1.1. Quantified decision summary

The central planning case converts the five published lines into approximately 345,000 vehicle-km per year. At 0.65 kWh/km traction consumption and a 10% charging-loss multiplier, the fleet requires approximately 246.7 MWh/year at the charger. The sensitivity range is 170.8-341.6 MWh/year. A fleet of six operating vehicles plus one reserve vehicle is used as a feasibility assumption; the final fleet must be derived from confirmed vehicle duties and deadhead movements.

Table 1. Central feasibility findings

Decision metric	Central result	Interpretation
Network scale	345,000 vehicle-km/year	Planning total from the five published lines
Fleet concept	6 operating + 1 reserve	Feasibility assumption; confirm through duty scheduling
Charging energy	246.7 MWh/year	Central case including 10% charging losses

Decision metric	Central result	Interpretation
Energy sensitivity	170.8-341.6 MWh/year	0.45-0.90 kWh/km traction range
Municipal PV portfolio	1,614.51 kWp across 17 systems	Latest public aggregate, 20 April 2026 [S1]
Community PV component	1,491.51 kWp; about 1,549 MWh/year	Thirteen systems allocated to 35 public consumers
Existing community demand	1,686.99 MWh/year	2025 total from the supplied meter list
Preferred configuration	Scenario 2	CERO depot plus WWTP daytime charging
Scenario 2 PV contribution	72.1 MWh/year; 29.2%	Modelled same-hour residual after existing load
Scenario 2 central economics	EUR 2.893 million gross CAPEX; 12-year NPV -EUR 0.222 million	No capital grant (central case); break-even capital support about EUR 0.22 million

The main correction to the earlier narrative is that the municipality's approximately 1.55 GWh/year community PV production is not an unused annual surplus. The 35 public consumers already use more electricity annually than the community systems are forecast to generate. Buses are an additional load. Their integration value comes from absorbing residual midday output in the same interval, or from an agreed settlement allocation under the applicable community rules.

1.2. Recommended implementation decision

Advance Scenario 2 as the preferred first full implementation: CERO Gajke as the main depot and controlled overnight charging base, with a secondary daytime charging point at the Ptuj wastewater treatment plant. Protect the option for later opportunity charging at the main bus station, but do not procure that charger or stationary storage until measured duties, grid conditions and at least one year of operational data show a specific need. Scenario 2 is preferred to the lower-cost Scenario 1 because the 9 m reference midibus cannot complete a full 200-250 km school-day duty on overnight charging alone (Section 7.2); the daytime top-up at the wastewater treatment plant closes this range gap for about EUR 0.15 million.

- Confirm actual vehicle duties, deadhead kilometres and reserve rules before fixing the bus count and battery specification.
- Obtain 15-minute PV, existing-load and export data before making a binding PV share or savings claim.
- Obtain separate distribution-system capacity conditions for CERO, the wastewater treatment plant and the optional bus-station site.
- Reconcile the full municipal operating organisation and cost base with the present EUR 1.2 million/year outsourced-service scope.
- Base the investment decision on the no-grant central case, because the published Borzen allocation for M2/M3 buses has already been reached [S6]. Scenario 2 needs about EUR 0.22 million of capital support, or about EUR 25,000/year of lower operating cost, to break even over 12 years; the funding options are set out in Section 8.6.

2. Introduction

2.1. Project background

The transition toward climate-neutral and energy-efficient urban systems represents one of the central challenges facing European cities today. Urban transport remains a major contributor to greenhouse gas (GHG) emissions, air pollution, and energy consumption. In response, the European Union has introduced a range of strategic initiatives aimed at decarbonizing the transport sector while increasing the share of renewable energy sources (RES) in final energy use.

Within this context, the Sustainable Urban Mobility Plan for the Balkans (SUMP4Balkans) project has been developed to support cities in Southeast Europe in designing and implementing integrated mobility solutions. The project places a strong emphasis on aligning transport electrification with renewable energy deployment, thereby addressing two critical pillars of the energy transition simultaneously.

The SUMP4Balkans project is supported under the EUKI (European Climate Initiative) framework and focuses on four pilot cities: Strumica, Ptuj, Cetinje, and Umag. These cities represent diverse urban contexts within the Balkan region, each facing specific challenges related to mobility, infrastructure, and energy systems.

A key component of the project is Activity A I.1, which involves conducting technical and economic feasibility studies for integrating photovoltaic (PV) systems into electric public transport fleets. These studies serve multiple purposes by providing evidence-based support for local decision-making, demonstrating the feasibility of integrated energy-transport solutions and enabling knowledge transfer and replication across the region.

In this framework, the present study focuses on the Slovenian case study of Ptuj, contributing to the broader objective of promoting sustainable, low-carbon mobility systems in the Balkans.

2.2. Scope of the study and the objectives

The case study in the City Municipality of Ptuj focuses on the optimization of the existing urban bus network combined with the electrification of the bus fleet. Currently, the municipality operates five urban bus lines that provide public transport services within the city. The services are operated by the public transport company Arriva on behalf of the municipality.

The Ptuj main bus station serves as the central junction and transfer point for all urban bus lines, as well as for regional bus services, making it the key node of the public transport network.

Public transport in Ptuj is provided free of charge for residents and visitors as part of the municipality's efforts to promote sustainable mobility and reduce the use of private cars. At present, the City Municipality of Ptuj allocates approximately 1.2 million EUR annually to finance the operation of these services.

One of the strategic options currently under consideration is the establishment of a municipal public transport system operated by the municipality's own public service company. Under this model, the municipality would assume responsibility for the operation of the existing bus lines. This would involve:

- employing operational and technical staff,

- procuring a fleet of electric buses,
- purchasing and installing the necessary charging infrastructure,
- using municipal-owned locations for the depot and charging facilities.

The main objective of the study is to evaluate the economic viability of operating the urban bus network through a municipally owned operator, compared to the current outsourced service model.

The existing bus network is closely linked to school transport needs. As a result, service schedules of lines 2 -5 are largely aligned with school timetables, which significantly influences operational planning and vehicle utilization.

2.3. Methodology

The methodological approach follows an integrated techno-economic framework, combining transport system assessment, electric bus energy demand estimation, PV potential assessment, charging infrastructure analysis and scenario development.

The methodology consists of the following steps:

1. Review of existing Ptuj transport information, including urban bus lines, route structures, service schedules and technical constraints.
2. Assessment of electrification requirements, including vehicle size, fleet size, route distance and charging needs.
3. Identification of potential charging locations and their suitability for depot charging, opportunity charging or mixed charging strategies.
4. Assessment of PV integration potential at selected locations.
5. Development of scenarios representing different levels of system integration.
6. Economic feasibility assessment based on investment costs, operating costs, energy values and funding options, complemented by an operational greenhouse-gas screening; external costs are not monetised.
7. Definition of the design-stage inputs and decision gates for the next project phase.

2.4. Evidence base and source hierarchy

The study uses a hierarchy that separates current public facts, supplied project documents, supplier claims and modelling assumptions. Where aggregate figures differ between document versions, the latest official municipal publication governs the current status, while earlier investment documentation is retained for the location-level design schedule. Vehicle specifications and prices are treated as indicative commercial evidence rather than independently certified performance.

Table 2. Evidence used in the upgraded assessment

Evidence group	Main inputs	Purpose in the study
Public transport	September 2026 Arriva timetables and supplied route-length tables	Service counts, operating windows and annual kilometres

Evidence group	Main inputs	Purpose in the study
Vehicles	Three supplier offers, anonymised by vehicle class: compact e-minibus, 9 m midibus and 9.5 m low-floor bus	Capacity, battery, charging, price and warranty comparison
PV and community	MO Ptuj publications, SONCE 8P programme and supplied allocation/meter workbooks	Installed/design capacity, production, consumption and allocation
Hourly solar resource	European Commission JRC PVGIS hourly series for Ptuj, 2014-2023	Typical hourly PV production shape
Funding	Borzen call status, Climate Change Fund programme, cohesion-policy (CTN) calls, Social Climate Plan and Eko sklad loans	No-grant central case, break-even support and funding options
Emissions	IJS Centre for Energy Efficiency national electricity factor	Operational greenhouse-gas screening

2.5. Hourly modelling method and calculation boundaries

The hourly model contains 8,760 intervals. A ten-year PVGIS profile for Ptuj is normalised to the municipal forecast of 1,549,270 kWh/year for the 13-system community component. The annual 2025 consumption of the 35 public consumers is distributed with a transparent public-building load profile. Published departures and route lengths are converted into a traction-energy timing profile and calibrated to the 345,000 km annual planning total.

Bus input energy = annual vehicle-km x traction consumption x 1.10 charging-loss multiplier

Incremental same-hour PV to buses = minimum of bus charging demand and positive PV generation remaining after existing community load

This method prevents the same solar electricity from being counted first against the 35 existing consumers and then again against the buses. It also distinguishes physical hourly coincidence from accounting allocation. A community settlement rule may allocate renewable energy to a charger even when the physical power flows through the public network; it does not remove the need for grid capacity, charger control and interval metering.

Table 3. Design-stage inputs and decision gates

Design-stage input	Effect on the result	Next step
Actual duty blocks and deadhead kilometres	Fixes the final fleet and charger count	Obtain operator scheduling or AVL export for school and non-school months
15-minute PV and consumer metering	Calibrates the modelled residual PV	Export inverter and electricity-portal data for all relevant meters
DSO connection studies	Sets connection power and reinforcement cost	Submit separate capacity enquiries for CERO, WWTP and the bus station
Passenger loads and route geometry	Confirms the vehicle mix	Carry out passenger counts and physical trials on constrained routes
Municipal staffing and service scope	Fixes the municipal OPEX and savings	Prepare an organisation plan and reconcile it with the current contract

3. Policy and strategic context

3.1. European policy Framework

The transition toward sustainable and low-carbon transport systems is a central pillar of European climate and energy policy. The European Union has established a comprehensive legislative and strategic framework aimed at achieving climate neutrality by 2050. Transport plays a particularly important role in this transition, as it accounts for approximately 29% of total EU greenhouse gas emissions.

A cornerstone of this framework is the **European Green Deal**, which sets the overarching objective of transforming the EU into a climate-neutral economy. Within this strategy, The Fit for 55 legislative package sets binding targets, including a reduction of net GHG emissions by at least 55 % by 2030 compared to 1990 levels. In the transport sector this translates into strengthening emission standards for vehicles, promoting the deployment of alternative fuels infrastructure and increasing the use of renewable energy.

The Renewable Energy Directive (RED II and its revision RED III) further reinforces these objectives by setting binding targets for renewable energy consumption, including through the electrification of transport supported by renewable energy sources such as solar PV Complementing this, the Sustainable and Smart Mobility Strategy outlines the roadmap toward a modernised transport system based on zero-emission vehicles, smart charging infrastructure and integration of renewable energy into transport systems.

Urban mobility is specifically addressed through the promotion of **Sustainable Urban Mobility Plans (SUMPs)**, which provide a strategic framework for cities to plan and implement integrated mobility solutions. The coupling of electric mobility with renewable energy sources, such as photovoltaic systems, represents a key measure promoted within these plans.

Overall, the European policy framework strongly supports the type of integrated solution analysed in this study, namely the combination of PV generation with electric public transport systems.

The modernisation of Ptuj's public transport system is aligned with European climate, energy and mobility policy. The European Green Deal, the Fit for 55 package, the Renewable Energy Directive and the Sustainable and Smart Mobility Strategy all support the transition toward zero-emission mobility, renewable energy use and integrated urban transport planning.

Electric public transport powered partly by local renewable electricity is directly aligned with these priorities. It supports the reduction of greenhouse gas emissions, improves air quality, reduces noise and strengthens local energy resilience.

3.2. National policy context - Slovenia

Slovenia's national climate and energy policy framework supports the decarbonisation of transport and the expansion of renewable energy sources. The transition to zero-emission public transport is supported through national and EU funding mechanisms.

The main national grant for zero-emission buses is the public call administered by Borzen for municipalities and financed by the Climate Change Fund. It covers up to 80% of eligible costs, with a maximum of EUR 600,000 per electric M2 or M3 vehicle shorter than 15 metres and EUR 650,000 for vehicles of 15 metres or more; investments must be completed by 15 November 2028 [S6].

Borzen reports that the funds available for M2 and M3 vehicles have already reached the advertised amount; the call remains open only until the remaining funds are allocated [S6]. This study therefore treats the grant as an upside and uses a no-grant central case. Other national and EU instruments that could support the investment, including the Climate Change Fund programme for 2025-2028, cohesion-policy integrated territorial investments, the Social Climate Fund and Eko sklad loans, are assessed in Section 8.6.

3.3. Local policy context – Ptuj

At the local level, the City Municipality of Ptuj has strengthened its commitment to sustainable mobility through the adoption of the Sustainable Urban Mobility Plan (Občinska celostna prometna strategija Mestne občine Ptuj), which represents the municipality's key strategic framework for integrated transport planning for the period up to 2031. The strategy addresses public passenger transport as one of its main thematic pillars and defines the improvement of the existing public transport system as a priority, including better accessibility, higher service quality and stronger competitiveness compared with private car use. Importantly, the public transport pillar also explicitly supports the promotion of electric mobility. Among the planned measures is the modernisation of the urban bus fleet through the introduction of smaller and environmentally oriented vehicles, with the stated objective of reducing the use of conventional fuels, lowering greenhouse gas emissions, noise and vibration, and establishing a zero-emission line in urban public transport. The action plan sets a concrete target to purchase one new vehicle, including the required charging infrastructure, by 2031. This provides a clear local policy basis for assessing the electrification of Ptuj's urban bus services and the integration of charging infrastructure with local renewable electricity generation.

3.4. Alignment with SUMP4Balkans Objectives

The proposed integration of PV systems into Ptuj's electric public transport system is strongly aligned with the objectives of the SUMP4Balkans project.

The project emphasises the integration of renewable energy into urban mobility systems, the development of replicable solutions for cities in the Balkan region and the strengthening of institutional capacity and stakeholder engagement.

In this context, this feasibility study provides both a practical decision-support tool for local authorities and a demonstration of the technical and operational viability of integrated energy-transport systems, while also supporting knowledge transfer to other municipalities in the region.

3.5. Barriers and Enabling Factors

The main enabling factors for electric bus and PV integration in Ptuj are:

- existing political support for free and sustainable public transport;
- clearly defined urban bus lines and route structures;
- municipal interest in a possible public service company operating model;
- availability of municipal-owned locations for charging infrastructure;
- national and EU co-funding instruments for zero-emission mobility (Climate Change Fund programme, cohesion-policy calls and Eko sklad loans);
- possibility of integrating PV at municipal infrastructure locations.

The main barriers are:

- high upfront investment costs for electric buses and charging infrastructure, while the current Borzen grant allocation for M2/M3 buses has been reached;
- uncertainty regarding the final fleet size and bus specifications;
- technical constraints related to narrow streets in the historic centre;
- need for grid capacity assessment at charging locations;
- the need to verify the modelled PV residual and the timetable-based duties with measured 15-minute data and operator duty schedules during design;
- need to define the institutional model for ownership and operation.

3.6. Institutional responsibilities before procurement

The project crosses transport operation, energy-community management, public infrastructure and procurement. A named owner is therefore required for every evidence stream before the municipality issues a vehicle or charger tender. The following responsibility split is recommended for the concept stage.

Table 4. Recommended concept-stage responsibilities

Actor	Primary responsibility	Required output
City Municipality of Ptuj	Service objective, funding, ownership decisions and interdepartmental coordination	Approved scope, decision gates and data-access mandate
Future municipal operator / Javne sluzbe Ptuj	Duty planning, depot workflow, staffing and operational acceptance	Duty blocks, operating plan and depot functional brief
Municipal PV / community manager	Production, consumer-load and settlement evidence	15-minute dataset and documented allocation method
Distribution-system operator	Connection capacity, protection and reinforcement conditions	Site-specific technical conditions and timetable
Vehicle and charger suppliers	Performance guarantees, interfaces, service and acceptance testing	Binding technical offers and test protocol
Licensed designers and authorities	Civil, electrical, traffic, fire, environmental and permitting review	Concept design, surveys, consents and cost plan

4. Technical feasibility assessment

4.1. Transport system overview

The City Municipality of Ptuj currently operates five urban bus lines. All lines are connected to the Ptuj main bus station (Avtobusna postaja Ptuj, Osojnikova cesta), which serves as the key transfer point for the urban and regional public transport network [S16]. In the stop tables and timetables the station is abbreviated "Ptuj AP" (AP = avtobusna postaja, bus station).

The five lines are:

- Line 1: Ptuj
- Line 2: Panorama
- Line 3: Jezero – Spuhlja
- Line 4: Breg – Turnišče
- Line 5: Ljudski vrt – Rogoznica

Line 1 operates throughout the year, including holidays. Lines 2 to 5 are more closely linked to school transport needs and operate mainly on weekdays until the end of June. This creates different operational profiles across the network and has implications for charging strategy, annual mileage and vehicle utilisation.

The urban lines are operated by Arriva under contract with the municipality, and travel is free of charge. The service is run entirely with conventional diesel buses; there are no electric or other alternative-fuel vehicles in the urban fleet. The city-centre Line 1 is operated with a diesel midibus approximately 8.3 m long with a 4.75 m wheelbase, which sets the geometric reference for the narrow streets of the historic centre. On school days the five lines run about 1,470 route-km, which corresponds to six buses in daily service at 200-250 km per bus. This six-bus operating fleet, plus one reserve vehicle, is the replacement basis assessed in this study.

