SUMP4Balkans

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Feasibility Study: Integration of PV Systems into Electric Public Transport – Case Study of CETINJE



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1. EXECUTIVE SUMMARY

This feasibility study examines the technical, economic and environmental potential of integrating photovoltaic (PV) systems into the electric public transport network of Cetinje. The analysis is conducted within the framework of the SUMP4Balkans EUKI project, which supports the transition toward sustainable urban mobility in the Western Balkans through the deployment of renewable energy solutions and low-carbon transport systems.

As the historical capital of Montenegro, Cetinje faces specific mobility and environmental challenges associated with its urban structure, surrounding mountainous terrain and the need to preserve cultural and environmental values. The introduction of electric buses represents an important step toward decarbonizing the local transport sector and improving the quality of life for residents and visitors. Coupling transport electrification with locally generated renewable electricity offers an opportunity to further reduce the environmental footprint of urban mobility while strengthening local energy resilience. Although Cetinje is characterized by a more complex topography than many lowland cities, it benefits from favorable solar resources that can support significant electricity generation from photovoltaic systems. The availability of municipal buildings, public facilities and suitable land areas creates opportunities for the deployment of distributed and centralized PV installations capable of supplying a substantial share of the electricity required for electric bus operations.

The integration of PV systems into the city's electric public transport network can contribute to reducing greenhouse gas emissions, decreasing dependence on externally supplied electricity and improving the long-term financial sustainability of public transport services. Furthermore, the use of locally generated renewable energy aligns with both national energy transition objectives and broader European climate policy goals. The objective of this study is to evaluate alternative approaches for integrating solar energy into the electric bus system in Cetinje through the development of four scenarios adapted to local spatial and energy conditions:

(i.) **Low PV integration** – Electric buses are supplied using surplus daytime electricity generated by photovoltaic systems installed on municipal buildings, educational facilities and other publicly owned rooftops.

(ii.) **Partial PV integration** – A larger share of the fleet's electricity demand is covered through a combination of PV installations on public buildings and suitable commercial or institutional rooftops within the urban area.

(iii.) **PV and BESS integration** – The entire electricity demand of the public transport fleet is supplied through a combination of rooftop and centralized PV generation, complemented by a battery energy storage system (BESS) located at the bus depot, enabling renewable-energy-based charging during both daytime and overnight periods.

These scenarios provide a basis for assessing the extent to which renewable energy can support the operation of electric public transport in Cetinje and identifying the most suitable pathway toward a fully sustainable and low-carbon urban mobility system.

2. INTRODUCTION

2.1. Project background

The transition towards climate-neutral and energy-efficient urban development has become a strategic priority for cities across Europe. Urban transport systems continue to contribute significantly to greenhouse gas (GHG) emissions, local air pollution and overall energy consumption. To address these challenges, the European Union has promoted policies and initiatives aimed at accelerating transport decarbonisation while increasing the utilization of renewable energy sources (RES). In addition, the Sustainable Urban Mobility Plan for the Balkans (SUMP4Balkans) project was established to support cities in Southeast Europe in developing sustainable, integrated and resilient urban mobility systems. A central objective of the project is to foster synergies between transport electrification and renewable energy deployment, thereby contributing simultaneously to climate mitigation, energy security and sustainable urban development goals.

The SUMP4Balkans project is implemented within the framework of the EUKI (European Climate Initiative) programme and involves four pilot cities: Strumica, Ptuj, Cetinje and Umag. Despite their different geographical, demographic and economic characteristics, these cities share common ambitions to modernize urban mobility and reduce their environmental impacts through innovative and sustainable solutions. One of the key activities of the project is the preparation of technical and economic feasibility studies assessing the integration of photovoltaic (PV) systems into electric public transport systems. These studies provide a scientific and analytical basis for local decision-making, support investment planning and facilitate the transfer of knowledge and best practices among participating municipalities. Following that, the present study focuses on Cetinje, the historical and cultural capital of Montenegro. The study contributes to the broader project objective of demonstrating how renewable energy can effectively support the operation of electric public transport systems and accelerate the transition toward low-carbon urban mobility in the Balkan region.

2.2. Objectives

The main objective of this feasibility study is to evaluate the potential for integrating solar photovoltaic systems into the electric public transport infrastructure of Cetinje. The study seeks to assess the technical feasibility, economic viability and environmental benefits of combining renewable energy generation with electric mobility solutions, thereby supporting future planning and investment decisions at the local level. More specifically, the study pursues the following objectives:

Assessment of public transport electrification requirements: To evaluate the electricity demand associated with the planned or operational electric bus fleet, taking into account local route characteristics, service schedules, topographical conditions and seasonal variations in energy consumption.

Evaluation of solar energy potential: To analyze solar resource availability within the territory of Cetinje and identify suitable locations for photovoltaic installations, including municipal

buildings, public facilities, transport-related infrastructure and potential ground-mounted PV sites.

Development of renewable energy integration scenarios: To design and compare alternative scenarios for integrating PV generation into the electric public transport system, considering different levels of renewable energy penetration and energy storage options.

Technical feasibility assessment: To evaluate the compatibility of PV systems with electric vehicle charging infrastructure, including charging strategies, grid interaction requirements and opportunities for intelligent energy management.

Economic and financial analysis: To estimate investment costs, operating and maintenance costs, potential electricity cost savings and overall financial performance under different development scenarios.

Environmental impact assessment: To quantify potential reductions in greenhouse gas emissions and assess the contribution of renewable-energy-powered public transport to improving environmental sustainability and urban quality of life.

Through these objectives, the study aims to provide a comprehensive evidence base for the implementation of renewable energy-powered public transport solutions in Cetinje and to support the city's long-term sustainability and climate goals.

2.2.1. Scope of the study

This feasibility study examines the integration of photovoltaic energy systems into the electric public transport network of Cetinje from technical, economic and environmental perspectives. The analysis covers the assessment of electricity demand associated with electric bus operations, the evaluation of local solar energy resources, and the identification of suitable locations for PV deployment. The study includes the development and comparison of multiple renewable energy integration scenarios, ranging from limited rooftop installations to more advanced configurations involving centralized PV generation and battery energy storage systems. Particular attention is given to the interaction between renewable electricity production and vehicle charging requirements, as well as the implications for grid utilization and operational planning.

Furthermore, the study evaluates investment and operational costs, estimates potential economic benefits and quantifies environmental impacts in terms of greenhouse gas emission reductions. The findings are intended to support municipal authorities and other stakeholders in identifying the most suitable pathway for integrating renewable energy into Cetinje’s public transport system and advancing the city's transition toward sustainable urban mobility.

2.3. Methodology

The methodological approach applied in this study is based on an integrated techno-economic assessment framework that combines transport demand analysis, renewable energy potential assessment, and scenario-based evaluation. The objective is to examine the feasibility of coupling electric public transport with photovoltaic (PV) energy generation under the specific conditions of Cetinje.

The analysis is conducted through several sequential steps:

1) Data collection and review

Relevant data are collected and systematically reviewed. This includes municipal planning documents, transport and mobility studies, available energy statistics and technical inputs obtained from local stakeholders and city authorities. The dataset is further complemented by a review of relevant scientific literature, policy frameworks and standard engineering assumptions used in comparable studies.

2) Baseline assessment of the transport system

A baseline analysis of the existing and planned public transport system is performed. Particular emphasis is placed on estimating the electricity demand associated with electric bus operations, taking into account route structure, service frequency, operational schedules, local topographical conditions and seasonal variability in energy consumption.

3) Solar resource assessment and PV potential estimation

A detailed assessment of solar irradiation potential is conducted in order to estimate photovoltaic energy generation at selected locations within the municipality. Potential sites include municipal and public buildings, transport infrastructure and other structurally suitable areas identified through preliminary spatial screening.

4) Scenario development for system integration

Based on the collected data and assessed potentials, multiple development scenarios are defined. These scenarios represent different levels of PV penetration and battery energy storage system integration, varying in installed capacity, system configuration and the balance between distributed and centralized renewable energy generation.

5) Techno-economic evaluation

A comprehensive techno-economic analysis is carried out, including estimation of capital expenditures, operational and maintenance costs, expected annual energy production and potential economic benefits such as reduced electricity procurement costs and long-term financial savings.

6) Environmental impact assessment

An environmental evaluation is conducted to quantify greenhouse gas emission reductions and to assess broader sustainability impacts associated with the transition to renewable-energy-powered public transport systems.

7) Consistency with integrated modelling frameworks

The methodological framework follows established approaches in integrated energy and transport system analysis and is compatible with modelling tools such as EnergyPLAN, ensuring coherence with broader energy transition and decarbonisation studies.

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 establishes binding targets, including a reduction of net greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels. In the transport sector, these objectives translate into stricter vehicle emission standards, accelerated deployment of alternative fuels infrastructure and increased utilization of renewable energy sources.

The Renewable Energy Directive (RED II and RED III) further supports these goals by promoting renewable electricity use across all sectors, including transport. At the same time, the Sustainable and Smart Mobility Strategy provides a roadmap for developing a modern transport system based on zero-emission vehicles, intelligent charging infrastructure and greater integration between mobility and energy systems.

Urban mobility is addressed through the promotion of *Sustainable Urban Mobility Plans (SUMPs),* which encourage cities to develop integrated and environmentally sustainable transport solutions. The integration of electric mobility with renewable energy sources, particularly photovoltaic systems, represents one of the key measures promoted under these frameworks.

Overall, European climate, energy and transport policies strongly support the type of integrated solution analysed in this study, namely the use of photovoltaic energy to support the operation of electric public transport systems.

3.2. National policy context – Montenegro

Montenegro's energy and climate policy framework is increasingly aligned with European Union objectives, Energy Community obligations and the Green Agenda for the Western Balkans. The country has committed to accelerating its energy transition through the expansion of renewable energy sources, improvements in energy efficiency and the gradual decarburization of key sectors, including transport.

A central strategic document is the National Energy and Climate Plan (NECP), adopted in 2025, which establishes Montenegro's energy and climate objectives up to 2030. The plan sets ambitious targets, including a reduction of greenhouse gas emissions by 55% compared to 1990 levels and an increase in the share of renewable energy sources to approximately 50% of final energy consumption. Particular emphasis is placed on the accelerated deployment of solar and wind energy, modernization of energy infrastructure, and increased integration of renewable electricity into end-use sectors, including transport.

