SUMP4Balkans

Supported by:
Federal Ministry for the Environment, Climate Action, Nature Conservation and Nuclear Safety
on the basis of a decision by the German Bundestag
European Climate Initiative EUKI

Assessment of the Optimal Location for the Photovoltaic Power Plant

Case Study of CETINJE

Feasibility-level assessment prepared within the SUMP4Balkans project as an annex to the study “Integration of PV Systems into Electric Public Transport – Case Study of Cetinje”.



Cetinje, 2026

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).

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1. EXECUTIVE SUMMARY

This annex provides a feasibility-level assessment of the optimal location for a photovoltaic (PV) installation intended to support the planned electric shuttle transport system in Cetinje. It consolidates the spatial, technical, energy and implementation considerations required to select the preferred location and define a phased development concept.

Two candidate locations are assessed: (i) the rooftop of the Municipality of Cetinje building and (ii) the planned photovoltaic installation at the former "Košuta" complex in the Industrial Zone of Cetinje. These locations were selected because they are the most mature publicly controlled opportunities identified during the feasibility-study process, they have identifiable installation surfaces and preliminary capacity estimates, and they can combine transport-related renewable electricity supply with on-site building consumption.

The Municipality Building can accommodate an estimated 54 kWp rooftop system with expected annual production of approximately 80,000 kWh. Its key advantage is the existing electric-vehicle charging station in the immediate vicinity, together with lower implementation complexity and strong demonstration visibility. The Košuta site has a planned installed capacity of approximately 62.6 kWp and expected annual production of around 81,520 kWh. It offers stronger potential for future expansion, energy management and integration of a battery energy storage system (BESS), while also supplying the planned innovation and business support centre.

FEASIBILITY RECOMMENDATION
The Municipality Building is recommended as the preferred location for the initial implementation phase because it offers the most direct operational link to the existing charging point, the lowest implementation complexity and a clear municipal demonstration function. The Košuta site is recommended as the preferred expansion and energy-storage location. The long-term optimum is therefore a phased two-site concept: Municipality Building first, followed by Košuta and, if justified by fleet expansion and load data, BESS integration.

The recommendation is made at feasibility level. Final investment approval remains subject to structural roof checks, detailed shading and layout analysis, confirmation of grid-connection conditions, verification of actual building electricity demand, fire-safety design, permitting and contractor quotations.

An indicative 25-year discounted cash-flow assessment also supports this prioritization. Under conservative base-case assumptions, the Municipality Building achieves an estimated NPV of approximately EUR 18,400 and an IRR of 9.1%, while Košuta achieves an estimated NPV of approximately EUR 11,600 and an IRR of 7.3%. Both results are positive at the assumed 5% real discount rate, but the Municipality Building provides the stronger initial investment case.

2. PURPOSE AND SCOPE

The purpose of this annex is to document the reasoning behind the selection of the PV location that will support the proposed electric public transport concept in Cetinje. The assessment focuses on the spatial, technical, energy and implementation-related aspects of PV siting and provides a transparent basis for selecting the preferred first-stage location.

The assessment considers why the Municipality Building and Košuta are the most relevant candidate sites at the present stage, how they compare in terms of installable capacity, annual production, connection to charging infrastructure, local electricity consumption and implementation readiness, which site should be treated as the optimal first-stage location, and how the second site should be integrated into a longer-term development pathway.

The assessment uses the project assumptions defined for the proposed electric shuttle and associated charging system. The proposed transport system consists initially of one 8+1 electric shuttle vehicle, with conservative annual electricity demand estimated at approximately 19.3 MWh/year. Charging is predominantly depot-based and takes place overnight. This creates a daily mismatch between daytime PV production and night-time vehicle charging, making grid interaction, daytime building demand and possible future battery storage relevant to site selection.

3. LOCAL CONTEXT AND SITE-SELECTION REQUIREMENTS

3.1 Cetinje context relevant to PV siting

Cetinje is located in a karst field at an average elevation of approximately 672 m and is surrounded by mountainous terrain. The city is positioned between the central region and the Adriatic coast and functions as an access point to Lovćen National Park, Njeguši, Rijeka Crnojevića and the upper station of the Kotor–Lovćen cable car. This spatial role supports a transport concept characterized by relatively short urban access movements combined with longer, topographically demanding tourist routes.