The current network includes both urban and peri-urban sections. It serves residential areas, schools, the hospital, shopping centres, the cemetery, industrial and commercial areas, and settlements on both sides of the Drava River.

4.1.1. Bus Lines

Line 1: Ptuj

The Ptuj city line operates throughout the entire year, including during holidays, and serves the following bus stops: Dom upokojencev Ptuj (Ptuj Retirement Home), Rimska peč (Roman site/furnace), Ulica 5. prekomorske 13, Bratje Reš, Pod gradom (Under the Castle parking area), Tržnica – City Market, Slovenski trg, OŠ Olge Meglič (Olga Meglič Primary School), Mihelič Gallery, Zadružni trg parking area, Terme Ptuj (Ptuj Thermal Spa), Ptuj Hospital, Ptuj Dornavska cesta – Merkur, Ptuj Rogoznica cemetery, Shopping Centre QCenter, Shopping Centre Super Mesto, and Ptuj Ormoška

Table 5. Bus stops and inter-stop distances – Line 1: Ptuj

Line 1: Ptuj	Length (m)
Ptuj AP	

Line 1: Ptuj	Length (m)
Ptuj AP	2.900

Line 1: Ptuj	Length (m)
Dom upokojencev	350
Rimska peč	450
Ul. 5 Prekomorske 13	650
Bratje Reš	600
Pod gradom parkirišče	650
Tržnica + Slovenski trg	700
OŠ Olge Meglič	270
Miheličeva galerija	400
Zadružni trg parkirišče	1.200
Terme Ptuj	1.400

Line 1: Ptuj	Length (m)
Bolnišnica	750
Merkur	2.000
Rogoznica n. pokopališče	900
Merkur	900
TC Qcenter	650
TC Super Mesto	1.200
Ptuj Ormoška	900
Ptuj AP	1.300
Total:	18.170

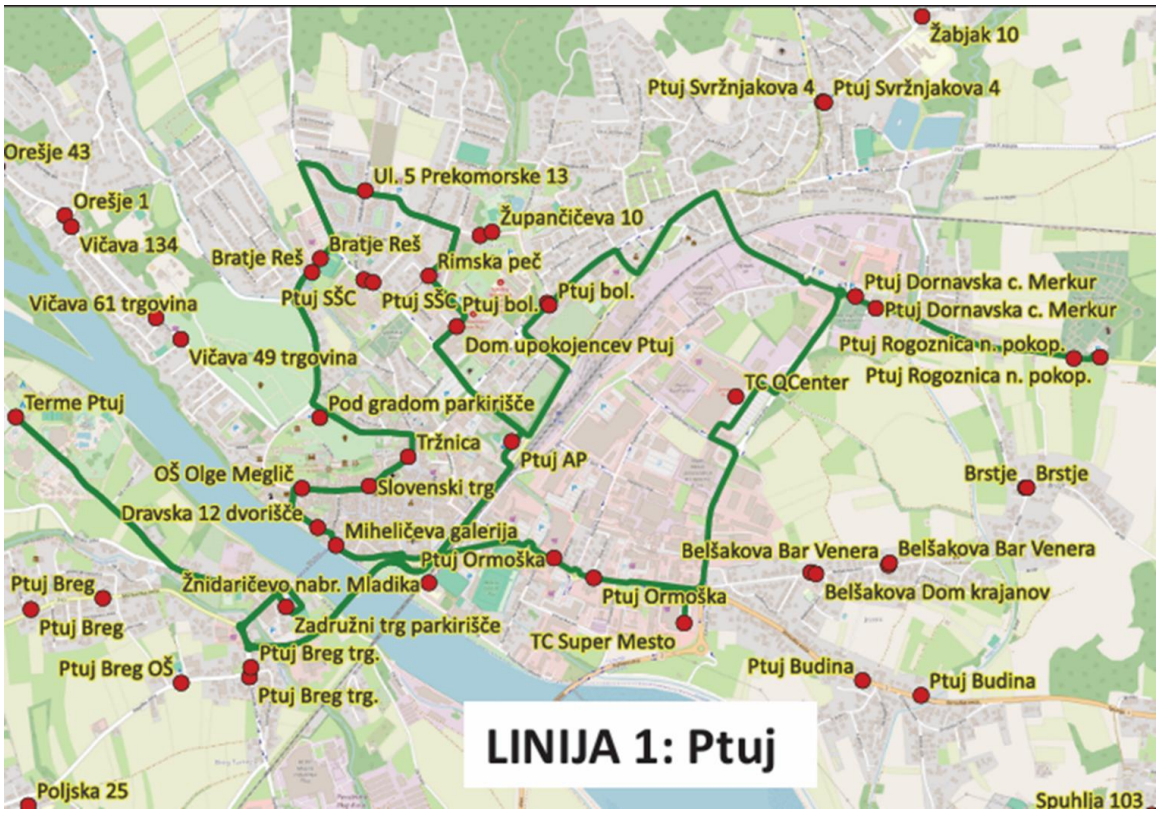


Figure 1. Route map – Line 1: Ptuj

Line 2: Panorama

The Panorama line partially covers the city centre, including OŠ Olge Meglič (Olga Meglič Primary School), and serves the stops Bratje Reš, Ptuj SŠC (Ptuj Secondary School Centre), Dom upokojencev Ptuj (Ptuj Retirement Home), Rimska peč, and Župančičeva 10. The route

then continues towards Vičava and Orešje, with the final stop at Krčevina pri Vurbergu 123, where the turning point is located.

Table 6. Bus stops and inter-stop distances – Line 2: Panorama

Line 2: Panorama	Length (m)
Ptuj AP	
Tržnica	650
Dom upokojencev	400
Slovenski trg	170
Ptuj SŠC	1.500
OŠ Olge Meglič	270
Bratje Reš	750
Pod gradom parkirišče	650
Vičava 49 trgovina	800
Orešje 1	600
Orešje 43	300
Orešje 117	600
Orešje 159	350
Orešje 178 Sekvoja	500
Orešje 182a	1.000
Orešje 192	650
Orešje 207	500
Krčevina pri Vurbergu 123	550
Orešje 208	500

Line 2: Panorama	Length (m)
Orešje 196a	280
Orešje 182a	600
Orešje 178 Sekvoja	1.000
Orešje 158	550
Orešje 91a	350
Orešje odcep Sovretova	400
Vičava 134	450
Vičava 61 trgovina	500
Dravska 12 dvorišče	1.000
Pod gradom parkirišče	950
Miheličeva galerija	1.300
Bratje Reš	1.400
Ptuj SŠC	500
Dom upokojencev	400
Rimska peč	450
Župančičeva 10	500
Bolnišnica	450
Ptuj AP	600
Total:	22.420

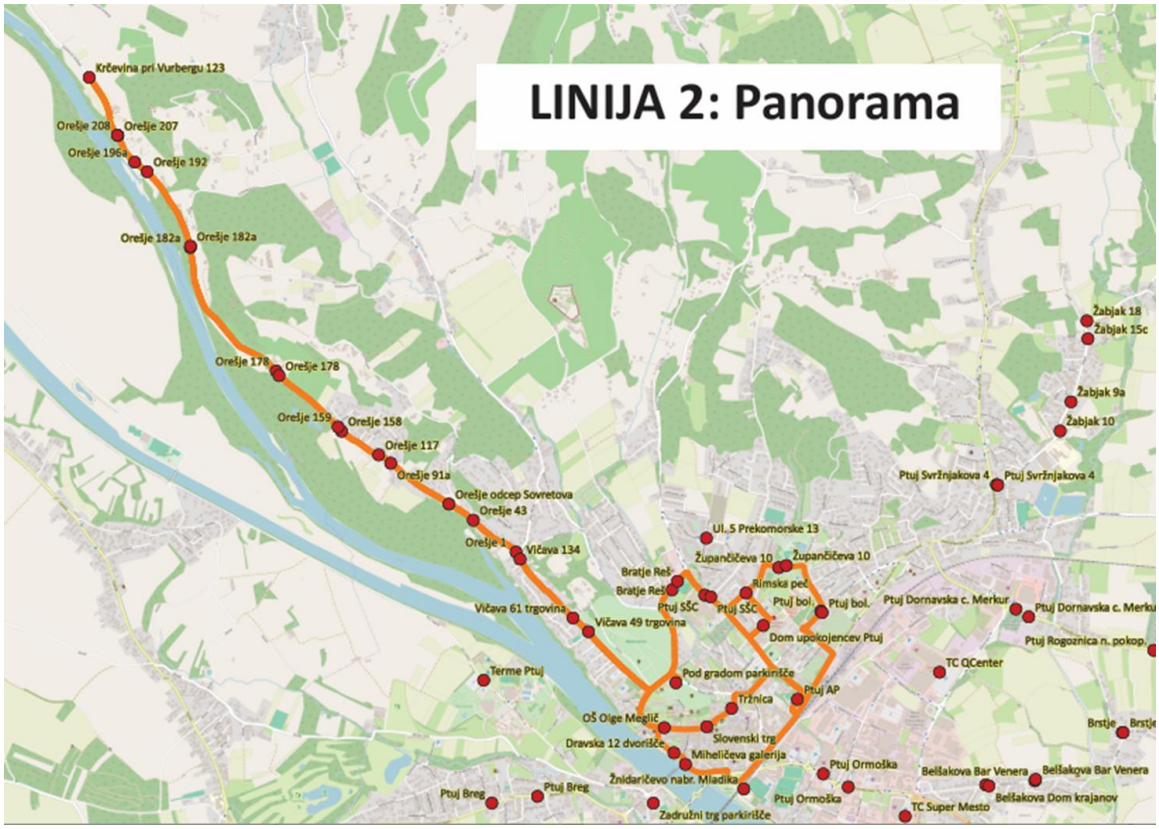


Figure 2. Route map – Line 2: Panorama

Line 3: Jezero – Spuhlja

The Jezero–Spuhlja city line operates on weekdays only, until the end of June, with services provided during the morning and afternoon periods. The line serves the settlement of Brstje and the village of Spuhlja, operates within the industrial zone, and provides connections to major shopping centres. It also covers the Rogoznica cemetery area, ensuring accessibility to key employment, commercial, and local service destinations.

Table 7. Bus stops and inter-stop distances – Line 3: Jezero – Spuhlja

Line 3: Jezero - Spuhlja	Length (m)
Ptuj AP	
Žnidaričevo nabr. Mladika	1.500
Ptuj Ormoška	600
Ptuj Budina	1.200
Spuhlja G	1.100
Spuhlja 103	450
Spuhlja 133a	350

Line 3: Jezero - Spuhlja	Length (m)
Brstje	1.100
Belšakova Bar Venera	550
Belšakova Dom krajanov	300
Ptuj Ormoška	1.100
Žnidaričevo nabr. Mladika	600
Ptuj AP	1.500
Ptuj Ormoška	1.300

Line 3: Jezero - Spuhlja	Length (m)
Spuhlja	1.900
Villa Monde parkirišče	1.000
Ptuj Rogoznica n. pokopališče	2.200
Merkur	900
TC Qcenter	650
TC Super Mesto	1.200
Spuhlja G	2.000
Ptuj Budina	1.100
Ptuj Ormoška	1.200
Žnidaričevo nabr. Mladika	600
Merkur	2.000

Line 3: Jezero - Spuhlja	Length (m)
Belšakova Dom krajanov	1.100
Belšakova Bar Venera	300
Brstje	550
Ptuj Rogoznica n. pokop.	1.100
Merkur	900
TC QCenter	650
TC Super Mesto	1.200
Ptuj Ormoška	900
Ptuj AP	1.300
Total:	34.400



Figure 3. Route map – Line 3: Jezero – Spuhlja

Line 4: Breg – Turnišče

The Breg–Turnišče city line operates on weekdays only, until the end of June, with services provided during the morning and afternoon periods. The line serves the right bank of the Drava River, including the settlements of Suha veja, Turnišče, and Breg, and extends into part of the Municipality of Hajdina, covering Draženci, Spodnja Hajdina and Zgornja Hajdina. It runs as two loops from Ptuj AP: Loop A via Draženci and Loop B via Zgornja Hajdina (Table 8).

Table 8. Bus stops and inter-stop distances – Line 4: Breg – Turnišče

Loop A – via Draženci	Length (m)
Ptuj AP	
Zadružni trg parkirišče	1.900
Ptuj Breg trg.	550
Ptuj Transservis	900
Ptuj Turnišče 03	1.000
Suha veja 02	1.200
Suha veja 01	120
Ptuj Breg OŠ	3.300
Poljska cesta 25	850
Poljska cesta 42	300
Jurčičeva 2	230
Na postajo 10	650
Ptuj Turnišče 01	300
Draženci 18e	1.100
Draženci 76c	1.100
Draženci obračališče	550
Draženci 21d	500
Draženci 34	500
Selska 31	2.100
Ptuj Turnišče 02	550
Na postajo 20	700
Jurčičeva 1	270

Loop B – via Zgornja Hajdina	Length (m)
Ptuj AP	
Zadružni trg parkirišče	1.900
Ptuj Breg	1.200
Sp. Hajdina	1.100
Sp. Hajdina trg.	850
Na postajo 20	950
Ptuj Turnišče 01	700
Zg. Hajdina	2.100
Zg. Hajdina 8/d	2.600
Zg. Hajdina 7	650
Selska 31	1.700
Selska 40	69
Suha veja 02	1.700
Suha veja 01	150
Ptuj Turnišča 02*, 04	1.300
Ptuj Transservis	1.000
Ptuj Breg trg.	900
Ptuj Transservis	900
Ptuj Turnišče 01	1.000
Selska 40	450
Zg. Hajdina 7d	1.900
Zg. Hajdina 6	900

Loop A – via Draženci	Length (m)
Poljska cesta 20B	230
Poljska cesta 2	400
Ptuj Breg OŠ	750
Sp. Hajdina trg.	1.400
Sp. Hajdina	850
Ptuj Breg trg.	2.000
Zadružni trg parkirišče	500
Ptuj AP	1.900
Total Loop A	**26.700**

Loop B – via Zgornja Hajdina	Length (m)
Zg. Hajdina	2.700
Sp. Hajdina trg.	500
Ptuj Breg OŠ	1.400
Zadružni trg parkirišče	800
Ptuj AP	1.900
Total Loop B	**31.319**



Figure 4. Route map – Line 4: Breg – Turnišče

Loop A is 26.700 km and Loop B 31.319 km long (route lengths in kilometres, with a dot as thousands separator in the stop tables). The planning model in Tables 10 and 13 conservatively applies the longer Loop B to all ten published Line 4 operations. If the operations alternate between the two loops, annual Line 4 mileage would be about 4,850 km

lower (approximately 60,900 instead of 65,800 km), i.e. 1.4% of the network total and about 3.5 MWh/year of charging energy, which lies within the demand sensitivity range.

Line 5: Ljudski vrt – Rogoznica

The Ljudski vrt–Rogoznica city line operates on weekdays only, until the end of June, with services provided during the morning and afternoon periods. In addition to the stops Župančičeva 10, Ulica 5. prekomorske 13, Ptuj SŠC (Ptuj Secondary School Centre), and Ptuj Hospital, the line also serves Svržnjakova Street and the Žabjak area. The route continues to the final stop at Kicar 1, where the turning point is located.

Table 9. Bus stops and inter-stop distances – Line 5: Ljudski vrt – Rogoznica

Line 5: Ljudski vrt - Rogoznica	Length (m)
Ptuj AP	
Župančičeva 10	1.100
Ul. 5 Prekomorske 13	550
Ptuj SŠC	650
Ptuj bol.	1.000
Ptuj Svržnjakova 4	1.500
Žabjak 10	650
Žabjak 15c	350
Kicar 7f	700
Kicar 1	600
Žabjak 18	1.200

Line 5: Ljudski vrt - Rogoznica	Length (m)
Žabjak 9a	500
Ptuj Svržnjakova 4	650
Župančičeva 10	1.700
Ul. 5 Prekomorske 13	550
Ptuj SŠC	650
Ptuj Svržnjakova 4	2.500
Ptuj bol.	1.500
Ptuj AP	700
Total:	17.050



Figure 5. Route map – Line 5: Ljudski vrt – Rogoznica

4.1.2. Technical Requirements for Vehicles

Due to the historic urban structure and narrow streets in the city centre, there are specific technical constraints on vehicle size, particularly on routes passing through Prešernova ulica.

Currently, Line 1 is operated with a bus that has:

- a total length of 8.3 metres, and
- a wheelbase of 4.75 metres.

The wheelbase is considered a key operational parameter due to manoeuvrability requirements in the historic street network. These constraints are particularly relevant for Lines 1 and 2, which operate through the narrowest parts of the city centre.

4.1.3. Published service volume and operating windows

The September 2026 timetables were combined with the supplied full-line route lengths. Each published timetable column is treated as one full operation for feasibility planning. The method is suitable for annual energy and charger screening, but it is not a substitute for vehicle duties because one bus may cover several departures and may travel additional deadhead kilometres.