Within the transport sector, the NECP identifies electrification as one of the key measures for reducing emissions and decreasing dependence on imported fossil fuels. The document highlights the importance of expanding electric vehicle charging infrastructure, promoting low-emission mobility solutions and increasing the use of renewable electricity in transport systems. The integration of renewable energy generation with electric mobility is recognized as an important component of achieving long-term decarburization objectives.

These priorities are consistent with Montenegro's broader Energy Development Strategy, which envisages a gradual transition toward a low-carbon energy system based on a significantly larger share of renewable energy sources. Strategic planning documents emphasize the development of solar and wind energy projects, strengthening energy security, reducing reliance on fossil fuels and increasing domestic electricity production from renewable sources. Long-term energy planning foresees substantial growth of solar photovoltaic capacity and wider deployment of energy storage technologies to support system flexibility and renewable energy integration.

Montenegro has also established a regulatory framework that supports distributed renewable energy generation and prosumer participation. National energy legislation enables municipalities, public institutions and local stakeholders to develop renewable energy projects and participate more actively in local energy management. In addition, local governments can access financing through national support programs, international financial institutions, EU-funded initiatives and regional investment mechanisms focused on climate action, sustainable mobility and renewable energy deployment.

For cities such as Cetinje, these policy and regulatory developments create favorable conditions for the implementation of integrated renewable energy and sustainable mobility projects. The combination of photovoltaic systems, battery energy storage technologies and electric public transport directly supports national climate and energy objectives while contributing to reduced greenhouse gas emissions, improved urban environmental quality and increased local energy resilience.

3.3. Regional and local policy context – Cetinje

At the local level, the Capital City of Cetinje has increasingly incorporated sustainability, environmental protection and sustainable mobility objectives into its strategic development framework. As the historical capital of Montenegro, Cetinje represents a key cultural and administrative center, while also functioning as an important tourism node within the broader coastal–mountain–inland tourism system of the country. Unlike purely urban or industrial municipalities, Cetinje exhibits a hybrid mobility and demand structure influenced by both resident population needs and significant tourism-related transport flows. The city serves as a gateway to several high-value national tourism destinations, including the Lovćen National Park and the Njeguši village area, which are key cultural and gastronomic heritage sites. In addition, the Lovćen Mausoleum represents one of the most visited national landmarks in Montenegro, generating continuous excursion-based travel demand throughout the year.

Furthermore, Cetinje is strategically positioned along the road corridor connecting the Montenegrin coast and the Bay of Kotor with the inland regions. This route supports intensive seasonal and daily

tourist movements, particularly during the summer months. The nearby Kotor–Lovćen cable car system has further strengthened regional tourism connectivity, significantly increasing visitor flows between the coastal zone and the mountainous hinterland, with Cetinje acting as a key intermediate access point.

From an environmental perspective, Cetinje is exposed to seasonal air quality variations, particularly during winter periods when meteorological conditions in the mountainous basin can contribute to temperature inversions and pollutant accumulation. At the same time, transport emissions linked to intercity traffic and tourism-related mobility represent an additional environmental pressure, especially during peak visitation periods. In response to national and EU-aligned sustainability frameworks, the City of Cetinje is gradually integrating low-emission mobility and energy efficiency objectives into its development policies. These efforts are aligned with Montenegro's National Energy and Climate Plan (NECP) and the Green Agenda for the Western Balkans, which emphasize decarburization of the transport sector, increased deployment of renewable energy sources and improved urban environmental performance.

Within this context, the integration of photovoltaic (PV) systems into municipal infrastructure and future electric mobility solutions represents a strategic opportunity. Such an approach would allow Cetinje to better align tourism-driven mobility demand with locally produced renewable energy, reduce indirect transport-related emissions and improve the resilience of municipal energy systems. In addition, it would support the city's positioning as a sustainable tourism destination, while contributing to reduced operational costs and enhanced energy independence of public services.

3.4. Alignment with SUMP4Balkans Objectives

The proposed integration of photovoltaic (PV) systems into a potential electric public transport system in Cetinje is strongly aligned with the core objectives of the SUMP4Balkans project. The project promotes the coupling of renewable energy generation with sustainable urban mobility systems, the development of scalable and replicable solutions for cities in the Balkan region and the strengthening of institutional capacity for integrated energy–transport planning.

In this context, the present feasibility study provides a structured decision-support framework for the City of Cetinje and relevant national and municipal stakeholders. Although Cetinje is currently in an early stage of public transport electrification compared to larger urban centers, the city represents an important case study due to its dual character as both a historical capital and a high-importance tourism destination within Montenegro's spatial mobility system.

Cetinje functions as a key inland tourism and transit node, connecting the Montenegrin coast with the mountainous hinterland, including Lovćen National Park, Njeguši and the Kotor–Lovćen cable car system. This creates a mobility environment characterized by a combination of resident travel demand, regional commuter flows and significant excursion-based tourism traffic. As such, the study provides a relevant analytical basis for assessing how renewable-energy-based mobility systems can be designed in municipalities with mixed demand profiles and strong tourism dependence.

By developing structured PV integration scenarios for future electric mobility development, the study supports knowledge transfer and methodological replication across similar heritage and

tourism-oriented cities in the Western Balkans, where electrification of transport systems is expected to play an increasing role in sustainable development strategies.

3.5. Barriers and Enabling Factors

Despite a generally supportive European and national policy framework for renewable energy and sustainable mobility, several local and structural barriers may influence the implementation of PV-integrated electric transport systems in Cetinje. Key barriers include:

Early-stage transport electrification: Cetinje is still in the preparatory or early planning phase of full-scale electric public transport deployment. Unlike larger urban systems with established operational fleets, this limits the availability of empirical consumption data and introduces uncertainty in long-term infrastructure sizing and operational modelling.

Grid and infrastructure constraints: As a smaller municipality with limited existing charging infrastructure, the integration of high-power charging systems combined with local PV generation may require significant grid reinforcement and coordination with the national transmission and distribution system operator.

Cold mountain climate and seasonal variability: Cetinje is located at approximately 670 m above sea level and is characterized by a cold mountain climate with pronounced winter conditions. In surrounding high-altitude zones, such as Lovćen National Park (up to 1,660 m) and the Njeguši area (approximately 1,380 m), winter conditions are even more severe, with frequent snow cover, low temperatures, fog and reduced solar irradiation. These conditions reduce photovoltaic generation efficiency during winter months while simultaneously increasing energy demand for electric bus operation, particularly due to heating requirements and reduced battery efficiency in low temperatures.

Topography and energy demand variability: The transport connection between Cetinje and surrounding tourism destinations, including Lovćen, Njeguši and the Kotor–Lovćen cable car corridor, involves steep elevation gradients. These mountainous routes increase traction energy demand for electric buses during uphill operation, although partial energy recovery through regenerative braking is possible during downhill segments. This results in higher variability in energy consumption compared to flat urban systems and requires more precise fleet energy management and battery sizing.

Investment constraints: High upfront capital costs for PV installations, charging infrastructure and potential energy storage systems represent a significant financial barrier, particularly given the limited fiscal capacity of municipality.

Seasonal tourism-driven demand variability: Cetinje experiences strong seasonal variations in mobility demand due to tourism flows toward Lovćen, Njeguši and coastal connections via the Kotor corridor. This variability can complicate optimal sizing and utilization of transport and energy infrastructure.

At the same time, several important enabling factors support the long-term feasibility of such systems:

Strong renewable energy potential: Despite winter limitations, Cetinje benefits from favorable annual solar irradiation levels, enabling strong long-term PV yield potential, particularly in spring and summer months when tourism demand is also higher.

Strategic tourism and mobility importance: Cetinje functions as a key inland tourism hub connecting the Adriatic coast with Lovćen National Park, Njeguši and the Bay of Kotor region. The presence of high-value tourism infrastructure, including the Lovćen Mausoleum and the Kotor–Lovćen cable car system, creates sustained mobility demand and strengthens the case for low-emission transport solutions. The association of clean transport with heritage and nature-based tourism (Lovćen National Park and surrounding attractions) further strengthens the socio-political case for implementation.

Alignment with national and EU policy frameworks: Strong alignment with Montenegro's NECP, Energy Development Strategy and EU Green Agenda commitments provides a stable strategic foundation for investment in renewable energy and electric mobility integration.

Access to international funding mechanisms: Cetinje can benefit from EU pre-accession funds (IPA), Western Balkans investment frameworks and climate-oriented financial instruments that significantly improve the financial feasibility of renewable energy and sustainable mobility projects.

Long-term cost and resilience benefits: Despite climatic constraints, the integration of PV systems with electric transport infrastructure, potentially supported by battery energy storage systems, offers long-term benefits in terms of reduced operating costs, improved energy autonomy and enhanced resilience to energy price volatility.

Overall, while Cetinje presents more complex operational conditions due to its mountainous terrain and cold climate, these same characteristics justify the need for carefully designed, flexible and resilient renewable-energy-based transport systems rather than limiting their feasibility.

4. TECHNICAL FEASIBILITY ASSESSMENT

4.1. Transport system overview

The total length of the road network within the territory of Cetinje Municipality is approximately 730 km. The most important transport corridor is the M-10 main road, which connects the Capital City of Podgorica with Cetinje and Budva, providing a strategic link between the central region of Montenegro and its southern coastal area. As such, it plays a vital role in supporting economic activities, goods distribution, tourism, and the daily mobility of residents. The M-10 carries an average daily traffic volume of approximately 12,000 vehicles and extends for around 50 km through the territory of Cetinje (Figure 4.1).

In addition, the newly constructed Cetinje–Čevo road is located within the municipality. It is expected to be officially classified as a state road (i.e., M-13) and assigned a route designation by the Transport Administration by the end of the current year, further strengthening regional accessibility and connectivity. In the longer term, this road is expected to serve as an important transport corridor connecting Cetinje with Nikšić, the second-largest city in Montenegro, thereby improving interregional mobility and supporting economic and social development between the two urban centers.