The local climate combines warm, comparatively dry summers with cool and wet winters. These conditions are important for the assessment: summer represents both the period of highest tourism-related shuttle demand and the period of highest PV generation, whereas winter brings lower solar production and potentially higher vehicle auxiliary loads. The seasonal alignment strengthens the case for solar-supported mobility, while the winter mismatch confirms the need to maintain a grid-connected system and to avoid sizing the project solely on peak summer production.

Annual global horizontal irradiation in the wider Montenegro context is estimated at approximately 1,400–1,600 kWh/m², while a feasibility-level specific PV yield of approximately 1,300–1,500 kWh/kWp/year is applied for Cetinje. The European Commission's PVGIS platform is an appropriate tool for the detailed design stage because it provides location-specific monthly and annual PV output estimates while considering solar radiation, temperature, wind and mounting configuration.

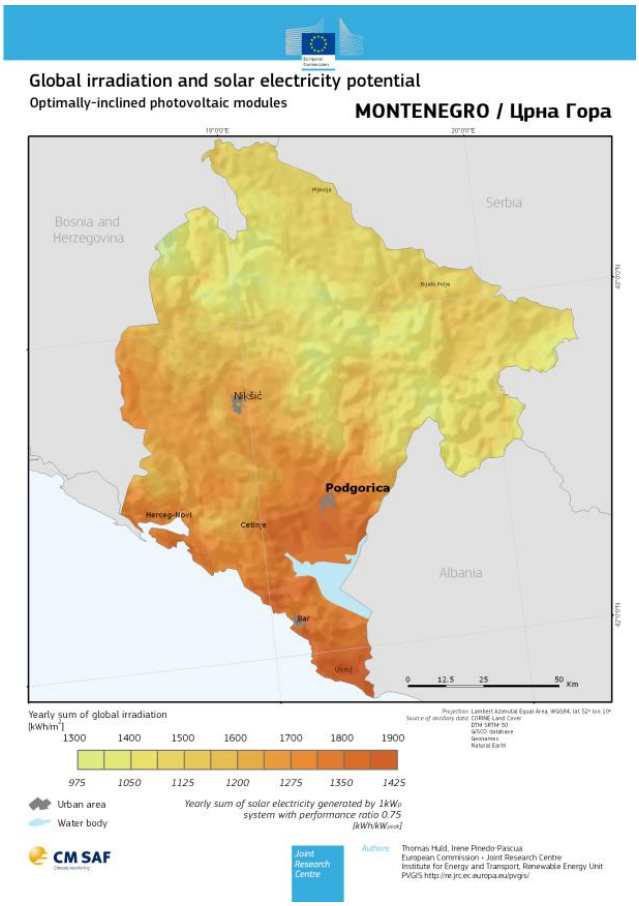


Figure 3.1. Solar irradiation and photovoltaic electricity potential in Montenegro.

3.2 Site-selection criteria

At feasibility level, an optimal PV location is not necessarily the site with the largest nominal capacity. It is the site that provides the best overall balance between technical suitability, transport-system integration, implementation readiness, local use of generated electricity and long-term scalability. The following criteria were therefore applied:

Criterion	Feasibility-level interpretation
Solar and spatial suitability	Available roof or installation area; reasonable orientation; limited shading; ability to accommodate the estimated PV capacity.
Electricity infrastructure	Access to a suitable low-voltage or medium-voltage connection; manageable cable routes; potential need for reinforcement.

Transport integration	Proximity and operational relationship to the shuttle terminal, depot or existing charging point.
Local self-consumption	Presence of daytime electricity demand in the associated building or complex, reducing reliance on export settlement.
Implementation readiness	Public control, maturity of planning information, ease of permitting, construction access and expected time to implementation.
Expansion and flexibility	Potential for additional PV, smart energy management, BESS and future electric-vehicle fleet growth.
Visibility and replicability	Demonstration value for citizens, visitors and other municipalities.