Table 10. Planning estimate of annual service volume

Line	Full operation	Published pattern	Operating days	Annual line-km	Indicative window
1 Ptuj	18.170 km	18 workday / 11 other-day	250 + 115	104,700	06:00-21:28
2 Panorama	22.420 km	11 school-workday	210	51,800	07:00-15:10

Line	Full operation	Published pattern	Operating days	Annual line-km	Indicative window
3 Jezero-Spuhlja	34.400 km	9 school-workday	210	65,000	06:40-16:13
4 Breg-Turnišče	31.319 km (Loop B)	10 school-workday	210	65,800	06:42-15:57
5 Ljudski vrt-Rogoznica	17.050 km	16 school-workday	210	57,300	07:00-15:38
Total	-	-	-	about 345,000	Planning total

Table 11. Modelled service-energy pattern by day type

Day type	Approximate route-km	Central input energy	Charging implication
School-regime workday	1,469 km	about 1,051 kWh	Multi-vehicle overnight charging plus a daytime top-up for midibus duties
Other workday	327 km	about 234 kWh	Predominantly Line 1; depot charging is sufficient
Weekend / holiday	200 km	about 143 kWh	Low total load and a broad overnight window

4.2. Planned electrification of public transport – Electric buses

As part of its transition toward sustainable mobility, the City Municipality of Ptuj is introducing electric bus lines alongside the development of necessary charging infrastructure and integration within the broader Sustainable Urban Mobility Plan (SUMP) framework. This represents a significant shift in both transport and energy system dynamics.

Electric buses offer several advantages in terms of zero tailpipe emissions, reduced noise pollution, and higher energy efficiency compared to diesel vehicles. However, their implementation also introduces new operational requirements, particularly in relation to electricity demand management, charging infrastructure planning, and integration with the local power system.

Energy demand and operational performance are influenced by factors such as route characteristics, driving patterns, service frequency and fleet size, which vary between peak and off-peak periods, as well as the need to maintain reserve capacity to account for maintenance activities and fluctuations in demand.

In Ptuj, these dynamics are further shaped by specific local conditions, including the fact that four out of five bus lines are closely linked to school transport. Their operation is strongly connected to the school calendar: buses currently run only on weekdays and do not operate during school holidays. This seasonal variability is therefore a key factor in the design of both charging infrastructure and renewable energy integration strategies.

Given the current operating pattern, system utilisation is substantially lower in July and August because Lines 2-5 follow a school-oriented regime. This reduces annual electricity demand but also removes bus charging load during the months with the highest solar production. The seasonal mismatch is therefore included explicitly in the monthly and hourly analysis.

4.2.1. Reference fleet and procurement performance

A mixed or midibus-dominant fleet is the most credible feasibility reference. Six 9 m electric midibuses plus one compact e-minibus give an indicative vehicle CAPEX of approximately

EUR 1.99 million. This configuration is a modelling device, not a tender recommendation. The offers are shown by vehicle class with indicative price ranges. The final technical specification should be written around verified duties, capacity, geometry, winter performance and charger compatibility.

Table 12. Anonymised vehicle offers by class and Ptuj relevance

Offer (anonymised)	Key specification	Energy / range evidence	Indicative price range	Ptuj relevance
Offer A – compact e-minibus	Approx. 6 m; approx. 115 kWh LFP; up to 25 passengers	Up to 250 km stated by the supplier	EUR 0.25-0.30 million	Constrained streets and lower-demand duties
Offer B – 9 m electric midibus	9 m; approx. 120 kWh NMC; up to 35 passengers	0.35-0.65 kWh/km stated; SORT-type test about 0.45 kWh/km	EUR 0.25-0.30 million excl. VAT	Core midibus candidate subject to duty and capacity test
Offer C – 9.5 m low-floor bus	9.5 m; approx. 350 kWh NMC; up to 65 passengers	Large battery reserve; no consumption in supplied offer	EUR 0.55-0.60 million	Selective higher-capacity use; verify manoeuvrability

- Demonstrate the complete winter duty with the required passenger load, heating setting and minimum end-of-duty state of charge.
- Complete a route trial and swept-path check on Presernova ulica and other constrained sections.
- Specify guaranteed usable battery capacity, degradation threshold, charging curve and battery warranty remedy.
- Require low-floor access, wheelchair and pram restraint, and accessible passenger information.
- Require open charger communications, remote diagnostics and contractual fault-response times.

4.2.2. Electric Bus Energy Demand

The introduction of electric buses creates a new electricity demand component within the local energy system. This demand depends on specific energy consumption, which varies with vehicle type, driving pattern, ambient temperature and passenger load. The study uses a central traction consumption of 0.65 kWh/km for the Ptuj fleet and tests it against an efficient 0.45 kWh/km case and a conservative 0.90 kWh/km case.

On a school-regime workday, each bus in service covers approximately 200-250 km, which corresponds to roughly 130-165 kWh of traction energy per bus at the central consumption value, before charging losses. This demand is not constant throughout the year, as summer operation is expected to be significantly lower. Energy consumption is further elevated in the winter months due to heating requirements.

On an annual level, total electricity demand depends on fleet size, operational mileage, and seasonal utilisation patterns, and can be generally expressed as the product of daily demand, number of buses and operational days. This estimation provides a basis for photovoltaic system sizing, scenario development, and subsequent economic analysis.

Table 13. Route lengths, service pattern and estimated annual line-kilometres

Line	Route length per full operation	Published service pattern used for planning	Assumed operating days	Estimated annual line-km
Line 1 - Ptuj	18.170 km	18 weekday operations; 11 Saturday/Sunday/holiday operations	250 weekdays + 115 other days	approx. 104,700 km
Line 2 - Panorama	22.420 km	11 weekday/school-regime operations	210 operating days	approx. 51,800 km
Line 3 - Jezero - Spuhlja	34.400 km	9 weekday/school-regime operations	210 operating days	approx. 65,000 km
Line 4 - Breg - Turnišče	31.319 km (Loop B; Loop A 26.700 km)	10 weekday/school-regime operations; longer Loop B applied to all (conservative)	210 operating days	approx. 65,800 km
Line 5 - Ljudski vrt - Rogoznica	17.050 km	16 weekday/school-regime operations	210 operating days	approx. 57,300 km
Planning total	-	-	-	approx. 345,000 km/year

Table 14. Annual traction energy by consumption case

Consumption case	Vehicle/operation interpretation	Traction energy at 345,000 km/year	With approx. 10% charging losses
Low case	Compact e-minibus or efficient midibus operation; 0.45 kWh/km	approx. 155 MWh/year	approx. 171 MWh/year
Central case	Mixed midibus operation; 0.65 kWh/km	approx. 224 MWh/year	approx. 246 MWh/year
Conservative case	Heavier duty, winter reserve, HVAC and degradation; 0.90 kWh/km	approx. 310 MWh/year	approx. 341 MWh/year

The central feasibility range is therefore approximately 170-340 MWh per year including charging losses. This demand is small compared with the expected annual production of the municipal SONCE 8P PV portfolio, but the decisive issue is not the annual balance alone. The decisive issue is whether the timing, metering arrangement, grid connection and allocation rules allow municipal PV production to be practically matched with electric bus charging.

The annual mileage estimate indicates that the full municipal electric-bus system should be designed for approximately 345,000 vehicle-km per year before adding deadhead movements, depot access, maintenance movements and possible future service improvements. A practical sizing margin of 5-10% is therefore recommended for energy and charging infrastructure planning.

For the purpose of this feasibility assessment, the published timetable structure was converted into full-line-equivalent annual kilometres. This is a planning-level method: each timetable column is treated as one complete operation of the respective line. The result is suitable for feasibility comparison and sizing of buses and chargers, while the final tender design should still be based on duty blocks, deadhead movements and confirmed daily vehicle rotations.

4.2.3. Energy-demand calculation and sensitivity

The central 0.65 kWh/km traction case is consistent with the upper end of the supplied midibus evidence and is tested against both an efficient 0.45 kWh/km case and a conservative 0.90

kWh/km case. A 10% multiplier represents charger and auxiliary losses between the grid meter and vehicle traction energy.

Table 15. Annual electric-bus energy sensitivity

Case	Traction consumption	Traction energy	Input energy incl. 10%	Use in the study
Low	0.45 kWh/km	155.3 MWh/year	170.8 MWh/year	Efficient compact / midibus operation
Central	0.65 kWh/km	224.3 MWh/year	246.7 MWh/year	Scenario and finance model
Conservative	0.90 kWh/km	310.5 MWh/year	341.6 MWh/year	Cold weather, HVAC and heavier duties

The busiest modelled school-regime day requires approximately 1.05 MWh across the fleet. This is a fleet total, not the duty of a single vehicle. The final vehicle-to-trip assignment must include deadhead, relief, cleaning, pre-heating or pre-cooling, reserve state of charge and the possibility that one vehicle covers several lines.

4.2.4. Charging infrastructure and load profiles

Charging infrastructure design plays a key role in shaping electricity demand profiles and determining the overall technical requirements of electric bus systems. Two main charging strategies are typically considered: depot charging, where buses are charged during nighttime or off-peak hours and which requires larger onboard batteries but simpler infrastructure, and opportunity charging, where charging takes place during operation at selected stops, reducing battery size requirements but increasing infrastructure complexity. In the case of Ptuj, depot charging is expected to dominate in the initial phase of electrification.

These strategies result in distinct load profiles. Depot charging typically leads to concentrated demand peaks during nighttime hours, while opportunity charging introduces additional daytime loads. This temporal behaviour is particularly important for photovoltaic integration, as it can create a mismatch between solar generation peaks during the day and electricity demand patterns, which is addressed in later sections of the analysis.

From a technical perspective, typical charging power requirements range from 50–150 kW per bus for depot charging systems and 150–450 kW for fast or opportunity charging systems. The initial deployment in Ptuj, which relies mainly on depot charging, therefore implies concentrated electricity demand during specific time periods and the potential occurrence of peak load issues.

Accordingly, the electrification of public transport requires adequate charging infrastructure and careful consideration of grid integration aspects. Key requirements include sufficient capacity of the local distribution network, potential upgrades of transformers, and the implementation of load management strategies to avoid peak demand penalties. These constraints may become increasingly relevant as both fleet size and PV capacity increase, making coordinated planning of charging infrastructure and energy systems essential.

4.2.5. Charging availability and control windows

Table 16. Practical charging windows derived from the published operating pattern

Window	Vehicle availability	PV relationship	Recommended use
00:00-06:00	All or nearly all buses at depot	No solar production	Primary reliability charge with sequenced load control

Window	Vehicle availability	PV relationship	Recommended use
09:00-15:30	Selected layovers; school lines operating	Main PV period	WWTP or controlled daytime top-up where the duty permits
16:15-21:00	Most Lines 2-5 vehicles available; Line 1 remains active	Solar falls rapidly	Restore reserve and prepare the next duty without creating a new peak
After 21:30	Line 1 returns	No solar production	Complete depot charging and conditioning

The hourly model represents Scenario 2 with an aggregate controllable peak of approximately 88.8 kW, compared with 177.6 kW in the overnight-only Scenario 1. These figures are scheduling outputs, not requested connection powers. Final connection capacity must include charger coincidence, auxiliary buildings, power factor, protection selectivity, future expansion and the DSO's technical conditions.

4.2.6. Interaction with the local energy system

The introduction of electric buses represents a new demand segment within Ptuj's local electricity system. This raises considerations related to distribution grid capacity, the ability to accommodate high-power charging loads, and the potential need for grid reinforcement.

At the same time, the integration of PV systems offers an opportunity to partially offset this new demand through local generation, thereby reducing reliance on the grid and improving overall system efficiency. This interaction between transport electrification and distributed energy generation is a central aspect of the system under study.

4.2.7. Key challenges and opportunities

The main technical risk is over-sizing or under-sizing the system. Oversizing would increase investment costs without improving service quality, while under-sizing would create range anxiety, operational delays and excessive dependence on emergency charging. For this reason, final procurement should be based on confirmed duty schedules, charging windows, minimum winter range and a reserve vehicle strategy.

The most important technical opportunity is the combination of a municipal electric fleet with existing and planned municipal energy assets. CERO Gajke can function as the main operating and charging base, while the wastewater treatment plant can provide a secondary charging function and a stronger link to municipal PV production. The main bus station is operationally important because all lines converge there, but it should be treated as a later-phase opportunity charging location unless grid capacity, space and permitting conditions are confirmed.

The technical feasibility assessment shows that electrification is feasible, but it should not be treated as a simple replacement of one diesel vehicle with one electric vehicle. Ptuj has a compact historic centre, several school-oriented lines, different operating seasons and a free public transport model. These factors create a specific operational profile and strongly influence the choice of vehicle size, battery capacity and charging concept.

5. Integration of PV in transport

5.1. PV potential in Ptuj

The City Municipality of Ptuj is located in the north eastern part of Slovenia in the region of Podravje.

Based on regional solar resource data, the area receives a global horizontal irradiation (GHI) of approximately 1222-1250 kWh/m2 per year and benefits from a high number of sunshine hours, particularly during the summer season.

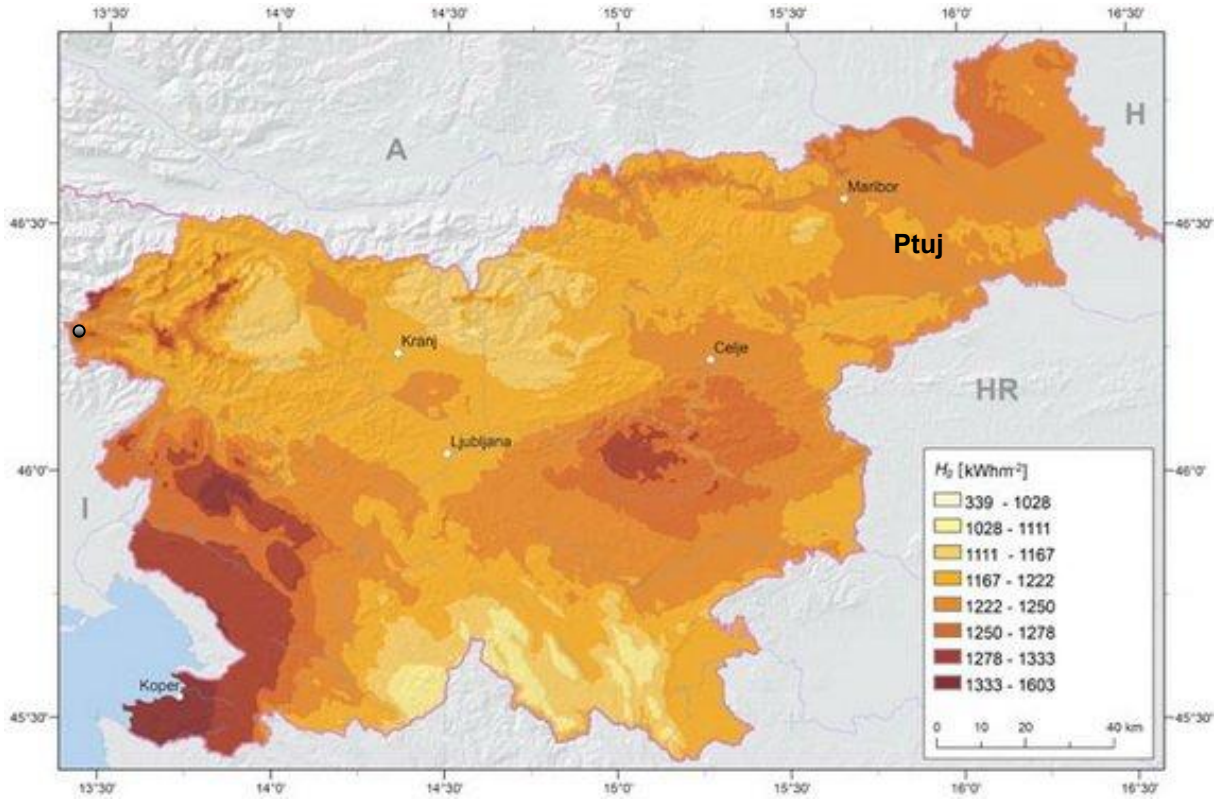


Figure 6. Annual irradiation on a horizontal surface in Slovenia



Figure 7. Photovoltaic system installed in Ptuj

5.2. Methodology for PV potential assessment

The estimation of photovoltaic potential in this study is based on a simplified yet robust methodological approach, suitable for feasibility-level analysis.

The assessment begins with the identification of suitable installation surfaces, followed by the estimation of installable PV capacity (kW) and the calculation of expected annual electricity generation (kWh).

The annual PV electricity generation can be estimated using the general relationship:

Annual PV output = Installed capacity × Specific yield,

where installed capacity is expressed in kWp, specific yield (kWh/kWp/year) depends on location, orientation and system performance. For Ptuj, typical specific yields range between 1100 and 1250 kWh/kWp/year. This range accounts for common system losses, including inverter and wiring losses, temperature effects, variation in orientation and tilt as well as general operational inefficiencies,

The methodology is consistent with standard practices in energy system analysis and compatible with tools such as EnergyPLAN.

5.3. Integration of PV

5.3.1. PV potential and existing municipal PV development

The City Municipality of Ptuj has already taken an important step toward local renewable electricity production through the development of a system of photovoltaic installations on public buildings and municipal facilities. This creates a strong basis for linking the electrification of public bus transport with locally generated solar electricity.

The latest municipal publication reports 17 photovoltaic systems with a combined installed capacity of 1,614.51 kWp. Four systems totalling 123.00 kWp were connected first, while the 13-system community component totals 1,491.51 kWp. The electricity community is expected to produce approximately 1,550 MWh/year and allocate energy among 35 public consumers on a monthly basis [S1]. This current aggregate is used for status reporting; the earlier SONCE 8P investment programme remains the source for the original plant-level design schedule.