The regional road network in Cetinje consists of routes R-1, R-14, R-15, R-17, R-25, and R-25.1, which play a crucial role in connecting the urban centre of Cetinje with the rural settlements of the Katunska Nahija region, Lovćen National Park, and neighbouring municipalities. The R-1 road connects Cetinje with Kotor via Njeguši and represents one of the most important historic and tourist routes in Montenegro. The R-14 provides a connection between Danilovgrad and Čevo, improving accessibility to the western part of the municipality. The R-15 links the areas of Ostros, Virpazar, and Rijeka Crnojevića with the M-10 main road near Donji Ulići, forming an important connection between Cetinje and the Skadar Lake region. The R-17 road connects Čekanje, Resna, and Čevo with the route towards Nikšić, contributing to improved accessibility of the Katunska Nahija area. Of particular importance for tourism are the R-25 and R-25.1 roads, which connect Cetinje with Ivanova Korita, Njeguši, and Lovćen, including access to the Mausoleum of Petar II Petrović Njegoš, one of Montenegro's most prominent tourist attractions. Collectively, these regional roads represent a key component of transport accessibility, regional integration, and the tourism development of the Cetinje area.

In addition to the main and regional roads, the road network of Cetinje includes an extensive system of local roads serving a variety of transport functions. The largest share of the network consists of unclassified roads (242.06 km), which primarily provide access to rural settlements and low-volume traffic areas. A significant proportion of the network is made up of urban residential streets (187.01 km), serving predominantly residential neighbourhoods and local traffic movements. The network is further complemented by service roads (67.27 km), which provide access to individual properties, industrial facilities, and other land uses. Local tertiary roads (47.94 km) play an important role in connecting smaller settlements and local communities. This structure reflects the predominantly rural character of the municipality, characterized by a dispersed settlement pattern and a highly developed network of local access roads necessary to ensure connectivity across its extensive territory.

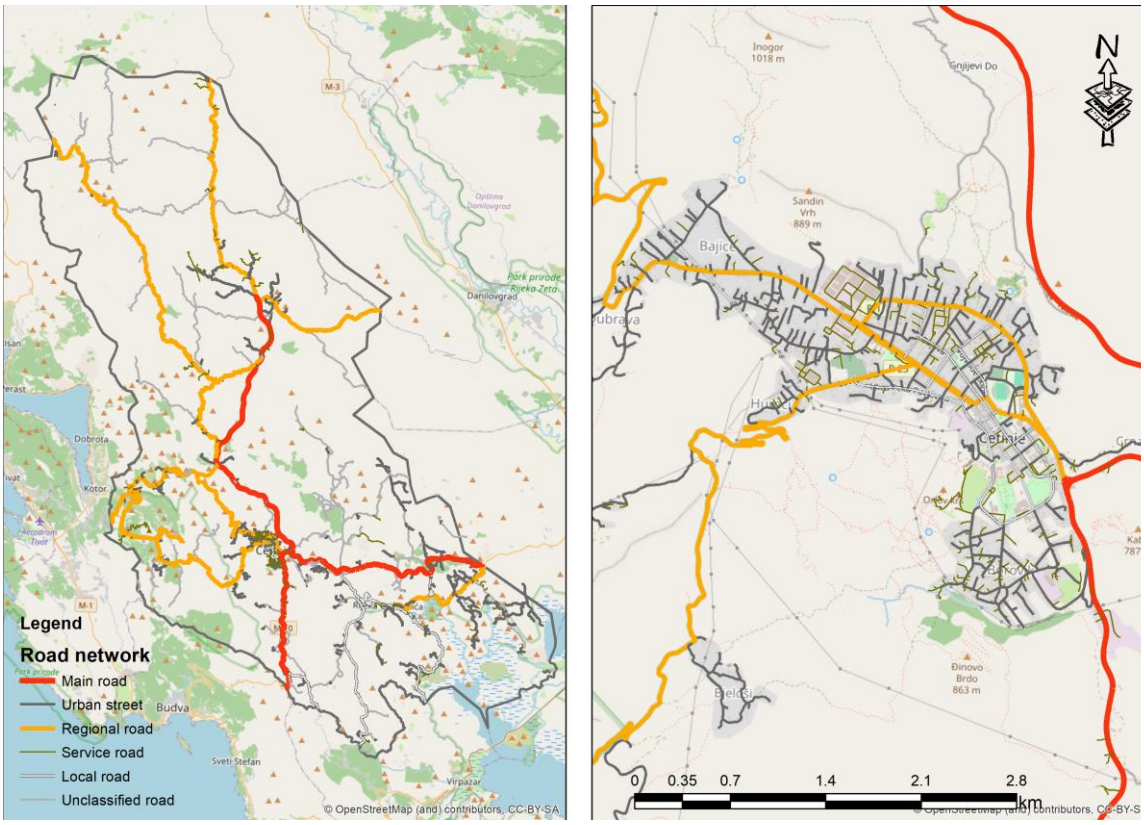


Figure 4.1. Road network in Cetinje

The public transport system in the Municipality of Cetinje is currently underdeveloped and does not provide a structured urban bus service. Due to the compact size of the urban area, relatively short travel distances, and prevailing socio-economic conditions, most daily trips are undertaken either by private car or on foot. Travel to destinations outside the municipality is primarily carried out using private vehicles or taxi services.

However, during the tourist season, when travel demand increases significantly, the limitations of the existing transport system become more evident. The growing number of visitors creates a need for organized public transport services capable of connecting the town centre with major tourist attractions and recreational destinations within the Cetinje area. Improving public transport accessibility to locations such as Lovćen National Park, Ivanova Korita, Njeguši, Rijeka Crnojevića, and other cultural and natural heritage sites could contribute to more sustainable mobility patterns, reduce dependence on private vehicles, alleviate parking demand, and enhance the overall visitor experience.

4.2. Planned Introduction of the Electric Bus System

The proposed electrification concept for Cetinje is based on the introduction of a small-capacity electric shuttle vehicle (8+1 seats) designed to serve the specific mobility needs of both residents and visitors. Unlike conventional urban public transport systems, Cetinje is characterized by dispersed tourist attractions, highly seasonal travel demand, significant topographical constraints, and relatively low passenger volumes outside the peak tourism season. Consequently, the

deployment of large electric buses would result in low occupancy rates, reduced operational efficiency, and unnecessary energy consumption.

The concept is therefore aligned with the principles of the Demand Responsive Electric Bus System (DREBS) developed within the SMART LAND framework. DREBS promotes flexible and scalable mobility solutions in areas where conventional fixed-route public transport is economically difficult to justify. The system combines scheduled services during periods of high demand with demand-responsive operation during periods of lower demand, thereby maximizing vehicle utilization and minimizing operating costs.

From a technical perspective, the findings of Berthold's techno-economic methodology for the electrification of urban bus networks indicate that the optimal configuration of an electric public transport system depends on balancing vehicle capacity, battery size, charging infrastructure requirements, and operational demand. In environments characterized by moderate passenger volumes and variable travel demand, smaller electric vehicles often provide superior overall system efficiency because they require lower battery capacities, consume less energy, reduce infrastructure requirements, and achieve higher vehicle occupancy rates (Berthold, 2019).

These findings are particularly relevant for Cetinje. The municipality is characterized by:

- mountainous terrain with significant longitudinal gradients;
- dispersed settlements and tourist destinations;
- strong seasonal fluctuations in travel demand;
- relatively low permanent population density outside the urban core;
- growing demand for sustainable tourism mobility solutions.

The terrain configuration represents an important factor in vehicle selection. Routes connecting Cetinje with destinations such as Lovćen National Park, Ivanova Korita, Njeguši, Rijeka Crnojevića and other rural attractions involve substantial elevation changes. While these gradients increase energy consumption during uphill travel, electric vehicles are particularly well suited to such operating conditions because regenerative braking systems can recover a portion of the energy during downhill sections. Furthermore, the lower mass of an 8+1 electric shuttle compared with a conventional city bus reduces overall energy requirements and improves operational efficiency on mountainous roads.

Based on preliminary demand assessments and stakeholder consultations, the proposed operational concept distinguishes between summer and winter service regimes. During the summer tourism season, when visitor numbers are significantly higher, the vehicle would operate as a scheduled shuttle service connecting Cetinje with key tourist destinations. The preliminary route structure includes:

- Cetinje – Lovćen – Ivanova Korita;
- Kotor – Lovćen Cable Car;
- Cetinje – Rijeka Crnojevića;
- Cetinje – Njeguši.

Regular departures would provide visitors with predictable access to major attractions while reducing dependence on private cars and mitigating parking pressure in sensitive tourist areas.

During the winter season and periods of lower demand, the system would transition to a demand-responsive operating model. In this mode, journeys would be booked through a mobile application, website, call centre, hotel reception, tourist information centre, or other partner organizations. The vehicle would operate only when passenger requests exist, significantly reducing operating costs while maintaining mobility accessibility for residents and visitors.

An important element of the proposed concept is the adoption of a depot-based charging strategy. The vehicle would be charged once, or at most twice per day, primarily during overnight periods when it is not in operation. This approach minimizes infrastructure requirements and eliminates the need for charging facilities at tourist destinations and intermediate stops. Instead, a single charging location would be established at the vehicle depot.

The depot is envisaged to be equipped with a dedicated charging station supplied, either partially or entirely, by a photovoltaic (PV) system installed as part of the project. Such a solution is fully aligned with the objectives of integrating renewable energy sources into the public transport system and contributes directly to reducing operating costs and greenhouse gas emissions.

The adoption of a depot-charging strategy has important implications for vehicle configuration. In accordance with the techno-economic principles identified in the literature (e.g., Berthold, 2019), particularly those related to the trade-off between battery capacity and charging infrastructure, the proposed shuttle should be equipped with a relatively high-capacity battery capable of covering most or all daily operating requirements without intermediate charging. Although a larger battery increases vehicle acquisition costs and slightly reduces energy efficiency due to additional weight, it significantly reduces infrastructure complexity, improves operational flexibility, and avoids the need for multiple charging locations across the service area.

This approach is particularly suitable for Cetinje, where tourist destinations are geographically dispersed and seasonal demand does not justify extensive charging infrastructure. Instead of investing in charging stations at locations such as Ivanova Korita, Njeguši or Rijeka Crnojevića, the proposed system concentrates charging activities at a single depot location while relying on a vehicle with sufficient energy autonomy to perform daily operations.