4. IDENTIFICATION OF CANDIDATE LOCATIONS

The assessment does not claim that every rooftop or parcel in Cetinje was subjected to a complete cadastral and engineering screening. The two selected sites are the most concrete, publicly controlled and technically defined opportunities identified through project preparation and stakeholder inputs. The comparison therefore focuses on realistic project candidates for which ownership, preliminary capacity, electricity infrastructure and implementation responsibility can be reasonably established.

The Municipality Building was selected because it is a municipal public building with an identifiable rooftop area, an estimated PV capacity, central visibility and an existing electric-vehicle charging point in the immediate vicinity. The Košuta site was selected because a PV project has already been envisaged within the redevelopment of the former industrial complex, technical capacity and production figures are available, and the future business complex creates a substantial potential daytime load and a suitable platform for energy management and future BESS integration.

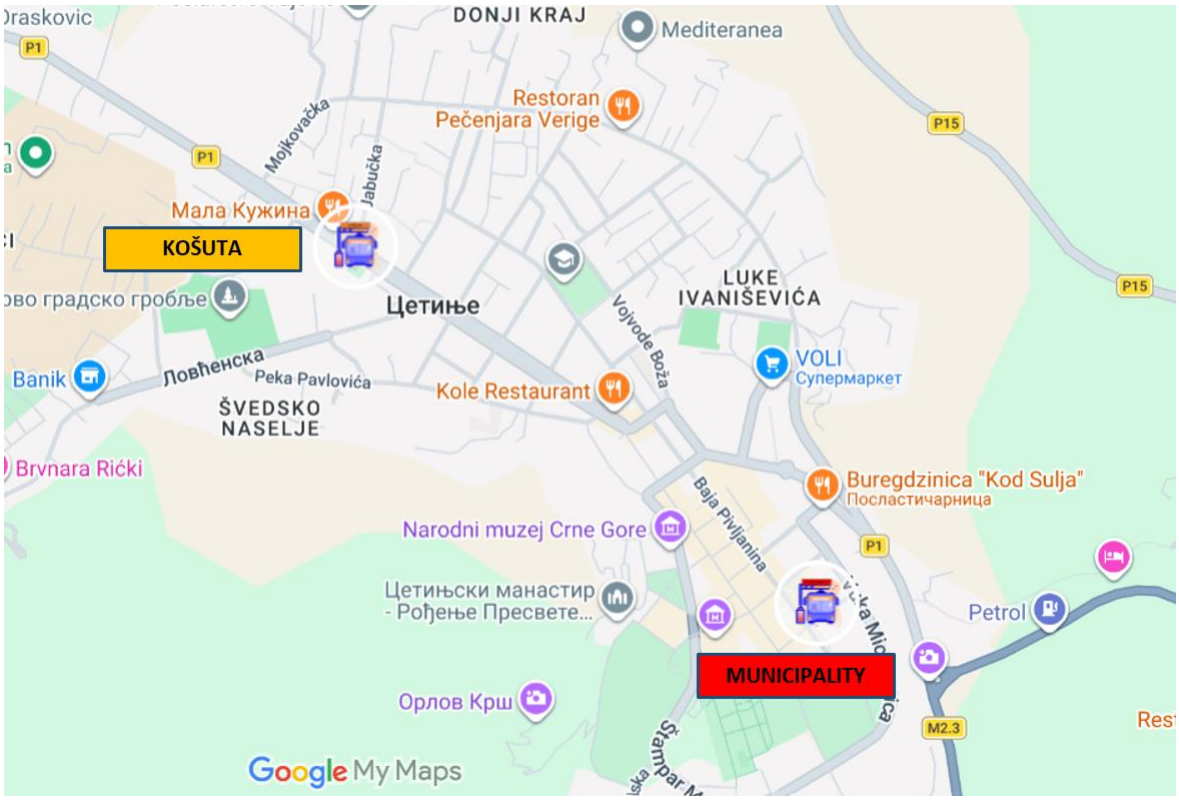


Figure 4.1. Location of the Municipality Building and the Košuta complex in the urban area of Cetinje.

Together, the two locations represent complementary rather than mutually exclusive functions. The Municipality Building is closely associated with the first transport pilot and public demonstration, while Košuta provides the more flexible basis for medium- and long-term energy-system development.