The PV installations are located on a diverse group of public buildings and facilities, including educational buildings, kindergartens, sports facilities, cultural and multi-purpose buildings, local community buildings, health infrastructure and communal infrastructure. The listed locations include OŠ Grajena, Vrtec Trobentica, Vrtec Vijolica, Vrtec Deteljica, Športno društvo Rogoznica, Športno društvo Grajena, NK Podvinci, Športni park Spuhlja, Dvorana Mladika I, Dvorana Mladika II, Večnamenska dvorana Spuhlja, Dom krajanov Bratje Reš, Dom krajanov Grajena, Dom krajanov Olge Meglič, Zdravstveni dom Ptuj, Čistilna naprava Ptuj and the farewell facility at Rogoznica cemetery.

From the perspective of public transport electrification, the most relevant characteristic of this system is that it establishes a local production base for public-sector electricity demand. Although the physical electricity flows will depend on grid connection points and metering arrangements, the municipal energy-community model enables the produced electricity to be managed across several public consumers. This creates a practical foundation for connecting electric bus charging demand with local PV production.

5.3.2. Relevance for electric bus charging

The integration of PV electricity into the electric bus system should be designed around the locations where transport operations, charging infrastructure and municipal electricity production can be most effectively linked.

The most relevant facility in this regard is the Ptuj wastewater treatment plant, as it is both included among the municipal PV locations and already identified as a possible location for charging infrastructure. This makes it a priority site for further technical assessment. If sufficient grid capacity, space and operational accessibility are available, the wastewater treatment plant could serve as a secondary charging location supported by on-site PV generation.

The main bus station remains the most important operational location from the transport perspective, as all urban bus lines converge there. At this moment, there is no PV installation at the main bus station. For this reason, PV integration at this location would require either a new dedicated PV installation, for example on canopies or nearby municipal surfaces, or the allocation of electricity from the wider municipal solar community.

CERO Gajke is also relevant as the main depot and charging base. It is not part of the existing municipal PV portfolio, but Javne službe Ptuj has offered a 19,622 m² (about 1.96 ha) area at the site for solar development [S15]. Section 7.2 sets out a 250 kWp PV plan on about 0.25 ha of this area and an optional PV canopy over the depot bays.

5.3.3. System architecture options

Three main PV integration options can be considered for Ptuj.

The first option is indirect PV integration through the municipal solar electricity community. In this model, electric bus chargers are included as one of the municipal electricity consumers benefiting from the electricity generated by the 13 community PV systems (1,491.51 kWp). This option is administratively and technically attractive because it builds on an existing municipal energy project and does not require that every charging point be physically located next to a PV system.

The second option is direct PV integration at charging locations. This is most relevant for the wastewater treatment plant, where PV generation and potential charging infrastructure could be located at the same facility. Direct integration can improve local self-consumption, reduce grid electricity purchases and provide a clear demonstration case for renewable-powered public transport.

The third option is a hybrid model combining the municipal solar community with additional dedicated PV installations at transport-related sites. Under this model, the existing municipal PV system would provide part of the renewable electricity supply, while new PV capacity would be assessed at CERO Gajke, the main bus station or other municipal transport facilities. This option would be the most robust in the long term, especially if the full urban bus fleet is electrified.

5.3.4. Energy balance implications

The approximately 1.55 GWh/year community forecast is significant compared with the central bus charging requirement of 246.7 MWh/year, but it is not an unused annual surplus. The supplied 2025 meter list totals 1,686.99 MWh for the 35 public consumers, producing an annual deficit of approximately 137.72 MWh before any bus load. Adding the central bus case raises combined annual demand to approximately 1,933.66 MWh and reduces generation-to-demand coverage to about 80.1%.

Annual deficit does not mean that no residual PV exists. On bright midday intervals, community generation can exceed simultaneous public-building demand, particularly outside the heating season. The correct planning question is therefore how much residual PV exists in every interval and whether a connected bus can accept energy at that time. The hourly model

estimates this physical coincidence while clearly separating it from monthly settlement allocation.

Daytime charging is most credible at the wastewater treatment plant and, subject to confirmed duties, during suitable layovers. In the model, Scenario 2 supplies approximately 72.1 MWh/year, or 29.2% of bus charging, from residual same-hour community PV. More aggressive PV-aligned strategies increase this share to about 43.8-49.1%, but they require additional infrastructure and operating control.

Stationary storage is not recommended in the first implementation. The municipality should first measure PV export, community load, charger peaks and vehicle availability in the same 15-minute intervals for at least one operating year. Storage should proceed only if those data identify a monetisable constraint such as curtailment, insufficient connection power, demand-charge exposure or a verified resilience requirement.

5.3.5. Priority locations for further assessment

Based on the available information, the following locations should be prioritised for PV-bus integration assessment.

The wastewater treatment plant should be assessed first because it is already part of the municipal PV system and is also a potential charging location. Required follow-up data include installed PV capacity, annual PV production, local electricity demand, available surplus production, grid connection capacity and available space for bus charging.

CERO Gajke should be assessed as the main depot and charging base. Although it is not part of the existing municipal PV portfolio, Javne službe Ptuj has offered about 1.96 ha at the site for solar development [S15], and this study plans a 250 kWp field on about 0.25 ha of it (Section 7.2). Required follow-up data include landfill-cap and gas-well constraints, ownership boundaries, transformer capacity, grid connection conditions and expected depot charging demand.

The main bus station should be assessed as a strategic opportunity charging location. Since it is the central node of the urban bus network, even limited fast or top-up charging could improve operational flexibility. PV integration at this site would likely require canopies, nearby public roofs or allocation of electricity from the municipal solar community.

The 13 community PV systems should be assessed as a collective renewable electricity source for the municipal public transport system. The main question is whether the future electric bus charging points can be formally included among the public consumers supplied through the municipal solar electricity community.

5.4. Reconciliation of PV capacity and production figures

Three related but different figures appear in the evidence. The 2024 investment programme describes an original 17-system design of 1,577.92 kWp and 1,685.77 MWh/year. The allocation workbooks describe the 13-system community component and its 1,549.27 MWh/year forecast. The municipal completion update of 20 April 2026 reports the latest aggregate capacity of 1,614.51 kWp across all 17 systems and approximately 1,550 MWh/year for the community [S1-S2]. The study preserves these distinctions instead of combining them into one misleading number.

Table 17. Reconciled municipal PV figures

Source / version	Capacity	Production	Interpretation
2024 SONCE 8P design	1,577.92 kWp	1,685.77 MWh/year	Original 17-system design list: 4 individual and 13 community plants
2025/2026 allocation workbooks	13 community systems	1,549.27 MWh/year	Generation allocated among 35 public consumers
MO Ptuj update, 20 Apr 2026	1,614.51 kWp	about 1,550 MWh/year stated for community	Latest aggregate: 123.00 kWp first phase plus 1,491.51 kWp community

5.4.1. Original SONCE 8P plant-level design schedule

The table below is retained because it identifies the original location-level capacity and production assumptions. It is a design schedule, not an as-built register. The wastewater treatment plant is the dominant single location in this schedule.

Table 18. Original 17-system design schedule

Original design location	Scheme	kWp	Forecast MWh/year
SD Rogoznica	Individual	17.60	20.59
OS Grajena	Individual	45.24	52.16
Funeral facility Rogoznica	Individual	36.96	39.88
Dvorana Mladika I	Individual	23.20	23.87
Dom krajanov Bratje Res	Community	50.16	51.23
VND Spuhlja	Community	121.80	138.47
Dom krajanov Grajena	Community	50.16	58.60
Dvorana Mladika II	Community	105.56	110.88
Vrtec Trobentica	Community	59.84	62.57
Dom krajanov Olge Meglic	Community	26.40	23.90
NK Podvinci	Community	42.24	45.51
SD Grajena	Community	33.44	34.19
Spuhlja sports park	Community	24.64	26.65
Vrtec Vijolica	Community	29.92	35.34
Vrtec Deteljica	Community	14.08	15.69
Health Centre Ptuj	Community	290.58	313.93
Wastewater treatment plant	Community	606.10	632.31
Design total	-	1,577.92	1,685.77

5.5. Monthly energy-community and bus balance

The modelled monthly profile demonstrates two simultaneous facts. First, the existing community consumers already use more energy than the community systems generate on an annual basis. Second, solar production is strongly seasonal, while the school-oriented bus

demand is lowest in July and August. A simple annual comparison therefore overstates the amount of solar electricity that can be physically matched to bus charging.

Table 19. Monthly model summary in MWh

Month	Community PV	Existing load	Bus charging	PV to buses in S2
Jan	71.9	164.9	25.7	4.6
Feb	94.9	144.0	22.5	6.7
Mar	142.5	149.4	23.8	8.2
Apr	157.3	136.7	24.6	8.6
May	162.1	133.2	24.8	8.7
Jun	179.2	123.0	23.7	8.3
Jul	181.0	125.5	6.6	2.3
Aug	173.6	125.0	6.4	2.3
Sep	138.7	132.5	24.6	8.5
Oct	112.4	148.9	25.7	8.2
Nov	71.2	151.2	22.8	3.9
Dec	64.5	152.6	15.5	1.7
Total	1,549.3	1,687.0	246.7	72.1

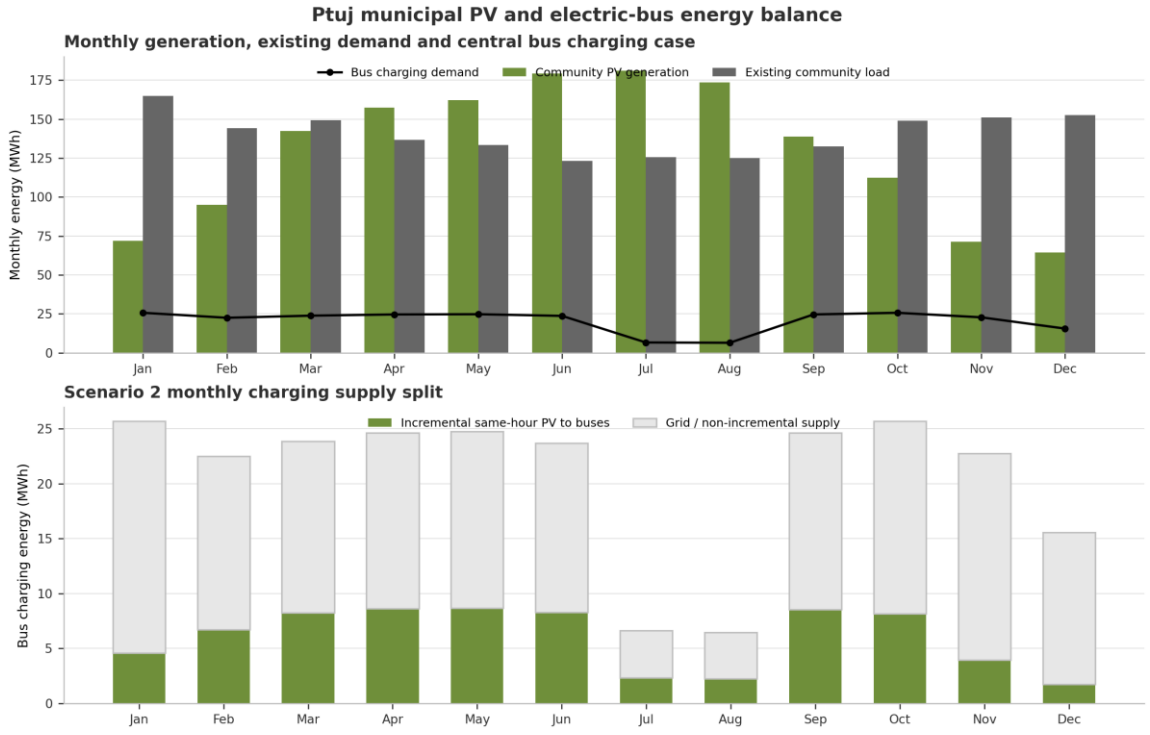


Figure 8. Monthly energy balance and Scenario 2 charging supply split

Values are generated by the 8,760-hour feasibility model.

5.6. Hourly PV generation and charging coincidence

The production shape is derived from JRC PVGIS hourly output for Ptuj at 46.420 N and 15.870 E, using a fixed 30 degree south-facing system and 14% system loss for 2014-2023. The ten-year mean timing is normalised to the more conservative municipal forecast of 1,549.27 MWh/year. This preserves the official annual energy while using a multi-year solar profile to determine the hours in which production occurs [S4-S5].

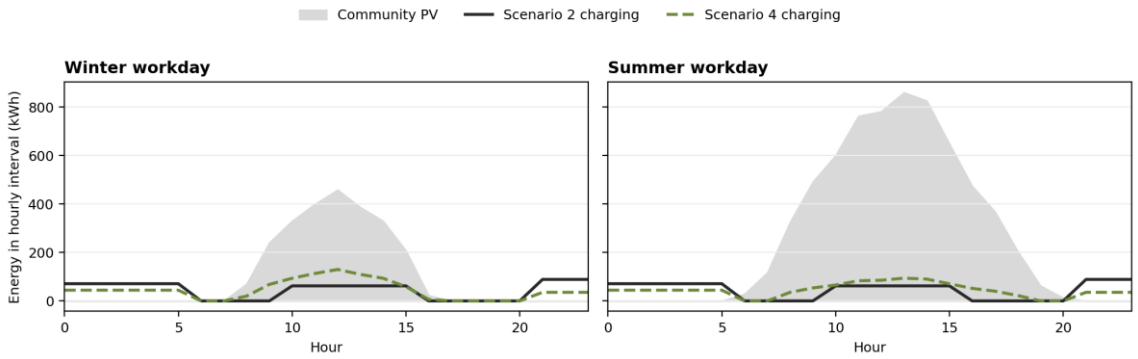


Figure 9. Representative winter and summer weekday profiles

Daytime charging improves solar coincidence; overnight charging remains necessary for service readiness.

The existing community demand profile is the principal sensitivity in the hourly result and is represented by a transparent public-building profile. The model is designed for comparing strategies; the same workbook is recalculated with 15-minute meter data in the concept-design phase before a renewable share is certified.

6. Scenario development

6.1. Purpose and construction of scenario analysis

The scenario analysis for Ptuj is developed around a strong operational focus because the feasibility of electrification depends first on the ability of electric buses to reliably cover the existing daily service requirements.

The central feasibility question is therefore:

Can the existing Ptuj urban bus network be operated with battery-electric buses at an annual cost equal to or lower than the current municipal public transport cost of approximately 1.2 million EUR, while using available municipal PV electricity to reduce operating costs and emissions?

The scenarios are constructed around three key dimensions:

Charging strategy

The analysis compares depot charging, secondary charging and opportunity charging. This is essential because the expected daily distance per bus is between 200 and 250 km, which exceeds the practical operating range of the 9 m reference midibus on one charge.

Charging location

The analysis considers three potential charging locations already identified for Ptuj: CERO Gajke, the wastewater treatment plant and the Ptuj main bus station. CERO Gajke is considered the main depot/base option, the wastewater treatment plant is considered a secondary charging location with direct PV relevance, and the main bus station is considered the most relevant location for opportunity charging.

PV electricity integration

The analysis uses electricity generated by the 13-system community component only after the modelled simultaneous demand of its 35 existing public consumers has been served. This produces a planning-level, auditable estimate of residual same-hour PV for bus charging. The estimate is updated with measured 15-minute data before it is used in a funding claim, tariff decision or contractual renewable-energy statement.

The scenarios therefore do not represent generic levels of PV integration. Instead, they represent progressively more advanced operating models for electric bus charging in Ptuj.

6.2. Baseline assumptions

The following baseline assumptions are applied consistently across the scenarios:

- Ptuj currently operates five urban bus lines.
- The current public transport service is provided free of charge to users.
- The current annual municipal cost of the service is approximately 1.2 million EUR.
- The future electric bus system would need to maintain at least the current level of service.
- The daily distance per bus is assumed to be between 200 and 250 km.
- Electric buses must be suitable for the historic urban structure and narrow streets, especially on Lines 1 and 2.
- The current vehicle used on Line 1 has a length of approximately 8.3 m and a wheelbase of 4.75 m, which indicates the need for compact or mid-size electric buses.

- The main candidate charging locations are CERO Gajke, the wastewater treatment plant and the Ptuj main bus station.
- The 13-system community component of the municipal PV portfolio is the renewable source used in the model. After the modelled demand of its 35 existing consumers, it can supply 72.1-121.0 MWh/year of same-hour PV to the buses, depending on the scenario (Table 22).

For the preliminary energy assessment, the annual electricity demand of the electric bus fleet can be estimated using the following relationship:

Annual electricity demand = number of buses × daily distance × specific electricity consumption × operating days

The final calculation requires confirmation of the number of buses, annual operating days, real vehicle consumption and the final operating schedule.

6.3. Range and need for opportunity charging

The need for opportunity charging depends on whether the selected electric buses can reliably complete the expected daily duty cycle of 200–250 km per bus.

In theory, depot charging may be sufficient if the selected mid-size electric bus has enough battery capacity to cover the full daily distance with an adequate operational reserve. However, nominal vehicle range should not be used directly as the planning basis. Real-world range is affected by several factors, including winter heating demand, summer cooling demand, passenger load, driving style, topography, battery degradation, detours, delays and the need to maintain reserve capacity.