Furthermore, the integration of photovoltaic generation with depot charging creates a strong synergy between renewable energy production and sustainable mobility. During the summer season, when solar irradiation levels are highest and tourism demand reaches its peak, locally generated solar electricity can supply a substantial share of the vehicle's energy needs. This contributes to improved energy self-sufficiency, lower lifecycle costs and enhanced environmental performance of the overall transport system. This hybrid operating model combines the advantages of both traditional and demand-responsive public transport systems:

The proposed concept offers several important advantages compared to conventional public transport solutions. Due to its smaller vehicle size and flexible operating model, the system is expected to achieve lower energy consumption and higher vehicle occupancy rates than traditional

fixed-route bus services. The use of a single depot-based charging facility significantly reduces charging infrastructure requirements and associated investment costs, while the integration of photovoltaic energy generation further lowers operating expenses and improves the overall environmental performance of the system. Moreover, the combination of scheduled summer services and demand-responsive winter operation enables the transport offer to adapt to seasonal tourism fluctuations, ensuring efficient resource utilization throughout the year. At the same time, the proposed service improves accessibility to key tourist destinations, reduces dependence on private vehicles, alleviates parking pressure in environmentally sensitive areas, and contributes to the broader sustainability and decarbonisation objectives of the Cetinje municipality.

Despite its advantages, the proposed concept also presents several challenges that should be considered during the planning and implementation phases. The relatively small vehicle capacity may limit the system's ability to accommodate exceptionally high passenger demand during peak tourism periods, potentially requiring additional departures or supplementary transport services. Furthermore, the successful operation of the demand-responsive service during the winter season depends on the availability of an efficient booking and dispatch platform, as well as effective coordination between transport operators, tourism stakeholders and users. The proposed depot-charging strategy also requires the installation of a larger battery pack to ensure sufficient daily driving range, which increases the initial vehicle acquisition cost. However, these additional vehicle costs are expected to be partially offset by the reduced need for charging infrastructure and lower long-term operating expenses. Finally, the overall performance of the system will depend on the accuracy of demand forecasting and the ability to adapt service levels to seasonal variations in visitor numbers and mobility needs.

4.2.1. Electric Bus Energy Demand

The introduction of the proposed electric shuttle service creates a new electricity demand component within the local energy system. The magnitude of this demand depends on vehicle characteristics, battery capacity, route profile, driving behaviour, passenger occupancy, ambient temperature and the use of auxiliary systems such as heating, ventilation and air conditioning (HVAC). Due to the mountainous topography of the Cetinje region and the seasonal nature of tourism demand, energy consumption is expected to vary throughout the year.

Based on the technical characteristics of currently available electric passenger shuttle vehicles with a seating capacity of up to 8+1 passengers, specific energy consumption is expected to range between approximately 0.25 and 0.35 kWh/km under real operating conditions. Energy consumption depends on vehicle weight, battery capacity, passenger load, driving conditions and auxiliary energy consumption. For planning purposes, a representative average value of 0.30 kWh/km has been adopted.

Assuming average daily operating distances between 80 and 150 km, depending on seasonal demand and route structure, the corresponding daily electricity demand is estimated to range between 24 and 45 kWh per vehicle. During the summer tourism season, when scheduled services are expected to operate between Cetinje and major tourist attractions, daily vehicle utilisation and energy consumption are likely to approach the upper end of this range. Additional electricity

demand during summer months will result from intensive use of air-conditioning systems and increased passenger volumes.

In contrast, winter operation is expected to be primarily demand-responsive, resulting in lower daily mileage and reduced overall energy consumption. Nevertheless, part of these savings may be offset by increased heating requirements and lower battery efficiency under colder ambient conditions.

The proposed operating concept is based on a depot-charging strategy, whereby the vehicle would normally be charged once per day, primarily during overnight periods when it is not in service. To support this operational model and provide sufficient operational flexibility during peak tourism periods, the selected vehicle should be equipped with a relatively large battery pack. Currently available electric shuttle vehicles typically offer battery capacities ranging from approximately 75 kWh to 90 kWh, enabling real-world operating ranges of approximately 200–300 km under the terrain and climatic conditions of Cetinje. Such battery capacities are considered sufficient to support a full day of operation without the need for intermediate charging.

At the annual level, total electricity demand depends on daily energy consumption, vehicle utilisation rates, seasonal demand patterns and the number of operational days. The annual electricity demand can therefore be expressed as the product of average daily demand and annual operating days. Assuming an average daily demand of approximately 35 kWh and year-round operation, the annual electricity consumption of a single vehicle is estimated at approximately 12.8 MWh. This estimate provides the basis for photovoltaic system sizing, charging infrastructure design, renewable energy integration scenarios and subsequent economic feasibility analysis.

The combination of a high-capacity battery vehicle and overnight charging from a photovoltaic-supported depot represents a technically robust and economically efficient solution for Cetinje. Such an approach minimizes charging infrastructure requirements, eliminates the need for charging stations at tourist destinations, maximizes operational flexibility and supports the long-term objective of integrating renewable energy into the local sustainable mobility system.

4.2.2. Charging infrastructure and load profiles

The design of charging infrastructure represents a critical element in the successful implementation of the proposed electric shuttle system in Cetinje. Charging infrastructure not only determines the operational flexibility of the vehicle but also directly influences electricity demand patterns, photovoltaic system utilization, and the overall integration of the transport system with the local electricity network.

In contrast to large urban electric bus systems that often require a combination of depot and opportunity charging strategies, the proposed DREBS concept for Cetinje is based on a simplified charging approach centred around a single depot charging facility. This approach is considered particularly suitable due to the relatively low number of vehicles, moderate daily travel distances, seasonal demand patterns, and the dispersed nature of tourist destinations served by the system.

The proposed operational model assumes that the electric shuttle vehicle will be charged primarily during overnight periods when it is not in service. Consequently, the system requires only one

charging location equipped with a dedicated charger and associated electrical infrastructure. This significantly reduces investment costs compared to solutions that require charging stations at multiple tourist destinations or intermediate stops.

The selected vehicle configuration is expected to incorporate a battery capacity ranging from approximately 75 to 90 kWh, allowing the vehicle to complete daily operations without intermediate charging. As a result, charging demand is concentrated during a limited period, typically during the night or early morning hours. Under these operating conditions, the charging load profile remains relatively predictable and easier to manage than in systems relying on frequent daytime charging.

From a technical perspective, charging power levels between 11 and 22 kW are considered sufficient for the proposed pilot operation. Assuming a daily electricity consumption of approximately 25–45 kWh, overnight charging periods of several hours would be adequate to fully recharge the vehicle battery. Such charging requirements are considerably lower than those typically associated with conventional electric bus fleets, where charging powers frequently exceed 100 kW.

The proposed charging facility is planned to be integrated with a PV system installed at the depot location. Although vehicle charging will primarily occur during nighttime hours, solar electricity generated during the day can be exported to the local distribution network or stored through future battery storage solutions, effectively offsetting electricity consumption associated with vehicle charging. This approach improves renewable energy utilization and reduces dependence on externally supplied electricity.

The resulting load profile is therefore characterized by relatively low and predictable charging demand compared to conventional electric bus systems. Unlike opportunity charging concepts, which introduce significant daytime power peaks, the proposed depot charging strategy concentrates electricity demand during off-peak periods, reducing potential impacts on the local distribution network and simplifying grid integration.

Nevertheless, several technical aspects should be considered during implementation. These include verification of available connection capacity at the selected depot location, assessment of transformer loading conditions, and evaluation of future charging requirements in the event of fleet expansion. As the DREBS concept develops and additional vehicles are introduced, coordinated planning of charging infrastructure, photovoltaic generation and electricity network capacity will become increasingly important.

4.2.3. Interaction with the local energy system

The introduction of the proposed electric shuttle service creates a new electricity demand component within the local energy system of Cetinje. However, due to the relatively low energy requirements of a single 8+1 electric vehicle, the impact on the local distribution network is expected to remain limited during the initial phase of implementation.

The integration of a PV system at the depot location provides an opportunity to partially offset vehicle charging demand through locally generated renewable electricity. This reduces dependence

on grid-supplied energy, improves overall system sustainability and contributes to the reduction of greenhouse gas emissions.

The interaction between transport electrification and local renewable energy generation is particularly favourable in Cetinje, as the highest transport demand occurs during the summer tourism season, which coincides with periods of maximum solar energy production. As a result, a significant share of the electricity required for vehicle operation can potentially be supplied from renewable sources.

4.2.4. Key challenges and opportunities

The proposed integration of an electric shuttle service and photovoltaic energy generation in Cetinje presents both challenges and opportunities. The main challenges are associated with seasonal variations in tourism demand, which result in fluctuating transport and energy requirements throughout the year. Additional considerations include the initial investment required for vehicle procurement, charging infrastructure and photovoltaic installation, as well as the need to ensure adequate electricity supply at the selected depot location.

At the same time, several factors create favourable conditions for successful implementation. Cetinje benefits from significant solar energy potential, enabling local renewable electricity generation to support vehicle charging. Furthermore, the highest transport demand occurs during the summer tourism season, coinciding with periods of maximum solar energy production and creating a natural synergy between mobility demand and renewable energy availability.

Additional opportunities arise from the application of smart charging strategies, future integration of energy storage systems and the possibility of expanding the concept within the broader DREBS framework. The project is also aligned with European and national policy objectives related to transport decarbonisation, renewable energy deployment and sustainable tourism development, which may facilitate access to future funding and support mechanisms.

5. INTEGRATION OF PV IN TRANSPORT

5.1. PV potential in Cetinje

Cetinje is located in the central part of Montenegro, at the foothills of Mount Lovćen, and is characterized by favourable conditions for the utilization of solar energy despite its mountainous terrain and specific climatic conditions.

As shown in Figure 5.1, Montenegro is located within a region characterized by above-average solar energy potential. The annual global horizontal irradiation (GHI) ranges from approximately 1400 to 1600 kWh/m², indicating favourable conditions for photovoltaic electricity generation throughout the country. Particular attention should be given to the Cetinje area, which is represented by darker orange-red shades on the map, indicating solar irradiation levels that are among the highest in Montenegro. This suggests that photovoltaic systems installed in the municipality can achieve relatively high energy yields, further supporting the feasibility of integrating solar energy into the proposed electric public transport system.

