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Abstract

The Republic of Serbia has a strategy to reduce greenhouse gas emissions in the energy sector and increase the participation of renewable energy sources in the gross final energy production. The total estimated technically usable solar energy potential of Serbia is 0.240 Mtoe per year. The energy potential of solar radiation is about 30% higher in Serbia than in Central Europe and the solar radiation intensity is among the highest in Europe (Mikić & Jovanović, 2017). The main objective of this paper is researching the potential, possibilities and advantages of installing solar power plants on public parking lots and on roof tops of public parking garages in combination with charging stations for electric vehicles in Serbian cities. Increasing dependence on cars has led to a large increase in parking spaces and today parking lots occupy large areas of valuable urban land. Implementing solar canopies provide an opportunity to use the land more efficiently and addresses multiple urban challenges like energy production, thermal mitigation but also aesthetics improvement. Asphalt and concrete in parking lots absorb and retain significant amount of heat, contributing to the Urban Heet Island (UHT) effect. Solar canopies reduce the heat absorption of these surfaces providing shade and reflecting sunlight. They also protect vehicles from the sun and time elements which results having cooler cars and reducing air conditioning use by drivers. Equipped with electric vehicle charging stations, solar canopies promote sustainable transport. Good architectural design of solar canopies can enhance the visual appeal of parking lots making them more attractive. They also visibly promote commitment to sustainability.

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1 INTRODUCTION

The EU has implemented a legally binding framework to achieve the goals of the 2015 Paris Agreement, setting ambitious targets for 2030 regarding renewable energy, energy efficiency, and greenhouse gas emissions reduction. Like EU member states, Energy Community contracting parties, including the Republic of Serbia, are required to develop Integrated National Energy and Climate Plans to monitor and report on these sectors. The signing of the Sofia Declaration on the Green Agenda for the Western Balkans additionally, obliges Serbia to develop an Integrated Energy and Climate Plan. In April 2021, Serbia adopted several energy and mining laws including the Law on the Use of Renewable Energy Sources, the Law on Energy Efficiency and Rational Use of Energy, and amendments to the Law on Mining and Geological Research and the Law on Energy. These laws mandate the creation of an Integrated National Energy and Climate Plan (INECP), and monitoring and reporting on INECP its implementation (www.mre.gov.rs, 2023).

Serbia currently obtains about 70% of its electricity from coal-fired power plants and the remaining 30% from hydropower plants, with wind and solar power accounting for less than 4%. This production structure is not sustainable in the long term due to environment impacts and aging of coal-fired power plants. The strategic directions for Serbia's energy development should be energy independence, ecologically and energy sustainability and the path should be the adoption of renewable energy sources (RES) like hydro, wind, and solar power. Although investment costs for the RES technologies are higher than the construction of conventional systems it's important to consider that there are no fuel costs for wind and solar radiation or depletion over time which, making this strategy economically advantageous in the long run. (Đurišić & Škrbic, 2022).

The energy potential from solar radiation in Serbia is approximately 30% greater than that in Central Europe, and the intensity of solar radiation ranks among the highest in Europe (Mikić & Jovanović, 2017).

The main objectives of this paper will be researching the potential, possibilities and advantages of installing solar power plants on public parking lots and on roof tops of public parking garages in combination with charging stations for electric vehicles in Serbian cities. Grid capability will be considered. Analysis and evaluation of the ecological, social and economic impact of such plants will be conducted with focus on two case studies and results will be presented.

Public parking lots and garages refers to the publicly accessible parking spaces available in Serbia. To determine and assess the potential of installing solar power plants on these sites this paper will address several questions:

- Which parking locations in Serbia are suitable for solar PV installation?
- Should we integrate energy storage systems?
- How many full-load hours can we expect on a monthly base and per year for electricity generation?
- What is the environmental impact of this technology?
- What is the social impact of this technology?
- What is the electrical efficiency of this technology?
- Is this technology economically viable and suitable for financial investment?

To answer this questions, few steps have been taken:

1. **Site Assessment:** Evaluating the suitability of a parking location for solar PV installation, considering factors such as sunlight exposure, shading, and available space.