For feasibility-level planning, the following logic is applied:

- If a selected bus can reliably cover 250 km per day with an operational reserve, depot charging may be sufficient.
- If the practical range is close to the daily duty cycle, secondary charging becomes advisable.
- If the practical range is below the required daily duty cycle, opportunity charging becomes necessary.
- If the municipality wants to maximise the use of daytime PV electricity, opportunity charging becomes beneficial even if it is not strictly required for range.

Opportunity charging should therefore be treated as a risk-reduction and optimisation measure. It increases infrastructure complexity and investment cost, but it can improve operational reliability, reduce required battery size, enable better use of solar electricity and reduce the risk of service disruption. For Ptuj, the 9 m reference midibus falls into the case where the practical range is below the daily duty: about 95-100 kWh of usable battery covers roughly 150 km at the central consumption and 105-110 km in winter conditions, against a 200-250 km school-day duty. A daytime top-up is therefore a requirement for this vehicle class, not only an optimisation.

6.4. Scenario definitions

Five scenarios are defined for the Ptuj feasibility study: the current outsourced model as Scenario 0 (baseline) and four electrification scenarios, Scenarios 1 to 4.

6.4.1. Scenario 0 - Current outsourced public transport model

Scenario 0 represents the existing situation and serves as the economic and operational baseline.

Under this scenario, urban public transport continues to be operated by the external operator under the current service model. Public transport remains free of charge for users, and the municipality continues to finance the service from its budget. The annual municipal cost of this model is approximately 1.2 million EUR.

Scenario 0 does not include electric buses, municipal charging infrastructure or direct PV integration into public transport. It is used as the benchmark against which all electrification scenarios are assessed.

The key evaluation question for the following scenarios is whether a municipally operated electric bus system can be implemented at an annualised cost that is lower than, equal to, or justifiably higher than the current 1.2 million EUR/year cost.

6.4.2. Scenario 1 - Electric buses with depot charging at CERO Gajke

Scenario 1 represents the basic electrification pathway.

In this scenario, the municipality establishes an electric bus fleet and uses CERO Gajke as the main depot and charging location. Charging is carried out primarily overnight or during longer non-operating periods. The scenario assumes that buses return to the depot for charging and that no regular opportunity charging is required during the operating day.

This is the technically simplest electric-bus scenario because it concentrates charging infrastructure at one main base location. It also fits the possible role of Javne službe Ptuj as a future municipal operator, since CERO Gajke is connected to municipal communal infrastructure and already includes space for operational vehicles.

The main technical risk in Scenario 1 is vehicle range. The expected daily distance per bus is 200-250 km (130-165 kWh), while the 9 m reference midibus has about 95-100 kWh of usable battery. Depot charging alone is therefore not sufficient for full school-day duties with this vehicle; Scenario 1 would require either large-battery 9.5 m buses or midday returns to CERO for recharging (Section 9.2).

This scenario does not rely on direct PV integration. Electricity for charging is primarily supplied from the grid. PV electricity from the municipal PV system may be included only indirectly if the legal and accounting framework allows the bus chargers to be included among municipal consumers.

Main purpose of Scenario 1:

To test whether the Ptuj bus network can be electrified using the simplest charging model and whether this model can remain economically competitive with the current 1.2 million EUR/year baseline.

6.4.3. Scenario 2 – Depot charging at CERO Gajke with secondary charging at the wastewater treatment plant

Scenario 2 builds on Scenario 1 by adding the wastewater treatment plant as a secondary charging location.

CERO Gajke remains the main depot and operational base, while the wastewater treatment plant provides additional charging flexibility. This scenario is particularly relevant because the wastewater treatment plant is both one of the identified possible charging locations and one of the municipal facilities included in the wider PV development framework.

The purpose of the secondary charging location is to reduce the operational risk of relying only on depot charging. It can provide top-up charging during the day, support buses operating longer daily duties, reduce pressure on the depot grid connection and improve resilience in case of charger unavailability at the main depot.

This scenario provides the daytime top-up that the 9 m reference midibus needs on full school-day duties, about 35-70 kWh per duty in the central case, and adds reserve under winter or high-consumption conditions.

PV integration in Scenario 2 is stronger than in Scenario 1. The hourly model assigns approximately 72.1 MWh/year of residual same-hour community PV to bus charging, equivalent to 29.2% of the central charging requirement. This is a feasibility estimate based on a modelled existing-load profile; the final contribution depends on measured interval data, metering and the legal allocation arrangement.

Main purpose of Scenario 2:

To test whether a secondary charging point at the wastewater treatment plant can make the electric bus system more robust while improving the use of municipal PV electricity.

6.4.4. Scenario 3 – Depot charging and opportunity charging using municipal PV surplus

Scenario 3 introduces opportunity charging as a planned part of the operating model.

In this scenario, CERO Gajke remains the main depot, while opportunity charging is introduced at one or more operationally relevant locations. The most important candidate is the Ptuj main bus station, because all urban bus lines converge there and buses may have dwell time between services. The wastewater treatment plant may also be used as a supporting charging location, depending on route planning and technical feasibility.

The key feature of Scenario 3 is planned PV-aligned opportunity charging. More charging is shifted to the solar window, raising modelled residual same-hour PV use to approximately 108.0 MWh/year, or 43.8% of charging. The scenario requires reliable dwell windows, suitable multi-site access, interval metering and coordinated charger control.

This scenario is particularly relevant if the municipality wants to maximise the use of daytime solar electricity. Since PV production is highest during daylight hours, opportunity charging can improve the match between PV generation and bus electricity demand. This can reduce grid electricity purchases and improve the environmental performance of the system.

The main limitation of Scenario 3 is not annual energy but operational and metering evidence. A bus must be at a suitable charger when residual PV is available, and the settlement rules must support the intended allocation. Measured 15-minute production, existing-load and charger data are therefore required before this scenario becomes the investment baseline.

Main purpose of Scenario 3:

To test whether opportunity charging can improve range reliability and enable meaningful use of residual electricity from the 13 community PV systems.

6.4.5. Scenario 4 – Smart charging system with CERO Gajke, wastewater treatment plant and main bus station

Scenario 4 represents the most advanced operating concept.

It combines depot charging at CERO Gajke, secondary charging at the wastewater treatment plant and opportunity charging at the Ptuj main bus station. Charging is managed through a smart charging system that optimises charging times according to vehicle schedules, electricity prices, grid capacity and available PV electricity.

This scenario assumes that the electric bus system is operated as an integrated energy and mobility system. Charging is no longer treated only as a vehicle-support function, but as a managed energy demand that can be shifted and optimised.

The smart charging system would aim to:

- ensure that all buses are sufficiently charged for their daily duties;
- keep the combined charging peak at each site within its available connection capacity;
- prioritise the use of available municipal PV electricity;
- avoid unnecessary grid reinforcement where possible;
- use daytime charging when PV production is available;
- maintain operational flexibility in case of delays or vehicle substitution.

Battery energy storage may be considered in this scenario, but only as an optional later-phase measure. It should not be included automatically. Storage becomes relevant only if there is significant PV surplus, insufficient grid capacity, high peak-power costs, or a clear need to shift solar electricity from daytime to evening or night-time charging.

Scenario 4 has the highest technical complexity and likely the highest investment cost. Therefore, it should only be considered economically favourable if the benefits from improved reliability, PV utilisation, reduced grid costs and operational flexibility justify the additional investment.

Main purpose of Scenario 4:

To test the long-term integrated model in which electric bus charging is coordinated across several locations and optimised according to PV availability, grid constraints and operating schedules.

6.4.6. Scenario comparison

Table 20. Scenario comparison by key indicator

Indicator	Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Operating model	Current outsourced service	Municipal electric fleet	Municipal electric fleet	Municipal electric fleet	Municipal electric fleet
Main charging location	None	CERO Gajke	CERO Gajke	CERO Gajke	CERO Gajke

Indicator	Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Secondary charging	No	No	Wastewater treatment plant	Wastewater treatment plant / bus station	Wastewater treatment plant and bus station
Opportunity charging	No	No	Limited / optional	Yes	Yes, optimised
PV integration	No	Indirect / limited	WWTP and municipal PV potential	Municipal PV surplus	Municipal PV surplus + smart charging
Battery storage	No	No	No	No / optional	Optional later phase
Technical complexity	Low	Medium	Medium	High	Very high
Range risk	Not applicable	Highest	Medium	Low	Lowest
Grid dependency	Not applicable	High	Medium/high	Medium	Medium/low
Investment cost	None for municipality-owned fleet	High	High	Very high	Very high
Economic benchmark	1.2 million EUR/year	Must be compared to baseline	Must be compared to baseline	Must be compared to baseline	Must be compared to baseline
Main feasibility question	Existing cost reference	Can depot charging alone work?	Does secondary charging improve reliability?	Can PV surplus support opportunity charging?	Is the integrated smart system economically justified?

Table 21. Qualitative assessment and recommended role of the scenarios

Scenario	Technical feasibility	Operational reliability	PV integration	Investment intensity	Recommended role
0 - Current outsourced model	High, because it is already operating	High under current contract	None	No municipal CAPEX, but recurring service cost	Baseline only

Scenario	Technical feasibility	Operational reliability	PV integration	Investment intensity	Recommended role
1 - Depot charging at CERO Gajke	Limited with the reference midibus; requires large-battery buses or midday depot returns	Moderate to good	Indirect only	Moderate	Minimum electrification scenario
2 - CERO Gajke + wastewater treatment plant	Strong	Strong because of secondary charging	Good, especially if WWTP PV/community allocation is enabled	Moderate to higher	Preferred first full implementation (Phase 2)
3 - Municipal PV surplus + opportunity charging	Strong after metering and legal checks	Very strong	High	Higher	Optimisation option after measured data (Phase 3)
4 - Smart charging including main bus station	Technically strongest but most complex	Very strong	Highest	Highest	Long-term integration option (Phase 4, to 2031)

The comparison indicates that Scenario 2 provides the best balance between technical robustness, investment proportionality and realistic implementation. Scenario 1 is possible only with larger-battery vehicles or midday returns to the depot, because the reference midibus cannot complete a full school-day duty on overnight charging alone. Scenario 3 and Scenario 4 are attractive from an energy-system perspective, but should follow after the municipality confirms electricity allocation rules, grid capacity and operational charging windows.

6.5. Quantified scenario results

Table 22. Annual charging, peak and PV results

Scenario	Charging MWh/year	Modelled peak kW	Incremental PV MWh	PV share	Grid / non-incremental MWh
S1	246.7	177.6	0.0	0.0%	246.7
S2	246.7	88.8	72.1	29.2%	174.6
S3	246.7	135.5	108.0	43.8%	138.7
S4	246.7	151.2	121.0	49.1%	125.7

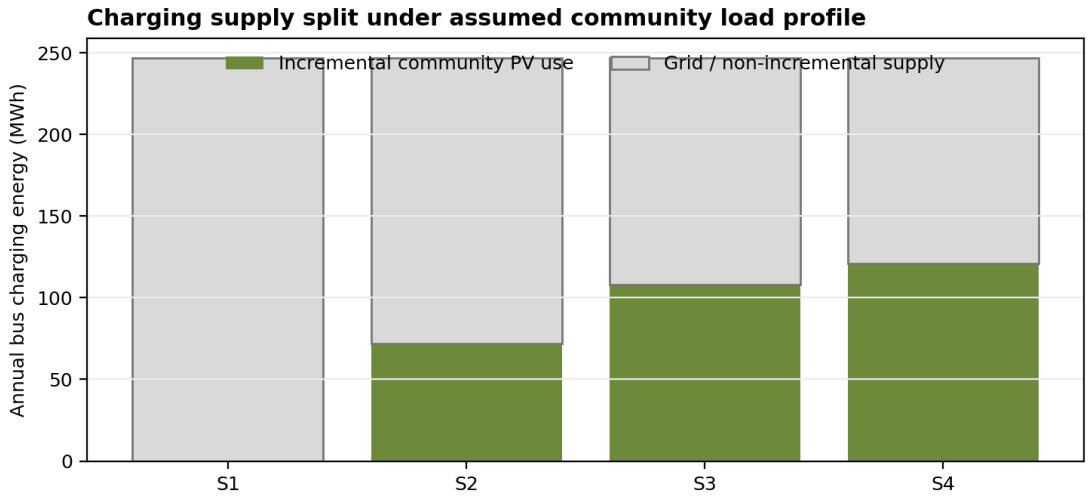


Figure 10. Annual charging supply split after prioritising the modelled existing community load

Table 23. Technical and implementation comparison

Criterion	S1	S2	S3	S4
Implementation complexity	Low-medium	Medium	High	Very high
Operational resilience	Moderate	Strong	Very strong	Very strong
Incremental PV share	0.0%	29.2%	43.8%	49.1%
Modelled peak	177.6 kW	88.8 kW	135.5 kW	151.2 kW
Indicative gross CAPEX	EUR 2.743m	EUR 2.893m	EUR 3.113m	EUR 3.243m
Recommended role	Minimum case	Preferred base (Phase 2)	Phase 3 option	Phase 4 option

Moving from Scenario 2 to Scenario 4 increases modelled PV use by about 48.9 MWh/year but adds approximately EUR 350,000 of indicative charging and control CAPEX. At the assumed EUR 0.08/kWh difference between grid electricity and PV opportunity value, the additional annual energy benefit is only about EUR 3,900. Advanced charging may still be justified by resilience, grid constraints or future tariffs, but not by energy arbitrage alone under the central assumptions. Scenario 2 also has the lowest modelled peak (88.8 kW); Scenarios 3 and 4 shift more charging into the midday solar window and add opportunity charging, which raises their peaks to 135.5 and 151.2 kW. Smart charging keeps each site within its connection limit but does not lower peak demand below Scenario 2.

7. Charging and photovoltaic integration location assessment

The location assessment identifies the functional role of each candidate site and the evidence required before design. Optimality is defined as the lowest-risk configuration for reliable bus operation and credible PV integration. It does not mean that any site is construction-ready. Cadastral, topographic, geotechnical, fire-safety and binding DSO connection studies follow in the concept-design phase.

7.1. Assessment framework

Table 24. Weighted site-assessment framework

Criterion	Weight	Test
Operational fit	30%	Depot circulation, deadhead, dwell windows, access and resilience
PV integration	25%	Existing PV, credible expansion potential and hourly charging coincidence
Grid readiness	20%	Indicative electrical context and ability to control load
Ownership / implementation	15%	Municipal control, agreements, phasing and procurement complexity
Spatial / environmental	10%	Available area, traffic safety, visual effects and site constraints

Each criterion is scored from 1 (poor) to 5 (strong). Weighted totals are also shown on the 0-100 scale used in the companion location assessment (weighted score multiplied by 20). The scores are evidence-informed planning judgements. Grid scores are planning-level because only the distribution-system operator can confirm connection power, protection, reinforcement, timing and cost. Physical power flow and community settlement eligibility are assessed separately.

7.2. CERO Gajke main depot and overnight charging

Table 25. CERO Gajke site assessment

Attribute	Assessment
Address / coordinate	Dornavska cesta 26, Ptuj; 46.421474, 15.912677
Proposed role	Main depot, overnight charging, parking, cleaning and operational control
Existing project link	Municipal waste-management site and publicly identified degraded-land context
Usable area (plan)	Depot about 1,450 m² (7 bays, manoeuvring aisle, charger island and service unit); area offered for PV by Javne službe Ptuj 19,622 m² (about 1.96 ha), of which about 0.25 ha is used by the 250 kWp plan [S15]
PV status	250 kWp ground-mounted PV plan on about 0.25 ha (Figure 11); optional depot PV canopy of about 80 kWp
Primary advantage	Controlled site and coherent fleet-base function
Primary constraints	Grid capacity, depot circulation, civil works, site conditions and deadhead

The feasibility model uses approximately 180 kW of aggregate controlled depot charging, represented by three modular outputs. This capacity recharges the whole fleet over the overnight and late-evening window. It does not, on its own, cover a full school-day duty with

the reference midibus: a bus covering 200-250 km needs about 130-165 kWh of traction energy (Section 4.2.2), while the 9 m reference midibus (Offer B) carries about 120 kWh, of which roughly 95-100 kWh is usable after the minimum state-of-charge reserve. Each duty therefore needs a daytime top-up of roughly 35-70 kWh, which Scenario 2 provides at the wastewater treatment plant. Final design should favour modularity, independent outputs and an N+1 operating philosophy instead of relying on one high-power charger.

7.2.1. CERO PV plan

Javne službe Ptuj has offered a 19,622 m² (about 1.96 ha) area at Dornavska cesta 26 for solar development [S15]. The study plans a 250 kWp ground-mounted field on about 0.25 ha of this area (about 13%), sized to the central bus energy rather than to the full plot, plus an optional PV canopy of about 450 m² (about 80 kWp) over the depot bays. At the community forecast yield of approximately 1,039 kWh/kWp/year, the 250 kWp field would generate about 259.7 MWh/year - similar to the central annual bus energy, but not in the same hours. Figure 11 shows the planning layout; landfill-cap loading, gas wells, shading and the connection point are fixed in the site survey of the concept-design phase.