The maps presented in this chapter illustrate the average values of global solar irradiation on a horizontal surface and the photovoltaic electricity generation potential for optimally inclined, south-facing solar panels. For most regions, the data represent average values for the period 1998–2011, while for areas located north of latitude 58°N, the values are based on a ten-year period from 1981 to 1990. All irradiation values are expressed in kWh/m².

In addition, the legend presents the photovoltaic electricity generation potential expressed in kWh/kWp, representing the amount of electrical energy generated annually by a 1 kWp photovoltaic system installed at the optimal tilt angle, assuming an overall system efficiency of 75%.

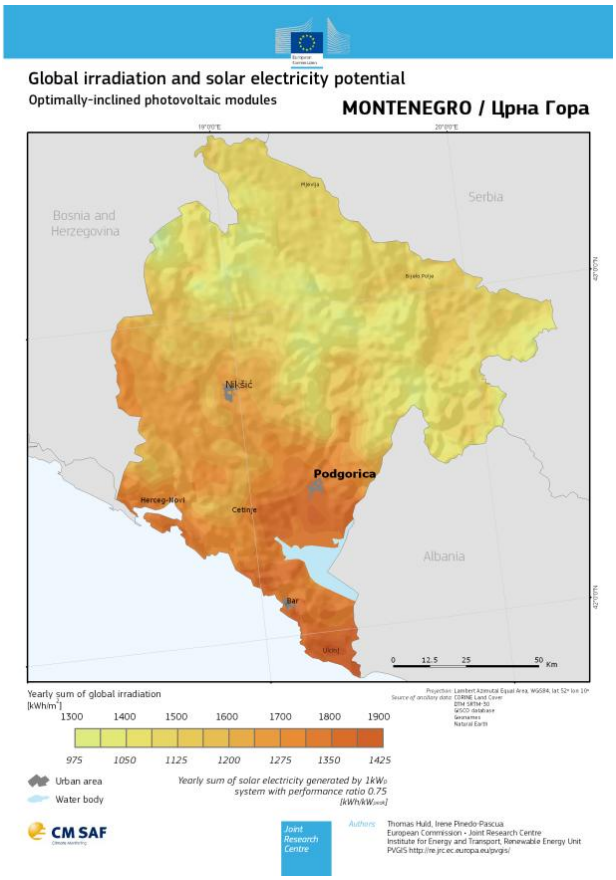


Figure 5.1. Solar energy potential in Montenegro

For the purpose of providing renewable electricity for charging the proposed electric shuttle vehicle, the "Košuta" photovoltaic power plant has been envisaged within the Industrial Zone of Cetinje. The facility is designed to utilize local solar energy resources and support the sustainable operation of the proposed transport system. The planned installation will generate clean electricity from solar energy and contribute to the sustainable operation of the transport system, with a total installed capacity of 62.64 kWp. The layout of the proposed PV system is presented in Figure 5.2. The system is expected to generate approximately 81,520 kWh of electricity annually.

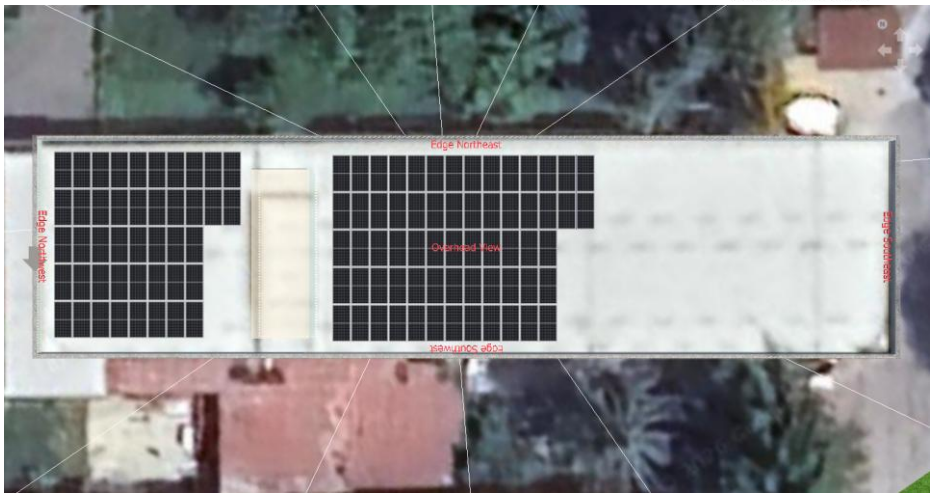


Figure 5.2. Layout of the proposed photovoltaic power plant

An additional advantage is that the period of highest photovoltaic electricity generation coincides with the main tourist season, when transport activity and mobility demand in the Cetinje area are generally increased. This temporal alignment may contribute to a higher utilization of locally generated solar electricity and improve the overall efficiency of the proposed system.

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:

$$Annual\ PV\ output = Installed\ capacity \times Specific\ yield;$$

where installed capacity is expressed in kWp, specific yield (kWh/kWp/year) depends on location, orientation and system performance. For the Cetinje area, typical specific yields are estimated to range between 1300 and 1500 kWh/kWp/year. This range accounts for common system losses, including inverter and wiring losses, temperature effects, variations in panel 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

The potential for PV deployment in Cetinje is primarily determined by the availability of suitable urban surfaces, particularly rooftop areas on public, municipal and industrial buildings, including schools, administrative facilities, sports centres and similar structures suitable for photovoltaic installations. One such example is the former “Košuta” factory complex, where the Municipality

of Cetinje has recognized the site's development potential and plans to establish a business complex equipped with a photovoltaic power plant. This site represents a suitable location for the integration of renewable energy technologies and supports the sustainable development objectives of the municipality.

PV generation follows a highly variable temporal pattern, with peak output during midday hours and no production during night-time. Seasonally, generation is highest in summer and lowest in winter. This profile is particularly relevant for Cetinje, as it partially aligns with increased transport demand during the tourist season, but still creates a daily mismatch between solar production and vehicle charging demand.

The effectiveness of PV integration is largely determined by the extent of local self-consumption. This depends on the temporal alignment between electricity generation and demand. Since the proposed electric shuttle vehicle is primarily intended to be charged during night-time hours, a temporal mismatch exists between photovoltaic electricity generation and vehicle charging demand. However, this limitation is partially mitigated by the fact that the electricity generated by the proposed PV system will not be used exclusively for vehicle charging. The generated electricity will also be available for supplying the future business complex, thereby increasing the level of local self-consumption, improving economic performance and reducing reliance on the electricity grid.

5.3.1. System architecture options

The integration of PV systems into electric public transport can be achieved through a range of technical configurations that vary in terms of complexity, operational flexibility and investment requirements.

The most straightforward solution is a grid-connected PV system with depot-based charging. In this arrangement, photovoltaic installations are located at bus depots and connected to the local distribution network. Electricity generated by the PV system is consumed on-site whenever possible, while excess production is exported to the grid. Due to its relatively simple design, limited infrastructure requirements and straightforward operation, this option is particularly suitable for scenarios involving partial PV integration.

A more sophisticated solution combines distributed PV installations with smart charging strategies. In this case, PV systems can be deployed across several urban locations, including depots, public buildings and parking canopies. Smart charging enables charging activities to be shifted towards periods of high solar generation, reducing peak demand and increasing the utilization of locally generated renewable electricity. Furthermore, load management measures such as scheduled charging, temporary power limitations and integration with energy management systems can contribute to more efficient use of both charging infrastructure and grid capacity. As a result, this configuration can achieve higher levels of self-consumption and overall system efficiency, although at the cost of increased operational complexity. Such an approach is suitable for both moderate and high levels of PV integration.

The most advanced configuration involves the integration of photovoltaic systems with battery energy storage systems (BESS). In this arrangement, surplus solar electricity can be stored and

utilized at a later time, particularly during periods when PV generation is unavailable, such as night-time vehicle charging. This improves the balance between electricity production and consumption while providing additional operational flexibility. However, the inclusion of battery storage requires advanced control strategies and results in higher capital costs. Despite these challenges, the combination of PV generation and energy storage can significantly reduce dependence on the electricity grid and improve the overall resilience of the system.

6. SCENARIO DEVELOPMENT

6.1. Purpose and construction of scenario analysis

The integration of photovoltaic (PV) systems into electric public transport in Cetinje involves several uncertainties and interrelated variables, including transport demand, available PV capacity, charging strategies and interaction with the electricity grid. To account for these complexities, a scenario-based approach is adopted.

This approach enables the evaluation of different pathways for integrating PV systems into the electric shuttle transport system, while assessing the impact of various system configurations on energy performance, economic feasibility and environmental benefits. Furthermore, it supports decision-making under uncertain conditions, which is particularly important during the early stages of planning. By comparing multiple scenarios, it becomes possible to identify solutions that provide an appropriate balance between technical feasibility, economic efficiency and decarbonization potential.

The objective of this analysis is to examine different system architecture options for coupling PV electricity generation with electric vehicle charging, together with the associated infrastructure requirements, operational strategies, and investment and operating costs of each scenario. In addition, the analysis considers the trade-offs between system complexity, cost and overall performance.

The scenarios are developed by considering different photovoltaic system configurations and installation locations, while maintaining the same transport service characteristics.

From the transport perspective, the same electric passenger shuttle vehicle and route network are assumed in all scenarios, providing a consistent basis for comparison. The electricity demand is determined by the average daily travel distance, specific energy consumption and seasonal variations in transport demand.

From the energy system perspective, the main variables include installed PV capacity (kWp), the spatial configuration of PV systems (centralized or distributed) and the specific PV yield (kWh/kWp/year), reflecting local solar conditions and system performance.

In addition, operational and flexibility-related parameters are considered, including charging strategy, charging schedule (daytime or night-time), the potential application of battery energy storage systems (BESS), and the level of interaction with the electricity grid, including electricity

import and export. Together, these parameters define the structure of each scenario and have a significant influence on overall system performance.

6.1.1. Energy balancing

Each scenario is assessed through an energy balance framework that includes the total electricity demand of the electric shuttle vehicle, PV electricity generation, the share of directly self-consumed PV energy, and the interaction with the grid in terms of imports and exports. Based on these components, key performance indicators (KPIs) are derived, including the share of renewable energy, self-consumption rate and level of grid dependency.