5. ASSESSMENT OF THE MUNICIPALITY BUILDING

5.1 Technical and spatial characteristics

The available rooftop area of the Municipality of Cetinje building is assessed as suitable for an installed PV capacity of approximately 54 kWp. Expected annual generation is approximately 80,000 kWh/year. This output is more than four times the conservative annual electricity demand of the initial electric shuttle vehicle, although only part of the PV generation would coincide directly with vehicle charging because charging is expected primarily at night.

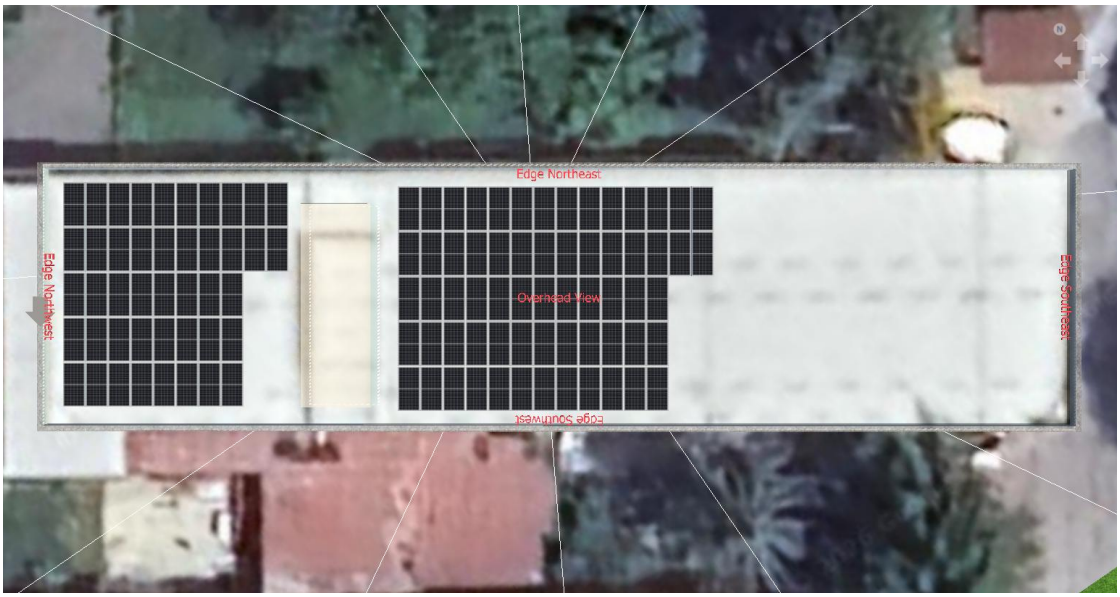


Figure 5.1. Preliminary rooftop PV layout considered for the Municipality Building.

5.2 Main advantages

The Municipality Building offers the strongest direct link between PV deployment and the initial electric-mobility pilot because an existing electric-vehicle charging station is located in its immediate vicinity. The site is under clear municipal control and has high institutional visibility, supporting a relatively straightforward governance structure and strong demonstration value in the central urban area. The estimated annual PV production is substantially higher than the electricity demand of the initial shuttle, leaving energy available for daytime consumption in the Municipality Building or export to the distribution grid. The installation can be implemented as a conventional grid-connected rooftop PV system without requiring battery storage in the initial phase.

5.3 Constraints and uncertainties

The principal limitation of the Municipality Building is the finite rooftop area, which restricts future expansion beyond the estimated 54 kWp. Final technical suitability remains subject to structural verification, assessment of the roof condition and waterproofing requirements, confirmation of fire-access provisions and a detailed shading analysis. Since the shuttle is expected to be charged mainly overnight, physical proximity to the charger does not by itself provide direct real-time use of solar electricity; the energy relationship is primarily achieved through the grid-connected balance unless charging schedules are shifted or storage is added. The actual daytime electricity demand of the building also requires confirmation in order to estimate the achievable self-consumption share with greater precision.



Figure 5.2. Existing electric-vehicle charging station in the vicinity of the Municipality Building.

SITE ROLE
Best suited for rapid first-stage implementation, municipal demonstration and direct association with the initial electric shuttle service.