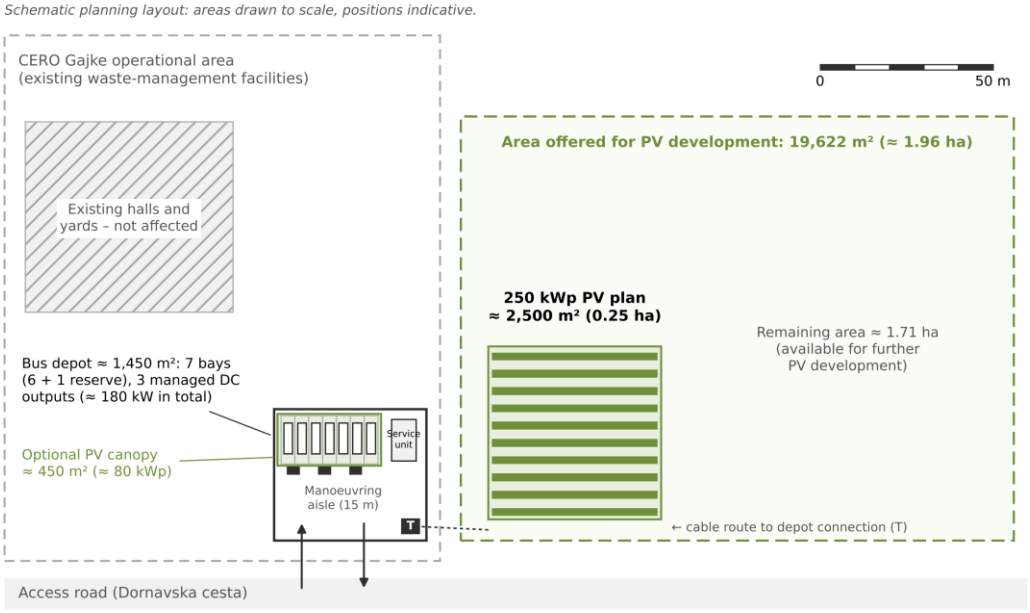


Figure 11. CERO Gajke depot and PV plan – schematic layout

Own planning sketch; PV development area from Javne službe Ptuj [S15]. Areas to scale, positions indicative.

The PV plan is screened with the same simplified unlevered, pre-tax discounted cash flow as the companion location assessment: 25 years at a 5% real discount rate, fixed O&M, 0.5% annual degradation and an inverter replacement allowance of 10% of initial CAPEX in year 14. Simple payback is initial CAPEX divided by the year-one net benefit. The values exclude VAT, financing, grants and site-specific premiums.

Table 26. CERO 250 kWp PV plan – inputs and results

Input / result	Central value	Comment
Planned capacity	250 kWp	Ground-mounted field on about 0.25 ha of the 1.96 ha area offered for PV
Year-1 generation	259.7 MWh	Scaled from 1,549.27 MWh / 1,491.51 kWp
CAPEX	EUR 250,000	EUR 1,000/kWp; excludes site-specific premiums and reinforcement
Fixed O&M	EUR 3,000/year	1.2% of initial CAPEX
Inverter replacement	EUR 25,000 in year 14	10% of initial CAPEX; mid-life allowance
Energy value	EUR 0.10/kWh	Central opportunity-value assumption
Year-1 gross value	EUR 25,970	Year-1 generation multiplied by the energy value
Year-1 net benefit after O&M	EUR 22,970	Basis for the simple payback
Degradation / discount / horizon	0.5% / 5% / 25 years	Constant 2026 EUR; no terminal value
Simple payback	10.9 years	EUR 250,000 / EUR 22,970
IRR / NPV	6.8% / EUR 44,300	Central case; identical in the companion location assessment

Table 27. Sensitivity of the CERO PV plan to energy value and CAPEX

Sensitivity case	IRR / 25-year NPV	Interpretation
Energy value -20% (EUR 0.08/kWh)	3.9% / -EUR 25,600	Below the break-even value of about EUR 0.087/kWh
Energy value -10% (EUR 0.09/kWh)	5.4% / +EUR 9,300	Marginally above the 5% discount rate
Base case (EUR 0.10/kWh)	6.8% / +EUR 44,300	Central case
Energy value +10% (EUR 0.11/kWh)	8.1% / +EUR 79,200	Moderate avoided-cost case
Energy value +20% (EUR 0.12/kWh)	9.4% / +EUR 114,100	Stronger avoided-cost case
EUR 0.16/kWh	14.2% / +EUR 253,800	High-value self-consumption case
EUR 0.20/kWh	18.6% / +EUR 393,400	Upper stress test
CAPEX -10% (EUR 900/kWp)	8.3% / +EUR 74,800	Lower contractor price
CAPEX +10% (EUR 1,100/kWp)	5.5% / +EUR 13,800	Site premiums remove most of the margin

The plan is most exposed to the realised value of its electricity and to the final installed cost. Break-even lies at approximately EUR 0.087/kWh, so the plan clears the 5% threshold only if most of its output displaces purchased electricity rather than being exported at a low settlement value. A 10% CAPEX increase leaves a narrow positive margin of about EUR 13,800.

7.3. Ptuj wastewater treatment plant secondary charging and PV hub

Table 28. Wastewater treatment plant assessment

Attribute	Assessment
Address / coordinate	Ob Dravi 7, Ptuj; 46.407907, 15.881046
Proposed role	Secondary daytime charging, emergency recovery and PV-integration hub
Original PV design	606.10 kWp and 632.31 MWh/year
Usable area (plan)	Existing PV about 3,000 m² of module area (606.10 kWp design); charging zone about 420 m² (one bay with drive-through lane) outside the treatment process area (Figure 12)
Relationship to bus demand	Original forecast output equals about 2.56 times central annual bus charging energy
Primary advantage	Strongest existing PV node and controllable infrastructure site
Primary constraints	Access, deadhead, plant operations, metering and DSO confirmation

The wastewater treatment plant is the best immediate site for demonstrating PV-aligned bus charging. The charger should not be treated as general parking: visits must be tied to duty blocks, secure access and safe separation from plant operations. Before charger power is fixed, the municipality should verify the as-built PV rating, inverter and export limits, metering boundary, 15-minute import/export profile, vehicle circulation and the deadhead effect for each candidate duty.

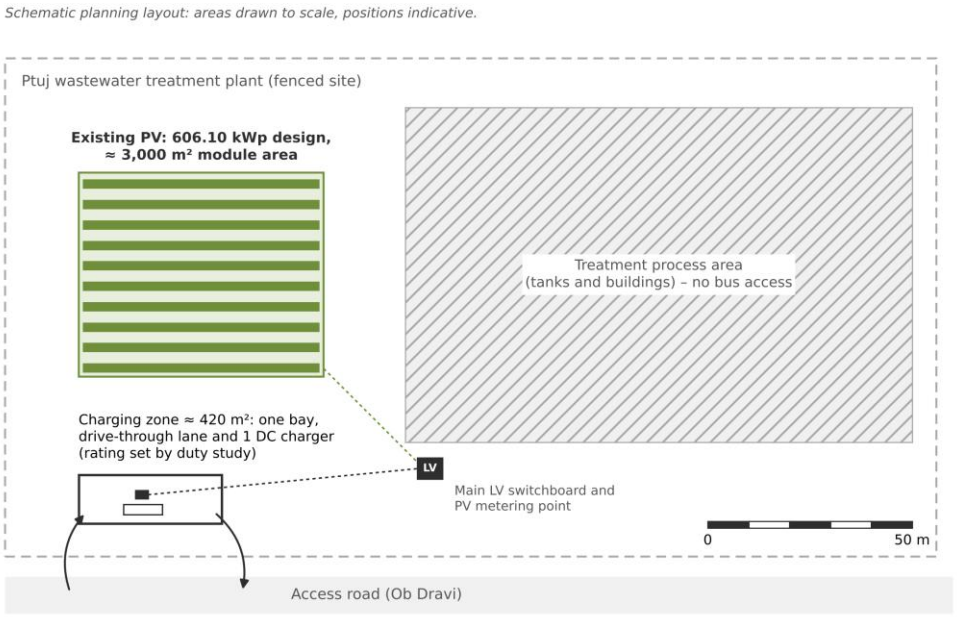


Figure 12. Wastewater treatment plant secondary charging point – schematic layout

Own planning sketch; module area derived from the 606.10 kWp design at about 5 m²/kWp. Areas to scale, positions indicative.

7.4. Ptuj main bus station future opportunity charging

Table 29. Main bus station assessment

Attribute	Assessment
Coordinate	46.421255, 15.876581
Proposed role	Optional short opportunity charging at the network hub
PV status	No PV installation at present; canopy or community allocation possible
Primary advantage	All five lines connect to the central node; no special passenger trip is required
Primary constraints	Bay occupation, pedestrian safety, regional services, visual impact, ownership and grid work

The bus station is operationally attractive but should not lead the first investment. A high-power charger could protect vehicle range, yet it could also constrain bay use and require an expensive connection. The municipality should preserve a future cable route and equipment zone where feasible, while deferring procurement until measured duties demonstrate a clear need.

7.5. Multi-criteria comparison and recommended site concept

Table 30. Weighted site comparison

Site	Operational 30%	PV 25%	Grid 20%	Implementation 15%	Spatial 10%	Weighted (1-5 / 0-100)
CERO Gajke	5	4	4	5	4	4.45 / 89.0
Wastewater treatment plant	4	5	4	4	4	4.25 / 85.0
Main bus station	5	2	3	2	2	3.10 / 62.0

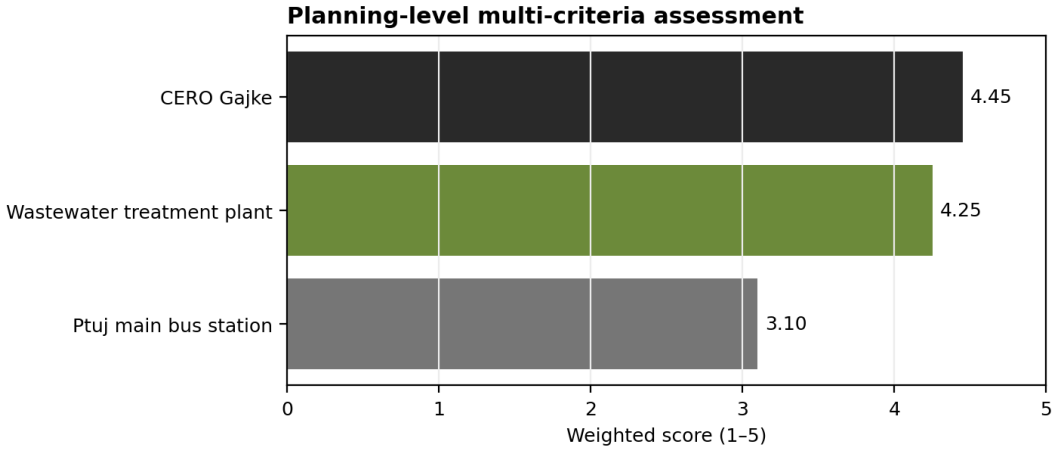


Figure 13. Planning-level site scores

CERO and the wastewater treatment plant are complementary rather than competing locations.

CERO leads because it is the strongest fleet base. The wastewater treatment plant nearly matches it because of the large PV asset and a credible daytime role. The main bus station scores lower because its excellent network position does not yet offset spatial, ownership,

safety and PV limitations. The recommended solution is therefore a two-site architecture, not a single universal charging site.

Table 31. Recommended phased site concept

Phase	CERO Gajke	Wastewater treatment plant	Main bus station
1 Evidence and concept design (2027)	Grid and depot survey; managed 180 kW concept	As-built PV, interval data, access and grid study	Protect route/equipment space; resolve circulation and ownership
2 Procurement and first implementation (2028-2029)	Main parking and controlled depot charging	One secondary DC charger if duties confirm the case	No charger in base procurement
3 Measured optimisation (2029-2030)	Decide on the 250 kWp PV plan after survey	Tune charging to measured residual PV	Reassess only if range and dwell data support it
4 Advanced integration (2030-2031)	Fleet energy-management expansion	Community and charger EMS integration	Opportunity charger only with a proven business case

7.6. Pre-design evidence checklist

Table 32. Minimum evidence before concept or detailed design

Evidence	CERO	WWTP	Bus station	Owner / output
Land, ownership and access	Required	Required	Required	Municipality / legal map
Topographic and utility survey	Required	Required	If option retained	Licensed surveyor
DSO connection study	Required	Required	Optional phase	Elektro Maribor / DSO conditions
15-minute meter data	Current site load	PV, load and export	Site load if considered	Municipality / portal export
Vehicle swept path	Depot circulation	Entry and turning	Bay and pedestrian interface	Traffic engineer
Environmental and fire review	Waste/degraded-land context	Treatment-plant operations	Public-space interface	Competent designers
CAPEX quotation	Depot, civil and electrical	Charger, cable and grid	Only after need confirmed	Suppliers and contractors

7.7. Location decision for concept design

The concept-design brief should therefore treat CERO and the wastewater treatment plant as one coordinated first-stage system. The next commission should deliver a CERO depot layout and managed charging concept, a WWTP access and secondary-charger concept tied to measured PV residual, and a protected but unfunded bus-station option. Any change to vehicle battery, charger rating or depot location must trigger an updated hourly and connection-capacity calculation.

- Confirm land, access, circulation and utility corridors at CERO and the wastewater treatment plant.
- Obtain DSO conditions before fixing charger power or issuing civil-work quantities.
- Keep stationary storage and a bus-station charger outside the base procurement unless measured evidence proves their value.

8. Economic feasibility analysis

8.1. Economic performance indicators

The economic feasibility analysis is prepared as a decision-support assessment rather than a final investment appraisal. The current municipal cost of the outsourced public transport service, approximately 1.2 million EUR per year, is used as the baseline reference. The purpose is to assess whether a municipally operated electric bus system could be technically viable and financially reasonable, not to replace the need for a later procurement-level total cost of ownership model.

The following indicators are used to compare the scenarios: initial investment requirement, exposure to subsidy availability, annual electricity demand, expected charging infrastructure complexity, potential use of municipal PV electricity, operational robustness, and long-term ability to reduce operating cost volatility.

Table 33. Economic performance indicators and data status

Indicator	Purpose in this study	Data status
CAPEX for vehicles	Measures the investment burden of replacing/establishing the municipal fleet	Indicative offers available for several vehicle classes
CAPEX for chargers and grid connection	Measures the cost of enabling depot, secondary or opportunity charging	Feasibility allowance; DSO and supplier quotations in the design phase
Annual energy cost	Tests sensitivity to electricity price and PV allocation	Estimated with central energy values; contracted tariffs applied at procurement
Funding effect	Tests affordability without a capital grant (central case) and with possible support	Borzen M2/M3 allocation reached; alternative sources in Section 8.6
Operational reliability	Tests whether the system can run all published services without unacceptable range risk	Requires final duty blocks and charging windows
PV utilisation	Measures the potential to link public transport with SONCE 8P and municipal energy communities	Hourly and monthly residual PV modelled

8.2. Investment and operational costs

The available vehicle offers show three relevant electric vehicle classes for Ptuj: a compact e-minibus suitable for the narrowest urban sections, a 9 m electric midibus suitable for most lines, and a larger 9.5 m low-floor electric bus with higher passenger capacity and a substantially larger battery. For the full municipal operating model, the most balanced procurement concept is a mixed or midibus-dominant fleet, with compact vehicles used where manoeuvrability is critical.

Table 34. Vehicle classes and indicative procurement logic

Vehicle class / offer basis	Main feasibility relevance for Ptuj	Indicative procurement logic
Compact e-minibus, approx. 6 m, approx. 115 kWh battery, up to 25 passengers	Suitable for narrow streets and lower-demand services; useful for Line 1/centre constraints	Useful as first vehicle or for constrained routes
Electric midibus, approx. 9 m, approx. 120 kWh battery, up to 35 passengers	Balanced option for school-oriented and peri-urban routes; reported efficient consumption range	Core fleet candidate for municipal takeover

Vehicle class / offer basis	Main feasibility relevance for Ptuj	Indicative procurement logic
9.5 m low-floor electric bus, approx. 350 kWh battery, up to 65 passengers	High capacity and range reserve, but higher cost and possible manoeuvrability concerns	Selective use only if passenger demand and street geometry justify it

For full service internalisation, the fleet should not be planned as exactly one vehicle per line without reserve. A realistic feasibility-level assumption is six operational vehicles plus one reserve vehicle for a full municipal model. A smaller first phase may begin with one to three electric vehicles, but it would not represent full replacement of the existing network.

Table 35. Cost elements by scenario

Cost element	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Vehicle procurement	Approx. 6+1 electric buses for full municipal model	Same basic fleet; better range support	Same fleet, possibly optimised with opportunity charging	Same fleet plus higher system integration requirements
Charging infrastructure	Depot chargers at CERO Gajke	Depot chargers + secondary charging at wastewater treatment plant	Depot + secondary + opportunity charging where justified	Multi-site smart charging and possible later storage
Grid/connection costs	Single-site assessment required	Two-site assessment required	Multiple-site assessment required	Highest grid and control-system complexity
Operational staffing	Drivers, dispatcher/coordination and technical support required	Same, with added charging coordination	Same, with active daytime charging management	Same, with smart energy management responsibility
Financial risk	Moderate CAPEX, but the reference midibus needs larger batteries or midday depot returns	Balanced; preferred risk/benefit ratio	Higher; depends on PV allocation and on opportunity charging at the main bus station (Ptuj AP)	Highest; suitable only as later optimisation

The Borzen zero-emission bus incentive would materially reduce the vehicle investment burden, but Borzen reports that the funds for M2 and M3 vehicles have reached the advertised amount [S6]. The financial analysis therefore uses a no-grant central case and shows the 80% grant only as an upside; Section 8.6 sets out the alternative funding options.