A central aspect of the analysis is the integration of photovoltaic generation with the proposed shuttle transport system. In Scenarios 1 and 2, the electricity generated by the photovoltaic systems is supplied directly to the distribution grid, from which the proposed electric passenger shuttle vehicle is charged, giving priority to vehicle operation. This approach enables efficient utilization of renewable electricity without requiring dedicated on-site energy storage. In Scenario 3, the integration of a Battery Energy Storage System (BESS) further enhances the system by storing surplus photovoltaic electricity generated during daytime and making it available for overnight vehicle charging, thereby increasing renewable energy utilization and overall system flexibility.

6.2. Baseline assumptions

To ensure consistency across scenarios, a set of baseline assumptions is defined. In the initial deployment phase, the proposed transport system consists of a single electric shuttle bus operating on two tourist-oriented routes. **The service is planned to operate three departures per day. Route 1 operates on Mondays, Wednesdays and Fridays, while Route 2 operates on Tuesdays, Thursdays and Sundays. As shown in Table 6.1, the planned daily travel distance is 137.1 km for Route 1 and 133.5 km for Route 2.**

Table 6.1. Bus lines with their route and distances

Bus line	Route	Distance per trip [km]	Daily departures	Daily distance [km]
Line 1	Cetinje - Donji Ulići - Rijeka Crnojevića - Rvaši - Cetinje	45.7	3	137.1
Line 2	Cetinje - Njeguši - Kotor Cable Car (Upper Station) - Lovćen National Park - Cetinje	44.5	3	133.5

The proposed shuttle bus routes are illustrated in Figures 6.1 and 6.2. The routes were designed to connect the historic centre of Cetinje with some of the municipality's most important tourist attractions, including Njeguši, Rijeka Crnojevića, the Kotor–Lovćen Cable Car and Lovćen National Park. These destinations represent key tourism assets of the region and contribute to the attractiveness of the proposed transport service.



Figure 6.1.Line 1: Shuttle bus route connecting Cetinje and Rijeka Crnojevića



Figure 6.2. Line 2: Shuttle bus route connecting Cetinje and the Kotor–Lovćen Cable Car

Considering the expected passenger demand and the technical characteristics of currently available electric passenger shuttle vehicles with a seating capacity of up to 8+1 passengers, an average electricity consumption of 0.35 kWh/km was adopted. Since this value does not account for the challenging operating conditions in the Cetinje area, including mountainous terrain, steep road gradients, cabin heating, cooling, ventilation and seasonal temperature variations, a 30% safety margin was applied.

Since the shuttle service operates according to a weekly timetable, the average daily travel distance was calculated based on the total weekly operating distance:

(137.1 km/day + 133.5 km/day) × 3 days/week=811.8 km/week

The average daily travel distance is therefore:

811.8/7=116.0 km/day

The resulting daily electricity demand for the electric passenger shuttle vehicle is therefore calculated as:

1.3 × 116.0 km/day × 0.35 kWh/km=52.78 kWh/day

Assuming the proposed annual operating schedule, the annual electricity demand is calculated as:

365×52.78 kWh/day=19265 kWh/year

The calculated annual electricity demand profile was subsequently implemented in the EnergyPLAN model for simulation and optimization purposes (Figure 6.3).

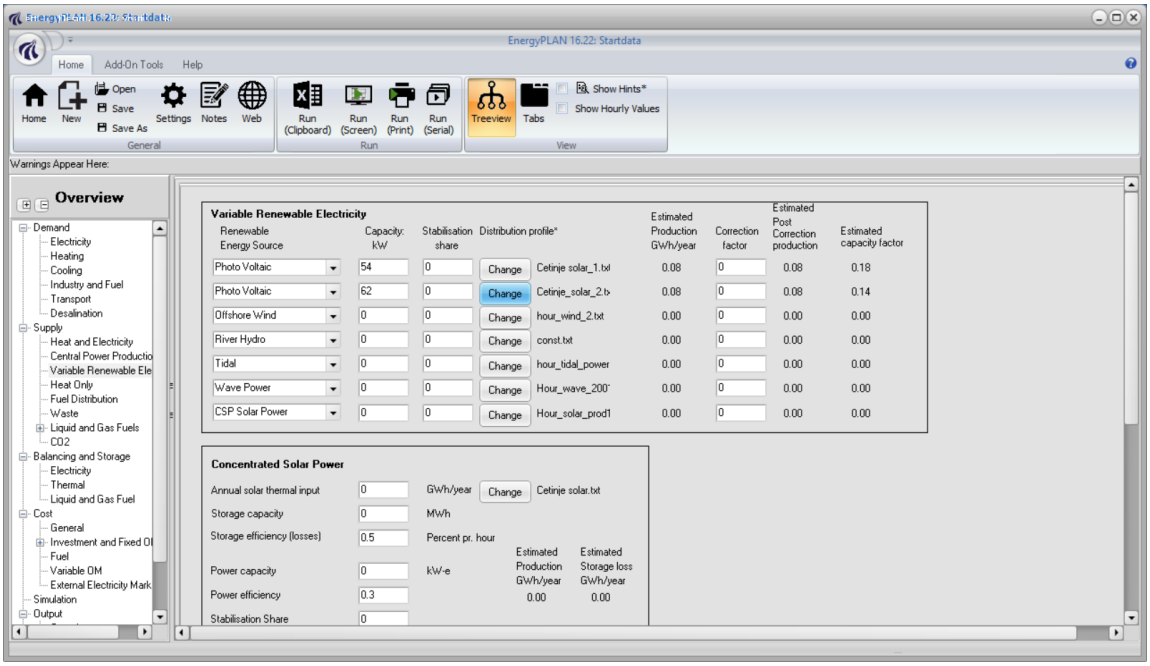


Figure 6.3 Adding installed PV capacity and hourly profiles of production into EnergyPLAN

The calculated annual electricity demand can be considered a conservative estimate, as the proposed electric passenger shuttle vehicle is unlikely to operate at the same intensity throughout the year. Lower tourist demand and less favourable weather conditions during the winter months may lead to fewer daily services and lower actual electricity consumption.

6.2.1. Charging strategy and load curve development

The proposed shuttle bus stops for Line 1 and Line 2 are presented in Tables 6.2 and 6.3, respectively. The selected stop locations provide access to the main tourist attractions along each route while maintaining a simple and operationally efficient shuttle service. The geographic

locations of the proposed stops can support future route planning, service optimization and the implementation of the proposed transport system.

Table 6.2. Proposed shuttle bus stops for Line 1

Stop	Latitude	Longitude
Cetinje – Stop 1	42.391681	18.925350
Cetinje – Stop 2	42.391731	18.925164
Rijeka Crnojevića	42.356305	19.020756
Rvaši	42.373072	19.093654

Table 6.3. Proposed shuttle bus stops for Line 2

Stop	Latitude	Longitude
Cetinje – Stop 1	42.391681	18.925350
Cetinje – Stop 2	42.391731	18.925164
Ivanova Korita	42.380456	18.830911
Kotor–Lovćen Cable Car (Upper Station)	42.396970	18.799448
Njeguši – Stop 1	42.427939	18.822437
Njeguši – Stop 2	42.432875	18.828885

The proposed shuttle service is based on overnight charging at the end of each operating day. Considering the estimated daily travel distance and the expected battery capacity of currently available electric passenger shuttle vehicles, a single overnight charging cycle is considered sufficient for normal operation. Therefore, opportunity charging during route operation was not considered necessary.

Since all routes start and end in the centre of Cetinje, a centralized charging facility is proposed at the main terminal area. This approach simplifies charging infrastructure requirements and supports efficient daily operation of the shuttle service.Based on the proposed operating schedule, an hourly charging profile for a typical operating day was developed and used to estimate the charging demand of the proposed shuttle service.

6.2.2. Potential rooftop PV locations

In the first phase of the analysis, rooftop photovoltaic systems installed on public and municipal buildings were considered. Particular attention was given to the Municipality of Cetinje building, where the available roof area provides an opportunity for the installation of a photovoltaic system. Installed capacities were estimated based on the available roof surface, typical system design assumptions and local solar resource conditions.

As an alternative scenario, the proposed “Košuta” photovoltaic power plant located within the Industrial Zone of Cetinje was considered. Compared to the rooftop installation on the Municipality building, this option represents a larger investment with a higher installed capacity and electricity generation potential. The technical characteristics of the system, including installed capacity and

expected annual electricity generation, were adopted from the available design documentation. The locations of the Municipality Building and the proposed "Košuta" photovoltaic power plant are shown in Figure 6.3.

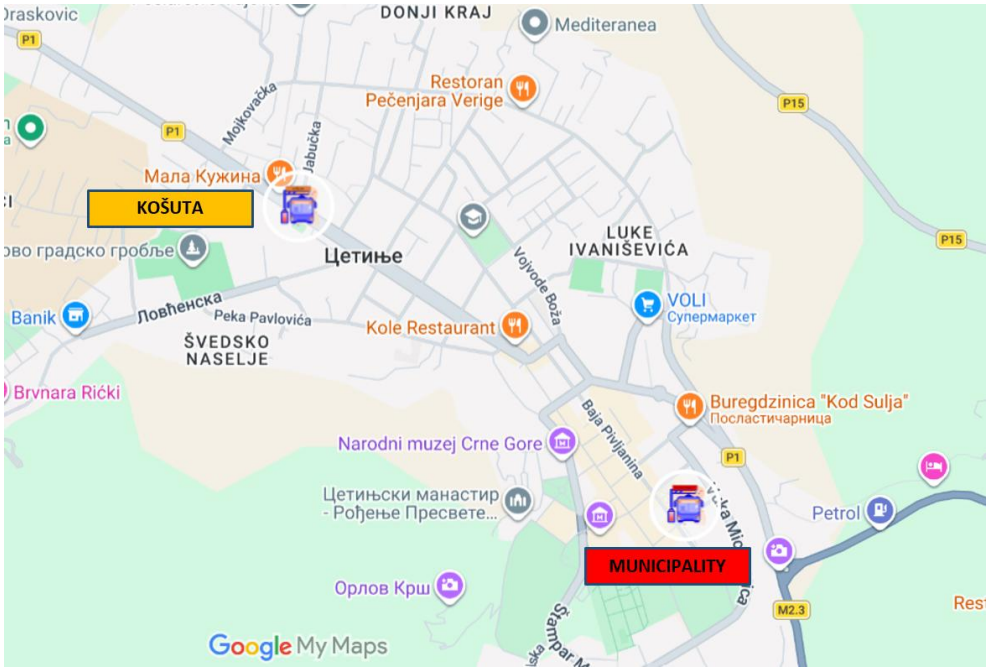


Figure 6.4. Potential PV installation locations in Cetinje

The estimated installed capacities of the photovoltaic systems considered in this study are presented in Table 6.4. The combined installed capacity of the Municipality Building rooftop system and the proposed "Košuta" photovoltaic power plant amounts to approximately 116 kWp, indicating a significant potential for local renewable electricity generation.