6. ASSESSMENT OF THE KOŠUTA SITE

6.1 Technical and development characteristics

The Košuta photovoltaic power plant is envisaged at the former “Košuta” facility in the Industrial Zone of Cetinje, which is planned for redevelopment as an innovation and business support centre. Available project information used in the feasibility assessment indicates an installed capacity of approximately 62.6 kWp and expected annual electricity generation of around 81,520 kWh/year.

The system is intended to be connected to the distribution network and supported by an energy management system. The associated future business complex is expected to have daytime electricity consumption, which can improve local self-consumption and reduce the share of PV output exported to the grid. The site is also the location considered in the main study for a future BESS of approximately 60 kWh, broadly corresponding to the estimated daily energy requirement of the shuttle.

6.2 Main advantages

The Košuta PV project is incorporated into a defined redevelopment concept, with preliminary capacity and production estimates available. The future innovation and business centre can provide a meaningful daytime electricity load, thereby improving the local utilization and economic value of solar generation. Compared with the Municipality Building, the site offers greater functional flexibility for energy management, battery storage and future transport-fleet expansion. Its industrial and business setting is also more suitable for equipment enclosures, BESS safety separation, maintenance access and later technical modifications. These characteristics allow Košuta to develop into a broader local energy hub rather than functioning only as a transport-linked PV installation.

6.3 Constraints and uncertainties

The immediate physical relationship between Košuta and the existing charging station is weaker than at the Municipality Building. The PV implementation schedule may also depend on the progress of the wider redevelopment project, future occupancy and overall investment sequencing. Distribution-network connection capacity, protection settings and the final internal electrical architecture must be confirmed during detailed design. The economic benefit will partly depend on the actual daytime electricity demand of the future business complex, which is not yet known in sufficient detail. Integration of a BESS would additionally increase investment cost, technical complexity, safety requirements and future replacement obligations.

SITE ROLE
Best suited for second-stage expansion, higher local self-consumption, advanced energy management and potential BESS integration.

7. COMPARATIVE MULTI-CRITERIA ASSESSMENT

A qualitative weighted assessment was prepared to make the recommendation transparent. Scores range from 1 (least favourable) to 5 (most favourable). The scores represent feasibility-level professional judgement based on the information available in the main study; they are not a substitute for measured structural, electrical or cadastral due diligence.

Criterion	**Weight**	**Municipality**	**Košuta**	**Weighted result**	**Rationale**
Solar/spatial suitability	15%	4	4	12.0 / 12.0	Both sites have defined preliminary capacity; detailed shading and structural checks remain outstanding.
Grid and electrical integration	15%	4	4	12.0 / 12.0	Both are grid-connected concepts; final connection studies are required.

Direct transport/charging integration	20%	5	3	20.0 / 12.0	Existing charger gives the Municipality Building a clear first-stage advantage.
Local daytime self-consumption	15%	4	5	12.0 / 15.0	Košuta's future business centre is expected to provide a stronger daytime load.
Implementation readiness	15%	5	3	15.0 / 9.0	Municipality rooftop concept is simpler; Košuta depends on wider redevelopment sequencing.
Expansion and BESS potential	10%	3	5	6.0 / 10.0	Košuta provides a stronger long-term platform for storage and system growth.
Visibility and demonstration value	10%	5	4	10.0 / 8.0	Municipality Building offers the strongest public-facing demonstration.
TOTAL	**100 %**	**87.0/100**	**78.0/100**	**Initial-phase ranking**	**The ranking changes when long-term expansion is given greater priority.**

Under the criteria and weights used for the initial project phase, the Municipality Building achieves a weighted score of 87.0/100, compared with 78.0/100 for Košuta. The difference is driven mainly by the existing charging point, implementation readiness and public demonstration value. Košuta scores better for self-consumption, expansion and battery integration.