On the operating-cost side, electric buses can reduce energy and maintenance costs compared with diesel buses, especially when part of the electricity demand is supplied through municipal PV. However, a municipally operated system also creates new costs: drivers, technical staff, scheduling, cleaning, insurance, depot management, spare vehicles, charger maintenance, software, grid charges and administration. These costs must be included in the final TCO model before a binding investment decision.

8.3. Central financial assumptions and boundaries

Table 36. Central economic assumptions

Input	Central value	Status
Reference fleet	6 x 9 m midibus + 1 compact e-minibus; approx. EUR 1.99m	Anonymised supplier offers; configuration to be tendered

Input	Central value	Status
Common depot / project CAPEX	EUR 0.400m	Feasibility allowance
Charging and site CAPEX	EUR 0.350-0.850m	Feasibility allowance; quotations and DSO studies required
Capital grant	None in the central case; 80% of vehicle CAPEX tested as upside	Borzen M2/M3 allocation reached [S6]; no other grant confirmed
Non-energy municipal OPEX	EUR 0.850m/year	Feasibility allowance requiring bottom-up validation
Grid electricity / PV value	EUR 0.18 / EUR 0.10 per kWh	Sensitivity assumptions
Discount rate / horizon	5% real / 12 years	Constant 2026 EUR; no terminal value

The EUR 1.2 million/year outsourced-service figure is a budget benchmark, not automatically the avoided cost of a municipal operation. Before the comparison becomes binding, the current contract must be reconciled against drivers, dispatch, maintenance, cleaning, depot, insurance, IT, replacement reserve, financing, tax and VAT treatment, transition cost and service-quality obligations.

8.4. Scenario CAPEX, OPEX and present-value results

Table 37. Investment and annual operating results

Scenario	Gross CAPEX	Annual OPEX	Saving vs EUR 1.2m	Payback without grant (central)	Payback with 80% grant (upside)
S1	EUR 2.743m	EUR 901,402	EUR 298,598	9.2 years	3.8 years
S2	EUR 2.893m	EUR 898,636	EUR 301,364	9.6 years	4.3 years
S3	EUR 3.113m	EUR 900,165	EUR 299,835	10.4 years	5.1 years
S4	EUR 3.243m	EUR 901,721	EUR 298,279	10.9 years	5.5 years

Table 38. Twelve-year NPV: central no-grant case and funding upside

Scenario	NPV without grant (central)	Break-even capital support	NPV with 80% grant (upside)	Interpretation
S1	-EUR 0.096m	EUR 0.10m (5% of vehicle CAPEX)	+EUR 1.498m	Better NPV, but the reference midibus cannot complete a full school-day duty on depot charging alone
S2	-EUR 0.222m	EUR 0.22m (11% of vehicle CAPEX)	+EUR 1.372m	Preferred: the WWTP top-up closes the range gap for about EUR 0.15m
S3	-EUR 0.455m	EUR 0.46m (23% of vehicle CAPEX)	+EUR 1.139m	PV optimisation option (Phase 3)
S4	-EUR 0.599m	EUR 0.60m (30% of vehicle CAPEX)	+EUR 0.995m	Highest complexity and investment (Phase 4)

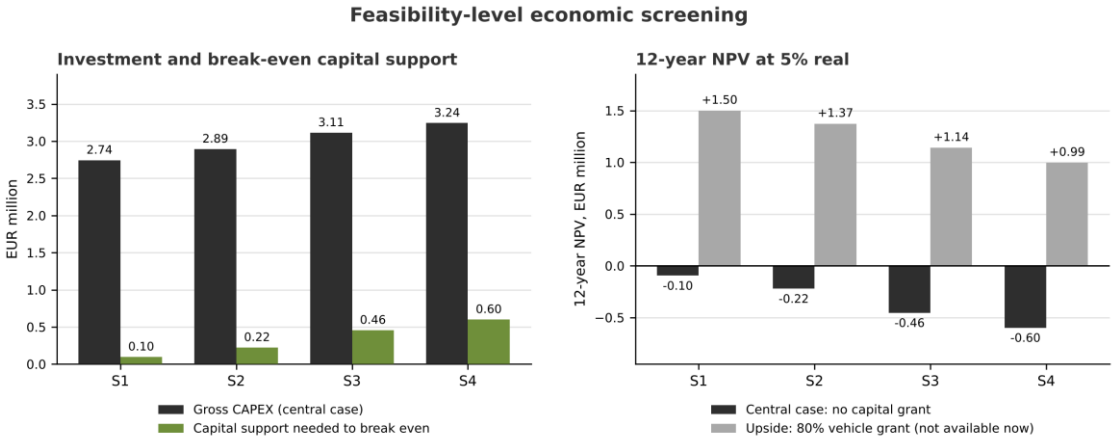


Figure 14. Feasibility-level economic screening

Central case without a capital grant; the 80% grant is shown only as an upside that is not currently available.

8.5. Sensitivity and interpretation

Without a capital grant, all four electrification scenarios have a slightly negative 12-year NPV under the central assumptions, from -EUR 0.10 million (S1) to -EUR 0.60 million (S4). Their simple paybacks of 9.2-10.9 years remain within the 12-year vehicle life, and the real internal rate of return of Scenario 2 is about 3.6%, below the 5% test rate. The Scenario 2 gap equals about EUR 0.22 million of capital support or about EUR 25,000/year of lower operating cost, which is about 2% of the current EUR 1.2 million service budget. An 80% vehicle grant would add about EUR 1.59 million to every NPV, but it is treated as an upside because the current Borzen allocation has been reached. A EUR 100,000/year upward error in municipal OPEX reduces the 12-year NPV by approximately EUR 0.89 million at a 5% real discount rate. The operating organisation therefore matters more than the grant gap or small differences in PV energy value.

Table 39. Key financial sensitivities

Variable	Central case	Sensitivity / consequence	Decision implication
Capital grant	None (central case)	80% grant would add about EUR 1.59m to every NPV; S2 breaks even with EUR 0.22m of support	Confirm the funding mix before contracting; keep the project application-ready
Municipal non-energy OPEX	EUR 0.850m/year	+EUR 0.100m/year reduces NPV by about EUR 0.89m	Prepare a bottom-up staffing and maintenance plan
PV vs grid energy spread	EUR 0.08/kWh	S2-S4 extra PV value is small relative to added CAPEX	Justify advanced charging through resilience or grid value, not solar arbitrage alone
Traction consumption	0.65 kWh/km	170.8-341.6 MWh/year input range	Require winter duty evidence and measure kWh/km after commissioning

8.6. Funding options and financing strategy

The central case assumes no capital grant because the Borzen allocation for M2/M3 vehicles has been reached [S6]. The gap to break-even is modest: Scenario 2 needs about EUR 0.22

million of capital support (about 11% of vehicle CAPEX or 8% of gross CAPEX), or about EUR 25,000/year of lower operating cost. Expressed against the all-grid operational reduction of about 217 tCO2e/year, the gap corresponds to roughly EUR 115 per tonne of CO2 avoided. The instruments below can close or exceed this gap; none is yet confirmed for Ptuj.

Table 40. Funding options for the municipal investment

Instrument	Status (checked 1 November 2026)	Possible use for Ptuj
Borzen call for zero-emission buses for municipalities (Climate Change Fund)	Up to 80% of eligible cost, max. EUR 600,000 per electric M2/M3 vehicle below 15 m; EUR 45 million call; M2/M3 allocation reached; investment by 15 November 2028 [S6]	Upside only: apply at once if funds are released or the call is topped up
Climate Change Fund programme 2025-2028	Government allocation plan of EUR 835 million, of which EUR 375 million for sustainable mobility including public transport and zero-emission vehicles, for the period to 2028 [S11]	Most likely source of a new grant; keep the project application-ready
EU cohesion policy 2021-2027: integrated territorial investments (CTN) for urban municipalities	About EUR 77 million mechanism, about EUR 70 million committed to 31 projects; third call (EUR 6.7 million) closed on 26 September 2026 [S12]	Charging, depot or digital components in a future call or the 2028-2034 programme
Social Climate Fund 2026-2032	Up to EUR 477.3 million for Slovenia (EU share EUR 358 million); plan submitted April 2026; transport measures focus on on-demand electric vans and mobility vouchers [S13]	Complementary services such as on-demand feeders, not the core fleet
Eko sklad loans	Public-sector loans for new electric vehicles; 2026 loan envelope for environmental investments raised from EUR 50 million to EUR 80 million [S14]	Finances the municipal share; improves cash flow, not NPV
Municipal budget and phased procurement	Current outsourced service about EUR 1.2 million/year; modelled Scenario 2 saving about EUR 0.30 million/year	Self-financing of the gap; phased start with the SUMP minimum of one zero-emission vehicle with charging by 2031

Recommended financing strategy: take the investment decision on the no-grant case; bring the project to application-ready level in Phase 1 (concept design, cost plan and entry in the municipal development programme) so that it can respond quickly to a new Climate Change Fund or cohesion-policy call; cover the municipal share from the budget and, if needed, an Eko sklad loan; and treat any grant as an upside that improves, but does not decide, the business case. If neither support nor the required operating savings can be secured, the municipality can start with a smaller first package in line with the SUMP target and expand in Phases 3 and 4.

9. Results

The results presented below summarise the technical and economic interpretation of the four electrification scenarios. The assessment is based on published routes and timetables, route lengths, available vehicle offers, the SONCE 8P municipal PV context and the currently identified charging locations. The results should be read as feasibility-level findings and not as final procurement specifications.

9.1. Scenario 1 results

Scenario 1 is the simplest electrification pathway: one main depot, one grid-connection focus and a clear operational base at CERO Gajke. With the 9 m reference midibus, however, it cannot cover full school-day duties on overnight charging alone and is feasible only with large-battery 9.5 m buses or midday returns to CERO.

The main weakness of Scenario 1 is its dependence on overnight/depot charging. If actual daily vehicle duties exceed the conservative planning range or if a vehicle returns with insufficient reserve, there is limited system flexibility. This scenario is therefore suitable as a minimum implementation case but should not be treated as the strongest long-term model.

Quantitatively, Scenario 1 has a modelled 177.6 kW peak, no same-hour solar contribution and EUR 2.743 million gross CAPEX. In the central no-grant case its 12-year NPV is approximately -EUR 0.096 million with a 9.2-year simple payback; an 80% vehicle grant would raise the NPV to +EUR 1.498 million.

9.2. Scenario 2 results

Scenario 2 is the most balanced scenario for Ptuj. By combining CERO Gajke as the main depot with the wastewater treatment plant as a secondary charging location, the municipality gains additional operational resilience without immediately moving into a highly complex smart-charging system. The wastewater treatment plant is particularly relevant because it can connect the transport system with the municipal energy system and the SONCE 8P logic.

This scenario reduces range risk, supports daytime top-up charging and creates a practical bridge between electric public transport and municipal PV production. It is therefore recommended as the preferred first full implementation scenario, subject to grid-capacity confirmation and legal/technical confirmation of PV electricity allocation.

The modelled peak falls to 88.8 kW, the lowest of all scenarios, and 72.1 MWh/year of residual same-hour PV supplies 29.2% of charging. Gross CAPEX is approximately EUR 2.893 million. In the central no-grant case the 12-year NPV is -EUR 0.222 million (simple payback 9.6 years, real IRR about 3.6%); about EUR 0.22 million of capital support would make it NPV-neutral, and an 80% grant would raise it to +EUR 1.372 million.

Why Scenario 2 rather than Scenario 1. Without a grant, Scenario 1 has the better 12-year NPV (-EUR 0.10 million against -EUR 0.22 million); the difference is essentially the EUR 0.15 million secondary charging function at the wastewater treatment plant. Scenario 1 is, however, calculated with the same 9 m midibus fleet, which cannot complete 200-250 km school-day duties on overnight charging alone. It would need 9.5 m large-battery buses, costing about EUR 1.5-2.1 million more for six vehicles and harder to manoeuvre on Lines 1 and 2, or midday returns to CERO that add deadhead kilometres and take buses out of service. The range limit of the reference bus is therefore the decisive argument for Scenario 2.

9.3. Scenario 3 results

Scenario 3 provides stronger PV integration by introducing planned opportunity charging and the active use of municipal PV surplus. Its value depends on whether the municipality can allocate PV electricity to electric bus charging in practice. From an energy perspective, this is attractive because daytime charging better matches solar production. From an operational perspective, it improves range security and may allow more flexible vehicle allocation.

The limitation is that Scenario 3 requires more detailed metering, energy management and possible additional charging infrastructure, especially if the main bus station becomes a charging point. It should therefore be treated as an optimisation option for Phase 3 (measured optimisation) rather than the first required step.

Scenario 3 raises residual same-hour PV use to 108.0 MWh/year, or 43.8%, at a modelled 135.5 kW peak. Gross CAPEX rises to approximately EUR 3.113 million and the central no-grant 12-year NPV falls to -EUR 0.455 million (simple payback 10.4 years).

9.4. Scenario 4 results

Scenario 4 offers the highest level of integration and long-term resilience. It combines CERO Gajke, the wastewater treatment plant and the main bus station with smart charging, and potentially later with battery storage. It maximises modelled PV use and operational flexibility but does not lower the modelled peak below Scenario 2 (151.2 kW against 88.8 kW); its smart-charging role is to keep each site within its connection limit.

However, Scenario 4 is also the most expensive and complex option. It requires strong institutional capacity, several grid connection assessments, smart-charging software, operational discipline and possibly battery storage. The scenario should therefore be maintained as a long-term development pathway, but not as the immediate baseline investment.

Scenario 4 reaches approximately 121.0 MWh/year of residual same-hour PV, or 49.1% of charging, but gross CAPEX increases to EUR 3.243 million. The central no-grant 12-year NPV is approximately -EUR 0.599 million (simple payback 10.9 years). Stationary storage is excluded from this base case.

Table 41. Best-performing scenario by result category

Result category	Best-performing scenario	Reason
Technical simplicity	Scenario 1	Single depot charging location and lowest infrastructure complexity
Operational robustness	Scenario 2 / Scenario 3	Secondary or opportunity charging reduces range and downtime risk
PV integration	Scenario 3 / Scenario 4	Better alignment between daytime solar production and charging demand
Investment proportionality	Scenario 2	Meaningful reliability improvement without excessive first-step complexity
Long-term strategic potential	Scenario 4	Integrated energy and mobility management across several sites
Recommended first full implementation	Scenario 2	Closes the midibus range gap at the lowest added cost; best balance of feasibility, risk and scalability

10. Discussion and interpretation of results

The assessment confirms that Ptuj is a technically suitable candidate for gradual electrification of urban public transport, but the project should be implemented as an integrated mobility-and-energy project rather than as a narrow vehicle procurement exercise. The main reason is that the municipality is simultaneously dealing with route optimisation, possible internalisation of operations, charging infrastructure, grid constraints and municipal PV production.

The annual distance estimate of approximately 345,000 vehicle-km shows that the future electricity demand of the bus fleet is material, but still manageable in relation to the scale of the municipal PV portfolio. Under the central consumption case, the bus system would require roughly 246 MWh/year including charging losses. Even under a conservative case, the demand would remain in the order of 340 MWh/year. This is well below the annual production scale of SONCE 8P, but annual comparison alone is not sufficient. Temporal matching, metering and allocation rules are decisive.

The choice of vehicle class is critical. A large 9.5 m bus provides comfort, capacity and battery reserve, but it may be unnecessarily expensive or less suitable for constrained parts of the network. A compact e-minibus is attractive for narrow streets and lower demand, but may not be sufficient for all school-related services. A midibus-dominant fleet, supported by at least one compact vehicle where geometry requires it, appears to be the most realistic direction at feasibility level.

The current outsourced model gives the municipality a predictable service arrangement but does not build municipal operational or energy-system capacity. A municipal electric-bus model could create stronger long-term control, better integration with municipal energy assets and potential cost stability. However, it also transfers operating responsibility and risk to the municipality or its public service company. This institutional question is therefore as important as the technical vehicle question.

Scenario 2 is interpreted as the most robust first full implementation step because it avoids both extremes: it is stronger than a single-depot model, but less complex than a multi-site smart-charging system. This creates a credible pathway: start with CERO Gajke and the wastewater treatment plant, then expand toward opportunity charging and smart PV-based management only after measured operating data is available.

11. Environmental and social impact

The transition from conventional bus operation to electric public transport would generate direct local environmental benefits for Ptuj. Battery-electric buses have no tailpipe emissions during operation, which means lower local emissions of nitrogen oxides and particulate matter in the urban environment. This is particularly relevant on routes passing through the historic centre, around schools, near the hospital and in areas with concentrated pedestrian activity.

Electric buses also reduce noise, especially during acceleration and low-speed operation. In a historic town such as Ptuj, this benefit is not only environmental but also urban-quality related, because reduced traffic noise improves the experience of residents, schoolchildren, visitors and users of public space.

The climate benefit depends on the electricity supply mix. If electric buses are charged only from the grid, greenhouse gas emissions are still reduced compared with diesel operation, but the full benefit is limited by the carbon intensity of grid electricity. If a meaningful share of charging demand is supplied or allocated from municipal PV production, the climate benefit increases substantially.