Table 6.4. Proposed photovoltaic installations and installed capacities

Location	Installed capacity [kWp]
Municipality Building	54
Košuta	62
Total capacity	**116 kWp**

It is expected that a portion of the electricity generated by the proposed photovoltaic systems will be consumed directly by the associated buildings. However, due to the lack of detailed electricity consumption data and future occupancy information, the exact share of locally consumed electricity cannot be determined with sufficient certainty at this stage. Therefore, the analysis focuses primarily on the electricity generation potential of the proposed PV installations and their ability to support the operation of the proposed electric passenger shuttle transport system.

6.3. Scenario definitions

Three core scenarios were defined to represent different photovoltaic integration options and levels of renewable electricity supply for the proposed electric passenger shuttle transport system. In all scenarios, priority is given to supplying renewable electricity for charging the proposed electric

passenger shuttle vehicle. In Scenarios 1 and 2, photovoltaic electricity is supplied directly to the distribution grid and used for vehicle charging through the existing electricity network, while Scenario 3 introduces a Battery Energy Storage System (BESS) to store surplus photovoltaic electricity and use it directly for overnight vehicle charging.

6.3.1. Scenario 1- Low PV integration

Scenario 1 is based on the installation of a rooftop photovoltaic system on the Municipality of Cetinje building. The available roof area provides suitable conditions for the deployment of solar panels, enabling the utilization of locally generated renewable electricity within the urban area.

An additional advantage of this location is the presence of an existing electric vehicle charging station in the immediate vicinity of the building (Figure 6.4). Although the charging station currently relies on electricity supplied from the conventional electricity grid, the proposed photovoltaic installation would enable renewable electricity to be supplied to the grid, with priority given to charging the proposed electric passenger shuttle vehicle. Any remaining electricity may be utilized by the Municipality Building or exported to the distribution grid. This would contribute to reducing greenhouse gas emissions, increasing the share of renewable energy in the transport sector, and supporting the municipality's broader sustainability and decarbonization objectives.

The installed capacity of the proposed rooftop photovoltaic system is estimated at 54 kWp, with an expected annual electricity generation of approximately 80,000 kWh/year.



Figure 6.5. Existing charging station

6.3.2. Scenario 2 – Partial PV integration

This scenario builds upon Scenario 1 by adding the proposed photovoltaic power plant at the former “Košuta” facility located on Bulevar crnogorskih junaka in Cetinje, which is planned to be redeveloped as an innovation and business support centre.

According to the available project documentation, the planned photovoltaic system has an installed capacity of approximately 62.6 kWp and an expected annual electricity generation of around 81,520

kWh/year. The system is designed to be connected to the existing electricity distribution network and supported by an energy management system for monitoring and operational control.

The proposed installation is located on the building of the future Innovation Centre, which is intended to support the development of new technologies, entrepreneurship and business activities. As in Scenario 1, priority is given to supplying renewable electricity for charging the proposed electric passenger shuttle vehicle. In this scenario, photovoltaic electricity is supplied to the distribution grid and used for vehicle charging through the existing electricity network, while any remaining renewable electricity can be utilized by the associated building or exported to the distribution grid.

As a result, this scenario increases the total installed photovoltaic capacity and annual renewable electricity generation, providing greater potential for future expansion of the proposed transport and energy system.

6.3.3. Scenario 3 - PV and BESS integration

Scenario 3 extends Scenario 2 by integrating a Battery Energy Storage System (BESS) at the proposed Košuta photovoltaic power plant. The battery system is intended to store surplus photovoltaic electricity generated during periods of high solar irradiation and make it available during periods of low or no photovoltaic generation, particularly for overnight charging of the proposed electric passenger shuttle vehicle.

In this scenario, both the Municipality Building rooftop photovoltaic system and the proposed Košuta photovoltaic power plant are combined with a Battery Energy Storage System (BESS) with an assumed storage capacity of approximately 60 kWh, corresponding to the estimated daily energy demand of the proposed shuttle vehicle. This configuration increases the utilization of locally generated renewable electricity, reduces electricity exports to the distribution grid, and decreases dependence on grid electricity during vehicle charging.

The integration of BESS also improves system flexibility and enables more efficient management of photovoltaic generation and electricity demand. However, the introduction of battery storage requires additional investment and more advanced energy management. Therefore, this scenario is considered a potential future development option following the successful implementation of the initial photovoltaic systems.

6.3.3. Scenario comparison

Table 6.5 presents a qualitative comparison of the three photovoltaic integration scenarios considered in this study. Scenario 1 represents the most practical initial solution due to the presence of an existing charging station and lower implementation costs. Scenario 2 builds upon the first scenario by increasing the total installed photovoltaic capacity and renewable electricity generation, thereby providing greater opportunities for future system expansion. Scenario 3 further enhances the system through the integration of battery energy storage, improving renewable energy utilization and reducing dependence on electricity imported from the grid. The estimated CO_2 emission reductions were calculated using an emission factor of 0.4 kg CO_2/kWh of renewable electricity generated.

Table 6.5. Comparison of scenarios

Indicator	Scenario 1	Scenario 2	Scenario 3
Instaled capacity [kWp]	54	116	116 + BESS
Annual generation [kWh/year]	80 000	161 500	161 500
Investment cost	Lower	Higher	Highest
Implementation complexity	Low	Medium	High
Existing charging infrastructure	Available	Available	Available
Renewable energy potential	High	Higher	Very high
CO_2 reduction [kg CO_2/year]	32 000	64 600	64 600

7. ECONOMIC FEASIBILITY ANALYSIS

7.1. Economic performance indicators

The economic feasibility of the proposed system can be assessed through several commonly used indicators, including investment costs, electricity generation potential, operational savings and payback period. Photovoltaic systems are generally considered a cost-effective renewable energy technology due to their relatively low operating and maintenance costs, long service life and continuously decreasing installation costs.

The economic benefits of PV integration are primarily associated with reduced electricity purchases from the grid and increased utilization of locally generated renewable energy. In addition, the electrification of transport contributes to lower operating costs compared to conventional fuel-based alternatives and reduces exposure to future increases in energy prices.

Although a detailed economic assessment is beyond the scope of this study, the considered scenarios demonstrate the potential to improve the long-term economic sustainability of the proposed electric passenger shuttle bus system while simultaneously supporting environmental and energy transition objectives.

7.2. Investment and operational costs

The investment requirements vary between the considered scenarios. Scenario 1 is based on the installation of a rooftop photovoltaic system on the Municipality Building and benefits from the existence of an operational charging point in the immediate vicinity. Consequently, the required investments are mainly related to photovoltaic panels, electrical equipment and potential upgrades of the charging infrastructure. Additional investments in battery energy storage may be considered to improve the utilization of solar electricity during night-time charging periods.

Scenario 2 involves the implementation of the proposed “Košuta” photovoltaic power plant and therefore represents a more capital-intensive solution. In addition to the photovoltaic installation itself, the system includes power conversion equipment, energy management components and grid connection infrastructure.

Operational costs vary between the analysed scenarios. In Scenarios 1 and 2, they are expected to remain relatively low and are primarily associated with system maintenance and electricity imports from the grid when photovoltaic generation is insufficient. In Scenario 3, additional operational costs are associated with the operation and maintenance of the battery energy storage system.

Although the proposed routes include challenging terrain, steep road gradients and seasonal weather variations, the average daily operating distance of approximately 116 km remains within the expected operating range of currently available electric passenger shuttle vehicles. Therefore, overnight charging is considered a suitable primary charging strategy, while fast charging is not treated as a mandatory requirement in any of the analysed scenarios. However, the need for additional charging infrastructure should be reassessed once the final vehicle specifications and battery capacity are defined.

8. RESULTS

8.1. Scenario 1 results

Scenario 1 considers the installation of a rooftop photovoltaic system on the Municipality of Cetinje building. The proposed system has an estimated installed capacity of 54 kWp and an expected annual electricity generation of approximately 80,000 kWh/year.

The annual electricity demand of the proposed electric passenger shuttle vehicle was estimated at 19,265 kWh/year based on the selected routes, operating schedule and assumed vehicle energy consumption. The key energy performance indicators for this scenario are summarized in Table 8.1.

The results indicate that the proposed photovoltaic system could fully satisfy the annual electricity demand of the proposed shuttle service. In this scenario, renewable electricity is supplied to the distribution grid and used for charging the shuttle vehicle through the existing electricity network. Any remaining renewable electricity may be utilized by the Municipality Building or exported to the distribution grid. An additional advantage of this scenario is the presence of an existing charging station in the immediate vicinity of the Municipality Building, which reduces the need for significant investments in new charging infrastructure.

Table 8.1. Energy performance indicators for Scenario 1

Parameter	Value
Installed capacity	54 kWp
Annual PV generation	80 000 kWh/year
Annual shuttle bus demand	19 265 kWh/year

8.2. Scenario 2 results

Scenario 2 builds upon Scenario 1 by integrating the proposed "Košuta" photovoltaic power plant located on Bulevar crnogorskih junaka in Cetinje. The combined installed capacity of the two photovoltaic systems is approximately 116 kWp, with an expected total annual electricity generation of around 161,500 kWh/year.

The annual electricity demand of the proposed electric passenger shuttle vehicle was estimated at 19,265 kWh/year, based on the selected routes, operating schedule and assumed vehicle energy consumption. The key energy performance indicators for this scenario are summarized in Table 8.2.