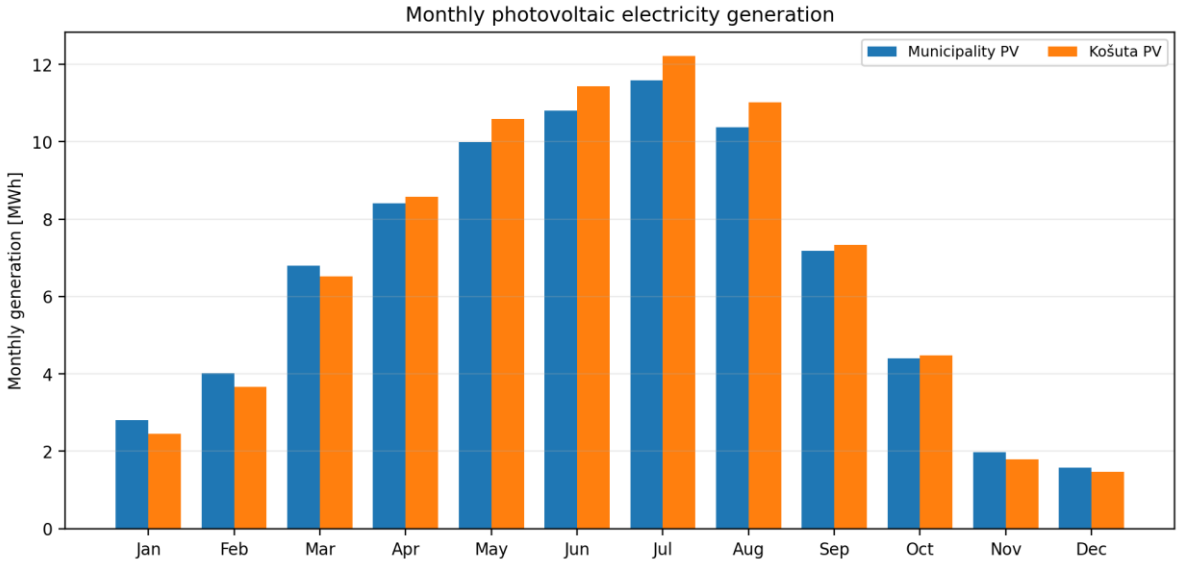


Figure 7.1. Monthly photovoltaic electricity generation profiles used for the Municipality and Košuta sites.

8. OPTIMAL LOCATION AND DEVELOPMENT CONCEPT

8.1 Preferred initial location

The Municipality Building is identified as the optimal location for the initial PV implementation associated with the electric shuttle pilot. The recommendation is not based solely on nominal energy production, which is similar at both candidate sites. It is based on project readiness and functional integration: the Municipality Building combines a sufficient PV capacity, existing charging infrastructure, clear municipal ownership/control, central visibility and lower implementation complexity.

A 54 kWp system generating approximately 80 MWh/year would be substantially larger than the annual electricity demand of the initial shuttle. Consequently, the system should be operated as a grid-connected municipal PV installation in which the shuttle receives priority in the project's energy accounting, while the building uses available daytime production and remaining surplus is exported under the applicable settlement arrangement.

8.2 Preferred expansion location

Košuta is identified as the optimal development location for the second phase. Once the innovation/business complex is operational and its electricity demand is measured, the 62.6 kWp installation can increase the total project capacity to approximately 116 kWp. Košuta should also be the preferred location for any future BESS because it provides greater technical flexibility and can combine transport charging, building demand and energy-management functions.

8.3 Recommended phased configuration

Phase	Main asset	Purpose	Decision trigger
Phase 1	54 kWp Municipality rooftop PV	Rapid demonstration; support initial shuttle; municipal self-consumption and grid export	Structural and grid approval; verified investment cost
Phase 2	62.6 kWp Košuta PV	Increase renewable generation and local daytime self-consumption	Completion/occupancy of business complex; confirmed connection conditions
Phase 3	Approx. 60 kWh BESS at Košuta	Shift daytime surplus toward night charging; reduce grid dependency	Measured hourly load/export data and positive updated economic case

For the project as a whole, the optimal solution is a phased two-site portfolio rather than the exclusion of one candidate. The Municipality Building is the priority implementation site; Košuta is the priority expansion and flexibility site.