Table 42. Expected environmental and social effects

Impact area	Expected effect	Relevance for Ptuj
Local air quality	Elimination of tailpipe emissions from buses	Important near schools, hospital, bus stops and historic centre streets
Noise	Lower vehicle noise during urban operation	Important in narrow streets and residential/public areas
Climate impact	Lower operational CO2 emissions, strongest when PV-linked	Supports municipal and SUMP4Balkans decarbonisation objectives
Energy resilience	Potential use of municipal PV production for public transport	Connects SONCE 8P with mobility policy
Public acceptance	Visible modernisation of free public transport	Can strengthen use of public transport and public support for transition
Social accessibility	Continuation of free urban transport with cleaner vehicles	Supports residents without private transport and sustainable access to services

The main environmental risks are related to infrastructure implementation rather than bus operation. Chargers, grid connections and possible later storage systems must be placed in a way that avoids visual, spatial and operational conflicts. Any charging point at the main bus station must be coordinated with passenger safety, bus circulation, regional services and public-space quality.

Overall, the environmental and social assessment is positive. The strongest public value is achieved when electrification is combined with reliable service, good passenger information, continued free access and visible use of municipal renewable electricity.

11.1. Quantified operational emissions screening

For screening, the diesel reference assumes 30 litres/100 km over 345,000 vehicle-km/year and 2.68 kg CO2 per litre. The electric case uses the IJS 2024 Slovenian location-based greenhouse-gas factor of 0.244 kg CO2e/kWh [S9]. The comparison covers operational energy only; vehicle and battery manufacture, infrastructure construction, end-of-life and refrigerants are outside the boundary.

Table 43. Operational greenhouse-gas screening

Indicator	Reference result	Boundary
Diesel reference	103,500 litres/year; about 277.4 tCO2/year	30 l/100 km and 2.68 kg CO2/l; combustion only
Electric fleet - all grid	about 60.2 tCO2e/year	246.7 MWh x 0.244 kg CO2e/kWh
Operational reduction - all grid	about 217 tCO2e/year or 78%	Excludes manufacture and infrastructure
Operational reduction - S2 attribution	up to about 235 tCO2e/year	If residual same-hour PV is attributed as zero operational emissions

11.2. Service quality and social safeguards

The environmental case should not be separated from service quality. The transition should preserve the free-fare policy unless a separate policy decision is taken, maintain or improve published frequency, provide accessible low-floor vehicles and passenger information, and monitor missed trips, punctuality and complaints. A technically efficient system that reduces frequency or fails on winter duties would not achieve the intended public value.

12. Implementation roadmap

Table 44. Integrated implementation roadmap

Phase	Years	Core actions	Gate / deliverable
1 Evidence and concept design	2027	Duty blocks, deadhead, passenger counts, 15-minute PV and load data, DSO enquiries and surveys for CERO and WWTP, depot and WWTP layouts, staffing model, funding applications	Concept approval and funding decision by the end of 2027
2 Procurement and first implementation (Scenario 2)	2028-2029	Performance-based vehicle and charger tender, CERO depot and controlled charging, WWTP secondary charger if duties confirm it, acceptance tests, training and winter procedures	Contracts only after funding and connection conditions; operational readiness certificate
3 Measured optimisation	2029-2030 (first 12 months of operation)	Monitor SOC, kWh/km, uptime, PV residual and service reliability; tune WWTP charging; decide on the CERO PV plan	Decision on PV allocation, CERO PV and any Scenario 3 element
4 Advanced integration	2030-2031 (SUMP horizon)	Fleet and community energy management; bus-station charger and storage only with a proven case	SUMP 2031 evaluation and input to the next SUMP cycle

The four phases are aligned with the 2031 horizon of the local SUMP and use the same numbering as the site concept in Table 31 and the companion location assessment. The programme goes beyond the SUMP action-plan minimum of one zero-emission vehicle with charging infrastructure by 2031; if funding allows only a partial start, Phase 2 begins with that minimum on Line 1 and further vehicles follow in Phases 3 and 4.

12.1. Phase 1 - Evidence and concept design (2027)

Phase 1 should focus on decision preparation and technical verification. The municipality should confirm the exact operational objective: full municipal takeover, partial phased electrification, or continuation of the outsourced model with electric vehicle requirements. In parallel, it should obtain confirmed duty blocks, deadhead kilometres, parking/depot requirements and actual vehicle rotation data from the current operation.

- Confirm final fleet concept, including whether the full system requires six operational vehicles plus one reserve or a different duty-based structure.
- Request distribution-system-operator assessments for CERO Gajke, the wastewater treatment plant and, if relevant, the main bus station.
- Prepare a procurement-level comparison of compact e-minibus, midibus and larger low-floor bus options.
- Prepare the funding mix and application-ready documentation (Section 8.6) and check whether a new Borzen or Climate Change Fund allocation for M2/M3 buses opens.

12.2. Phase 2 - Procurement and first implementation (2028-2029)

Phase 2 should implement the first reliable electrification package. The preferred concept is Scenario 2: CERO Gajke as the main depot and charging base, supported by a secondary charging point at the wastewater treatment plant. This phase should prioritise reliability and avoid unnecessary technology complexity.

- Procure the first electric vehicles and depot charging infrastructure.

- Install and test secondary charging at the wastewater treatment plant if grid and spatial conditions are confirmed.
- Develop charging procedures, driver training, emergency procedures and maintenance arrangements.
- Start collecting operational data on energy consumption, range, passenger loading and charging performance.

12.3. Phase 3 - Measured optimisation (2029-2030)

Phase 3 should optimise PV integration. After the first operating data is available, the municipality should evaluate how much of the bus charging demand can realistically be supplied or allocated from municipal PV production and whether chargers can be included in the relevant energy-community or self-supply arrangement.

- Analyse monthly and hourly PV production and consumption at the relevant SONCE 8P locations.
- Confirm the legal and metering model for allocating municipal PV electricity to bus charging.
- Decide on the 250 kWp CERO PV plan on the basis of the site survey and measured depot load.
- Assess whether opportunity charging at the main bus station is technically justified.

12.4. Phase 4 - Advanced integration (2030-2031)

Phase 4 should be treated as the advanced integration phase. It may include smart charging, multi-site energy management, demand peak control and, if justified by measured data, battery storage. Storage should not be procured automatically. It should only be considered if PV curtailment, peak charges or operational constraints create a clear business case.

12.5. Risk Assessment and Mitigation

Table 45. Main risks and mitigation measures

Risk	Potential consequence	Mitigation
Insufficient bus range in winter	Missed services or need for emergency charging	Use conservative winter range specifications and secondary charging
Grid capacity limitations	Delayed implementation or higher connection costs	Early DSO assessment for all candidate charging sites
Overestimated PV availability for buses	Unrealistic economic or climate assumptions	Use measured hourly/monthly data and confirmed allocation rules
Procurement of unsuitable vehicle size	Manoeuvrability problems or insufficient capacity	Test vehicle geometry on Lines 1 and 2 and match vehicle class to duty
Underestimated municipal operating costs	False comparison with current outsourced model	Prepare full TCO including staff, maintenance, insurance, depot, software and reserve vehicle
No capital grant in the central case	Municipality carries the full investment; S2 NPV -EUR 0.22m	Decide on the no-grant case and pursue the funding mix in Section 8.6
Institutional capacity gap	Operational disruption after municipal takeover	Introduce phased implementation and clear responsibility within municipal public service company

The risk assessment supports a phased approach. Ptuj should not jump directly to the most complex smart-charging scenario. The recommended path is to secure a robust first electric operating model and then expand PV integration after technical, legal and operational conditions are confirmed.

Table 46. Risk register and decision gates

Risk	Rating	Consequence	Mitigation / decision gate
Insufficient capital support	High	Central no-grant case: S2 NPV -EUR 0.22m; a grant would add up to EUR 1.59m	Secure about EUR 0.22m of support or equivalent OPEX savings; do not contract before the funding mix is confirmed
Underestimated staffing / OPEX	High	Business case may reverse	Prepare a bottom-up organisation plan and independent cost review
Winter range or degradation	High	Missed service or spare-bus pressure	Duty-level guarantee, winter trial, minimum arrival SOC and WWTP recovery
Insufficient connection power	High	Delay and reinforcement cost	Early DSO studies, managed charging and staged connection
PV double counting	Medium-high	Overstated savings and climate claim	Use interval data and separate physical from settlement attribution
Unsuitable geometry or capacity	Medium-high	Service or safety failure	Route trial, swept-path study and passenger counts
Multi-vendor interoperability	Medium	Vehicle or charger downtime	Protocol, acceptance-test and support requirements in the tender
Bus-station spatial conflict	Medium	Unsafe or impractical charger	Keep the site optional pending circulation and ownership study

12.6. Minimum monitoring indicators

- Vehicle-km, deadhead-km, missed trips and late trips by line and vehicle.
- Traction kWh/km by month, route, temperature band and HVAC mode.
- Start and end state of charge, maximum depth of discharge and battery health.
- Charger availability, sessions, kWh, peak kW, failed sessions and recovery time.
- PV production, existing community load, residual export and bus charging in the same 15-minute intervals.
- Actual staffing, maintenance, insurance, grid, energy and depot cost against the feasibility model.

13. Conclusions and recommendations

The feasibility study confirms that the electrification of Ptuj urban public transport is technically feasible and strategically aligned with the objectives of SUMP4Balkans, the local SUMP framework and municipal renewable-energy development. The project is especially relevant because Ptuj already has a defined five-line urban bus network, an established free public transport model, identified candidate charging locations and a significant municipal PV programme through SONCE 8P.

The strongest immediate recommendation is not to pursue the most complex model first. The preferred first full implementation pathway is Scenario 2: electric buses with depot charging at CERO Gajke and secondary charging at the wastewater treatment plant. This scenario offers the best balance between operational reliability, investment proportionality and future PV integration potential. It is preferred to Scenario 1 because the daytime top-up at the wastewater treatment plant is what allows the 9 m reference midibus to complete full school-day duties.

Scenario 1 has the better no-grant NPV, but it can serve only as a minimum option: with the 9 m reference midibus, overnight charging at one base does not cover a full school-day duty, so it would need larger and much more expensive vehicles or midday depot returns. Scenario 3 is attractive as a Phase 3 optimisation because it can improve the use of municipal PV electricity and support daytime charging. Scenario 4 should remain the long-term integrated vision for Phase 4, up to the 2031 SUMP horizon, but only after measured data confirms that smart charging, multi-site control or battery storage are justified.

Before moving to procurement, the municipality should complete four technical checks: first, confirm duty blocks and actual daily vehicle rotations; second, obtain grid-capacity assessments for CERO Gajke, the wastewater treatment plant and the main bus station; third, prepare a full TCO model for the municipal operating option; and fourth, confirm the legal and metering conditions for allocating municipal PV electricity to bus charging.

Subject to these checks, the proposed project can become a strong demonstration of how a medium-sized historic Slovenian municipality can combine clean public transport, municipal renewable electricity and long-term energy-cost stability. The recommended implementation logic is gradual, technically conservative and scalable: start with reliable electric operation, then increase PV integration, and only afterwards move toward full smart charging and advanced energy management.

The quantified central case is therefore clear: approximately 246.7 MWh/year of charging energy, a preferred CERO plus wastewater-treatment-plant architecture, about 29.2% modelled same-hour PV contribution in Scenario 2 and, without a capital grant, a 12-year NPV of about -EUR 0.22 million with a 9.6-year simple payback. The project becomes NPV-neutral with about EUR 0.22 million of capital support or equivalent operating savings, and strongly positive if a new zero-emission bus grant becomes available. The recommendation is technically credible at feasibility level, but it becomes procurement-ready only after the six evidence gates of the pre-procurement checklist are closed.

14. Technical appendices

14.1. Calculation chain and assumption handover

Table 47. Main calculation chain

Step	Input	Calculation / output	Refinement in the design phase
Service volume	Published route lengths and departures	About 345,000 vehicle-km/year	Operator duty and AVL export including deadhead
Bus energy	0.45 / 0.65 / 0.90 kWh/km	170.8 / 246.7 / 341.6 MWh/year incl. losses	Measured winter and annual kWh/km
Community PV	1,549.27 MWh/year forecast	8,760-hour PVGIS shape normalised to forecast	Plant-level 15-minute production
Existing community load	1,686.99 MWh/year	Modelled public-building profile	35-consumer 15-minute imports
Incremental PV to buses	Positive PV after existing load	0-121 MWh/year across S1-S4	Interval settlement and physical meter data
Finance	CAPEX, OPEX and energy values; no grant in the central case	Payback, 12-year NPV and break-even support	Tender prices, organisation plan and confirmed funding

14.2. Pre-procurement decision checklist

Table 48. Evidence gates before investment approval

Gate	Evidence	Acceptance condition
Operations	Duties, deadhead, layovers, reserve and passenger demand	Fleet and charger count withstand winter and disruption cases
Vehicle	Route trials, capacity, charging curves and warranties	Selected class fits geometry and completes guaranteed duties
Grid and sites	DSO conditions, surveys, fire and access concept	Connection, layout, cost and schedule are acceptable
Energy	15-minute PV, community load, export and settlement rules	Renewable share is demonstrated without double counting
Finance and organisation	Staffing, maintenance, insurance, depot, tax and funding	Full TCO acceptable in the no-grant central case or with confirmed support
Procurement	Performance-based specifications and acceptance tests	Contract allocates battery, range, interoperability and support risks

14.3. Model and document handover

The companion workbook contains the assumptions, scenario comparison, 8,760-hour model, fleet data, site scores and source register. When new data is received, update the existing community-load profile first, then vehicle duties and consumption, then charger and grid CAPEX, and finally the staffing and operating model. Recalculate every scenario before changing the recommendation. The detailed designer should also receive current single-line diagrams, DSO correspondence, cadastral and utility surveys, fire and traffic constraints, inverter/export data and final vehicle charging curves.

15. References

Public sources were checked on 1 November 2026. Supplied project files are listed separately because they are not public web sources.

Table 49. Source register

ID	Source
S1	City Municipality of Ptuj, PV system completion update, 20 April 2026. https://www.ptuj.si/objava/1283519
S2	City Municipality of Ptuj, successful SONCE 8P application, 3 February 2025. https://www.ptuj.si/objava/1049498
S3	Arriva Slovenia, Ptuj urban bus timetables, September 2026 PDFs. https://arriva.si/avtobusni-prevozi/mestni-avtobusni-prevozi/mestni-avtobusni-prevozi-ptuj/vozni-redi-in-cenik-ptuj/
S4	European Commission Joint Research Centre, PVGIS 5.3 seriescalc API. https://re.jrc.ec.europa.eu/api/v5_3/seriescalc
S5	European Commission Joint Research Centre, PVGIS hourly-radiation documentation. https://joint-research-centre.ec.europa.eu/photovoltaic-geographical-information-system-pvgis/using-pvgis-5/pvgis-5-tools/hourly-radiation_en
S6	Borzen, subsidies for environmentally friendly buses (public call for municipalities), call and status page, checked 1 November 2026. https://borzen.si/sl-si/podpore-za-mobilnost/subvencije-za-okolju-prijaznejse-avtobuse
S7	Javne sluzbe Ptuj, CERO Gajke regional centre. https://www.js-ptuj.si/odpadki/koristne-informacije/regijski-center
S8	Komunalno podjetje Ptuj, wastewater-treatment-plant location and infrastructure information. https://www.komunala-ptuj.si/
S9	Jozef Stefan Institute, Centre for Energy Efficiency, Slovenian electricity greenhouse-gas factor for 2024. https://ceu.ijs.si/izpusti-co2-tgp-na-enoto-elektricne-energije/
S10	Supplied project documents: SONCE 8P investment programme, PV and meter/allocation workbooks, three electric-bus offers, Ptuj route material and the original feasibility-study draft.
S11	Government of Slovenia, Climate Change Fund allocation plan 2025-2028 (EUR 375 million for sustainable mobility), reported by Balkan Green Energy News, 3 October 2025, updated 2 June 2026. https://balkangreenenergynews.com/slovenia-allocates-eur-375-million-for-sustainable-mobility/
S12	Association of Urban Municipalities of Slovenia (ZMOS), third CTN call for sustainable mobility, 26 August 2026. https://zmos.si/objavljeno-je-3-povabilo-ctn-za-trajnostno-mobilnost/
S13	Government of Slovenia, Social Climate Fund and Social Climate Plan 2026-2032. https://www.gov.si/zbirke/projekti-in-programi/socialni-sklad-za-podnebje/
S14	Eko sklad, public-sector loans for new electric vehicles. https://www.ekosklad.si/javni-sektor/pridobite-spodbudo/seznam-spodbud/nakup-novih-elektrinih-vozil/nakup-novih-elektricnih-vozil-kredit-797; loan envelope raised to EUR 80 million, Portal24, 8 October 2026. https://portal24.si/eko-sklad-siri-kreditiranje-na-80-milijonov-evrov-prihaja-nov-poziv-za-elektricne-avtomobile/
S15	Javne službe Ptuj, call for expressions of interest for solar power plants on 19,622 m² at CERO Gajke, Dornavska cesta 26, reported by Ptujinfo, 10 January 2025. https://ptujinfo.com/novica/lokalno/cero-gajke-bo-dobil-novo-vlogo-javne-sluzbe-ptuj-iscejo-partnerje-za-soncne
S16	City Municipality of Ptuj, Ptuj city bus: five lines via the main bus station Ptuj AP, Osojnikova cesta. https://www.ptuj.si/post/334556