The results indicate that the combined photovoltaic systems could fully satisfy the annual electricity demand of the proposed shuttle service. As in Scenario 1, renewable electricity is supplied to the distribution grid and used for charging the shuttle vehicle through the existing electricity network. The increased photovoltaic capacity provides additional renewable electricity that can be utilized by the associated buildings or exported to the distribution grid. Compared to Scenario 1, this scenario offers significantly higher renewable electricity generation and greater opportunities for future expansion of the proposed transport and energy system.

Table 8.2. Energy performance indicators for Scenario 2

Parameter	Value
Installed capacity	62 kWp
Annual PV generation	161 500 kWh/year
Annual shuttle bus demand	19 265 kWh/year

8.3. Scenario 3 results

Scenario 3 extends Scenario 2 by integrating a Battery Energy Storage System (BESS) at the proposed Košuta photovoltaic power plant. The battery system, with an assumed storage capacity of approximately 60 kWh, is intended to store surplus photovoltaic electricity generated during daytime and make it available for overnight charging of the proposed electric passenger shuttle vehicle.

The combined installed photovoltaic capacity remains approximately 116 kWp, with an expected total annual electricity generation of around 161,500 kWh/year. The annual electricity demand of the proposed electric passenger shuttle vehicle remains 19,265 kWh/year, based on the selected routes, operating schedule and assumed vehicle energy consumption. The key energy performance indicators for this scenario are summarized in Table 8.3.

The integration of battery storage increases the utilization of locally generated renewable electricity by reducing electricity exports to the distribution grid and enabling a larger share of photovoltaic generation to be used directly for vehicle charging. Compared with Scenario 2, this scenario

improves system flexibility and energy self-consumption, although it also requires additional investment and a more advanced energy management system.

Table 8.3. Energy performance indicators for Scenario 2

Parameter	Value
Installed capacity	62 kWp
Annual PV generation	161 500 kWh/year
Annual shuttle bus demand	19 265 kWh/year

9. DISCUSSION AND INTERPRETATION OF RESULTS

The scenario analysis conducted for the City of Cetinje demonstrates that the integration of photovoltaic systems into the proposed electric passenger shuttle transport system is technically feasible and capable of supporting the electricity demand of the planned service. Both analysed scenarios provide sufficient renewable electricity generation to fully cover the estimated annual energy demand of the shuttle vehicle, while simultaneously creating additional renewable energy capacity that can be utilized by other consumers.

The results indicate that the annual electricity generation of both photovoltaic systems significantly exceeds the estimated annual electricity demand of the proposed shuttle service. This suggests that the available renewable energy capacity could support future expansion of the transport system, including the introduction of additional shuttle routes, increased service frequency, or the deployment of additional electric vehicles. Such flexibility is particularly important considering the potential growth of tourism-related transport demand in Cetinje.

From an implementation perspective, Scenario 1 represents the more practical short-term solution. The proposed rooftop photovoltaic installation on the Municipality Building benefits from the presence of an existing charging station in the immediate vicinity, reducing the need for additional charging infrastructure and limiting overall investment requirements. At the same time, the estimated annual electricity generation is sufficient to satisfy the energy requirements of the proposed shuttle service, making this scenario an attractive initial step toward transport electrification.

Scenario 2, based on the proposed “Košuta” photovoltaic power plant, represents a more ambitious long-term development option. Although it requires higher initial investment and additional infrastructure, it offers greater opportunities for future system expansion and integration with other local electricity consumers. This scenario may become particularly relevant if transport demand increases in the future or if the municipality decides to expand the electric shuttle network beyond the initially proposed routes.

Scenario 3 further extends the proposed system through the integration of a Battery Energy Storage System (BESS) at the Košuta photovoltaic power plant. By storing surplus photovoltaic electricity generated during daytime and using it for overnight charging of the shuttle vehicle, this scenario increases renewable energy utilization, reduces electricity exports to the distribution grid, and

improves overall system flexibility. Although additional investment is required, battery storage represents a logical future step toward maximizing the use of locally generated renewable electricity.

Overall, the results suggest that a phased implementation approach may be the most appropriate strategy for Cetinje. Under such an approach, the Municipality Building photovoltaic system could be implemented in the initial phase to support the introduction of the electric shuttle service. The proposed "Košuta" photovoltaic power plant could then be added as transport demand and renewable energy requirements increase, while battery energy storage may be introduced in a later phase to further improve renewable energy utilization and system flexibility.

10. ENVIRONMENTAL AND SOCIAL IMPACT

The proposed integration of photovoltaic systems and electric shuttle transport in Cetinje is expected to generate several environmental and social benefits. By replacing conventional fossil-fuel-based transport with an electric passenger shuttle vehicle supplied partially by renewable electricity, the system contributes to the reduction of greenhouse gas emissions and supports local climate objectives.

In addition to climate-related benefits, the use of an electric shuttle vehicle can contribute to improved local air quality and reduced noise levels, particularly in areas of high tourist activity such as the historic city centre, Rijeka Crnojevića, Njeguši and the Kotor–Lovćen Cable Car station.

The project also supports the broader transition toward renewable energy sources by increasing the utilization of locally generated solar electricity. Both analysed scenarios demonstrate that photovoltaic generation can fully satisfy the annual electricity demand of the proposed shuttle service while providing additional renewable electricity for other consumers.

From a social perspective, the proposed system may improve accessibility to major tourist attractions, including Njeguši, Rijeka Crnojevića and the Kotor–Lovćen Cable Car. Improved accessibility can enhance visitor mobility, support the development of sustainable tourism and contribute to local economic activity. The proposed shuttle service may also improve regional connectivity. In particular, the route serving the Kotor–Lovćen Cable Car enables passengers to continue their journey towards the coastal municipalities of Kotor, Tivat and Herceg Novi, thereby strengthening connections between Cetinje and the Montenegrin coast. In addition, the project may increase public awareness of sustainable transport solutions and renewable energy technologies.

Overall, the proposed system represents not only a transport improvement measure but also a contribution to the wider environmental, energy and sustainability objectives of the city.

11. IMPLEMENTATION ROADMAP

The implementation of the proposed photovoltaic-integrated electric passenger shuttle transport system in Cetinje should follow a phased approach in order to minimize investment risks and enable gradual development of the required infrastructure.

11.1. Phase 1 – Initial implementation

The first phase involves the introduction of the electric passenger shuttle vehicle and the installation of a rooftop photovoltaic system on the Municipality Building. This option benefits from the presence of an existing charging station in the immediate vicinity, reducing infrastructure requirements and enabling a relatively rapid implementation. The primary objective of this phase is to establish operational experience with electric mobility while utilizing locally generated renewable electricity.

11.2. Phase 2 – System expansion

The second phase considers the implementation of the proposed "Košuta" photovoltaic power plant. This phase may be justified if transport demand increases in the future through the introduction of additional shuttle routes, increased service frequency or the deployment of additional electric vehicles. The larger generation capacity of the Košuta system would provide additional renewable electricity and support the long-term expansion of the transport system.

11.3. Risk assessment

Potential implementation risks include investment costs, uncertainty regarding future transport demand, photovoltaic generation variability and regulatory procedures related to renewable energy projects. These risks can be reduced through a phased implementation approach, early stakeholder involvement and the use of available national and European funding mechanisms.

Overall, the proposed roadmap enables a gradual transition towards sustainable mobility and renewable energy utilization in Cetinje. The phased approach allows the municipality to address current transport needs while minimizing initial investment requirements and implementation risks. At the same time, it preserves sufficient flexibility for future expansion of both the transport and energy systems in response to growing tourism demand, evolving mobility requirements and future sustainability objectives.

12. CONCLUSION AND RECOMMENDATIONS

This feasibility study demonstrates that the integration of photovoltaic systems into the proposed electric passenger shuttle transport system in Cetinje is technically feasible and has the potential to generate environmental, social and economic benefits.

The analysis showed that the estimated annual electricity demand of the proposed shuttle service amounts to approximately 19,265 kWh/year. Three photovoltaic integration scenarios were analysed to evaluate different levels of renewable electricity supply for the proposed transport system. The Municipality Building rooftop photovoltaic system, with an installed capacity of 54 kWp, is expected to generate approximately 80,000 kWh/year. The combined photovoltaic systems in Scenario 2 have a total installed capacity of approximately 116 kWp and an expected annual electricity generation of around 161,500 kWh/year.

Scenario 3 further enhances the proposed system through the integration of a Battery Energy Storage System (BESS) at the Košuta photovoltaic power plant. Although it requires additional investment, battery storage increases renewable energy utilization and system flexibility by

enabling surplus photovoltaic electricity to be stored and used for overnight charging of the shuttle vehicle.

The obtained results indicate that all three scenarios are capable of fully supporting the energy requirements of the proposed shuttle service. Furthermore, the available photovoltaic generation creates opportunities for future system expansion, including additional shuttle routes, increased service frequency or the introduction of additional electric vehicles.

From an implementation perspective, Scenario 1 represents the most practical short-term solution. The presence of an existing charging station in the immediate vicinity of the Municipality Building reduces infrastructure requirements and enables a relatively straightforward implementation process. At the same time, the available photovoltaic generation is sufficient to support the planned transport service.

Scenario 2 represents a logical continuation of Scenario 1, providing greater renewable electricity generation capacity and creating opportunities for future expansion of both the transport and energy systems. Although it requires higher investment and additional infrastructure, it may become increasingly relevant if tourism-related transport demand continues to increase.

Beyond the direct transport benefits, the proposed system contributes to greenhouse gas emission reduction, improved local air quality, reduced noise levels and increased utilization of renewable energy sources. The project may also improve accessibility to key tourist destinations and strengthen regional connectivity through integration with the Kotor–Lovćen Cable Car system.

Based on the obtained results, it is recommended that implementation begins with Scenario 1, followed by a gradual expansion toward Scenario 2 as transport demand increases. Scenario 3 may be considered in a later development phase to further improve renewable energy utilization through battery energy storage. Such a phased approach minimizes implementation risks, reduces initial investment requirements and provides sufficient flexibility for future development.

Overall, the proposed system represents an important opportunity for Cetinje to promote sustainable mobility, renewable energy utilization and sustainable tourism development while supporting the city's broader environmental and development objectives.