9. INDICATIVE TECHNO-ECONOMIC ASSESSMENT

9.1 Assessment approach

A simplified unlevered, pre-tax discounted cash-flow assessment was prepared to test whether the two candidate PV investments are economically reasonable at planning stage. The assessment covers a 25-year operating period and treats the value of generated electricity as a combination of avoided electricity purchases and/or settlement of surplus electricity through the distribution network. Because verified hourly building-load profiles and final electricity settlement conditions are not yet available, a single conservative electricity value of EUR 0.065/kWh is applied to all PV generation in the base case. This avoids overstating the benefits of daytime self-consumption and allows the two locations to be compared on a consistent basis.

The assessment includes initial PV investment, annual fixed operation and maintenance expenditure, annual module degradation and a one-off inverter replacement allowance. The results are indicative screening values rather than a bankable investment appraisal. They exclude VAT, financing structure, taxes, grants, major roof reconstruction, transformer replacement, extensive grid reinforcement and costs that can only be established after structural and connection studies.

9.2 Base-case assumptions

Parameter	Municipality Building	Košuta
Installed PV capacity	54 kWp	62.6 kWp
Year-1 PV generation	80,000 kWh	81,520 kWh
Turnkey PV CAPEX	EUR 43,200	EUR 50,080
CAPEX basis	EUR 800/kWp	EUR 800/kWp
Electricity value	EUR 0.065/kWh	EUR 0.065/kWh
Fixed annual O&M	1.0% of initial CAPEX	1.0% of initial CAPEX
Annual PV degradation	0.5%	0.5%
Inverter replacement	10% of initial CAPEX in year 14	10% of initial CAPEX in year 14
Real discount rate	5.0%	5.0%
Assessment period	25 years	25 years

The assumed CAPEX values correspond to the base feasibility estimate of EUR 800/kWp. The generation values are the location-specific annual outputs used in the project assessment. No additional economic value has been assigned to improved resilience, reduced exposure to future electricity-price volatility, public demonstration benefits or greenhouse-gas reductions.

9.3 Indicative financial results

Metric	Municipality Building	Košuta	Combined portfolio
Initial CAPEX	EUR 43,200	EUR 50,080	EUR 93,280
Year-1 generation	80.0 MWh	81.5 MWh	161.5 MWh
Year-1 gross electricity value	EUR 5,200	EUR 5,299	EUR 10,499
Year-1 net benefit after O&M	EUR 4,768	EUR 4,798	EUR 9,566
NPV at 5%	EUR 18,444	EUR 11,575	EUR 30,019
IRR	9.1%	7.3%	8.2%
Simple payback	9.1 years	10.4 years	9.8 years

Under the base-case assumptions, both candidate investments produce a positive NPV and an IRR above the assumed 5% real discount rate. The Municipality Building produces the stronger relative financial result, with an indicative IRR of approximately 9.1%, an NPV of approximately EUR 18,400 and a simple payback period of approximately 9.1 years. Košuta remains economically positive, with an indicative IRR of approximately 7.3%, an NPV of approximately EUR 11,600 and a simple payback period of approximately 10.4 years.

The difference is primarily explained by the relationship between estimated investment cost and annual generation. Although Košuta has slightly higher annual output, its generation advantage is relatively small compared with its additional installed capacity and investment. This does not weaken its strategic role as an expansion site. Once the future business complex is occupied, a greater proportion of PV electricity may be consumed directly during daytime and valued at the full avoided retail electricity cost, which could materially improve the Košuta result.

9.4 Sensitivity and interpretation

Sensitivity case	Municipality: IRR / NPV	Košuta: IRR / NPV
Electricity value -10%	7.6% / EUR 11,452	5.9% / EUR 4,451
Base case	9.1% / EUR 18,444	7.3% / EUR 11,575
Electricity value +10%	10.6% / EUR 25,435	8.6% / EUR 18,699
CAPEX -10%	10.7% / EUR 23,591	8.8% / EUR 17,542
CAPEX +10%	7.8% / EUR 13,297	6.0% / EUR 5,608

The sensitivity results indicate that both projects are most exposed to the realized economic value of PV electricity and to final installed cost. The Municipality Building remains above the 5% investment threshold in all cases shown. Košuta remains positive in NPV terms in the tested cases, but its return approaches the

discount rate when electricity value is lower or CAPEX is higher. This reinforces the need to confirm the future building load, connection conditions and contractor pricing before final investment approval.

FINANCIAL INTERPRETATION
The indicative financial assessment supports the location recommendation: the Municipality Building is the preferred first-stage investment because it combines stronger financial performance with the existing charging link and lower implementation complexity. Košuta remains the preferred expansion site, particularly once measurable daytime demand at the future business complex can increase the value of local PV self-consumption.

10. IMPLEMENTATION REQUIREMENTS AND NEXT STEPS

Before procurement or construction, the following due-diligence activities should be completed for the selected first-stage site and, subsequently, for Košuta:

Required action	Purpose
Structural and roof-condition survey	Confirm reserve load-bearing capacity, roof waterproofing, wind and snow loading, anchoring method and remaining roof life.
Detailed solar and shading assessment	Prepare a georeferenced layout; verify orientation, tilt, row spacing, shading from roof elements and realistic system losses using PVGIS or equivalent software.
Electrical connection study	Confirm connection point, available capacity, protection requirements, metering, export limits, cable routes and any transformer or switchboard reinforcement.
Hourly load verification	Obtain at least 12 months of interval electricity data for the Municipality Building and, once available, Košuta; compare with shuttle charging profile.
Charging and energy-management concept	Define whether the shuttle remains on overnight charging, whether limited daytime charging is operationally possible, and how PV priority is recorded and controlled.
Permitting and heritage/urban requirements	Confirm planning, building, fire-safety and any heritage-related requirements applicable to the central municipal building.
Updated financial assessment	Replace feasibility assumptions with contractor quotations, applicable electricity tariffs, export compensation and confirmed financing conditions.
BESS decision gate	Do not procure storage solely to maximize renewable share; base the decision on measured surplus, night charging demand, tariff spread, backup value, safety and lifecycle cost.

10.1 Key implementation risks

Key implementation risks include roof or electrical reinforcement costs that are not included in preliminary PV estimates, lower-than-expected building self-consumption resulting in higher grid export and lower economic value, and delays in the Košuta redevelopment or uncertainty regarding its future occupancy and

electricity demand. Changes in exported-energy settlement, electricity tariffs or permitting requirements could affect financial performance. Battery investment should therefore not precede the availability of measured hourly load and export data. Changes to shuttle routes, annual mileage or the charging schedule could also alter the energy balance and should be reflected in the final design.

11. CONCLUSIONS

The location assessment confirms that the two candidate sites identified for the project are justified by their public character, available preliminary technical information, connection to municipal development priorities and ability to combine PV generation with building and transport electricity demand.

The Municipality Building is the optimal first-stage location. It offers the clearest and quickest link to the planned electric shuttle through the existing nearby charging station, while its estimated 54 kWp capacity is sufficient to generate substantially more electricity annually than the initial shuttle requires. Its key limitations are restricted expansion space and the need to verify structural and self-consumption conditions.

Košuta is the optimal second-stage and long-term flexibility location. Its planned 62.6 kWp PV system, future daytime business load, energy-management concept and greater suitability for BESS make it the stronger platform for system expansion. Its implementation should be coordinated with the wider redevelopment project and supported by measured demand data.

The indicative economic assessment is consistent with the technical and implementation findings. Both locations show positive investment performance, while the Municipality Building provides the higher IRR, higher NPV relative to investment and shorter simple payback. Košuta should be reassessed when actual business-complex demand and final connection costs are available, since higher direct self-consumption could improve its financial performance.

Accordingly, the recommended project pathway is: (1) implement the Municipality Building PV system as the visible and operationally linked pilot; (2) implement the Košuta PV system as the expansion asset; and (3) evaluate BESS only after actual PV production, building load, export and shuttle charging data are available. This pathway provides the best balance between readiness, technical feasibility, renewable-energy utilization and future scalability.

12. LIMITATIONS OF THE ASSESSMENT

This annex is a feasibility-level location assessment based on the available project information and contextual data. It does not constitute a final structural design, grid-connection approval, cadastral verification, detailed environmental assessment, heritage consent, fire-safety design or construction permit. No additional on-site measurements were performed specifically for this separate deliverable.