2. **System Design:** Designing and optimizing the PV system layout, including the number and placement of solar panels, mounting structures, and electrical infrastructure.

3. **Energy Storage:** Integrating energy storage systems, such as batteries, to store excess solar energy for use during periods of low sunlight or high demand.

4. **Load Management:** Managing the electrical load and demand of the parking facility, including charging stations for electric vehicles, to maximize the utilization of solar energy.

5. **Social Impact:** Evaluating the social impact of PV parking.

6. **Economic Analysis:** Assessing the financial viability of the PV parking project, considering factors such as installation costs, energy savings and return on investment.

7. **Environmental Impact:** Evaluating the environmental impact of the PV parking system.

2 DETERMINATING STATE OF ART AND POTENTIALS

2.1 Method of approach

This work is based on research from various literature sources (scientific literature, industry reports, government websites, company websites, online forums and communities) and consulting experts from the industry.

2.2 State of Art

Solar carports on parking lots (PV canopies) are becoming more and more popular in many countries in EU and around the word. Germany and France are at the forefront of the way with adopting regulations requiring new parking spaces to include photovoltaic installations. The new law on the production of renewable energy sources in France requires that all existing and new parking lots that can accommodate at least 80 vehicles must install solar panels. Owners of parking lots from 80 to 400 spaces have five years to conform to these regulations, whereas those with larger capacities have a three-year deadline. At least half of the area the surface of these parking lots must be covered with solar panels (balkangreenenergynews, 2023). These regulations show a strong commitment to renewable energy sources and recognize the significant potential of solar canopies in urban planning. France aims to generate up to 11 GW of energy by covering parking lots with solar panels (Stumbraite, 2024).

Germany and France are at the forefront of adopting regulations that mandate the inclusion of photovoltaic installations in new parking spaces. In France, a new law on renewable energy production stipulates that all existing and new parking lots with the capacity to hold at least 80 vehicles must install solar panels. Lot owners with 80 to 400 spaces have five years to conform to these regulations, whereas those with larger capacities have a three-year deadline.

In Europe 3,2 million new electric cars were registered in 2023, which is almost 20% more relative to 2022 (IEA, 2024). EVs in Europe will rise from about 16% market share in 2023 to 65% in 2030 (Winton, 2024), making the need for development of a robust charging infrastructure essential.

In Serbia presence of PV carports is still under development. In Belgrade, Novi Sad and other major cities in Serbia, there are initiatives to improve energy efficiency and reduce pollution and there have been more and more investments in renewable energy sources, including solar panels, but specific projects involving solar carports on parking lots are not yet widespread.

Several commercial establishments and shopping centers are considering such projects in bigger scale, but till the present day, only few private companies have smaller scale PV carports in operation on their sites, rated capacity 10 – 22 kW. This is a positive sign but do not have a real impact on energy transition.

“Parking servis” Belgrade, a public city company that manages public parking lots in Belgrade, has outfitted the rooftops of its "Obilićev Venac" and "Zeleni Venac" garages with solar power systems, providing the buildings with electrical power. The 30 kW solar power system on the rooftop of “Zeleni Venac” garage, comprises 155 PV panels, manufactured by “Canadian Solar“. The system features a smart meter device that controls the inverter's operation, adjusting its power to match the garage's demand and ensuring no electricity is fed back into the grid (balkangreenenergynews.com, 2019). During the reconstruction in 2016, garage Obilicev Venac was transformed into a facility with 804 parking spaces, solar power system on the rooftop 50,4 kW, six 22 kW EV charging stations, and a waste sorting system. The solar power plant produces electricity for its own needs, which means that the electricity produced is consumed by consumers within the facility. The solar power plant operates in parallel with the distribution system (Biljana Vlajić "Parking servis" Beograd, 2024).

Figure 1: Garage Obilicev Venac (Biljana Vlajić "Parking servis" Beograd, 2024)

On the roof of the public garage in Kragujevac in 2020 was installed a solar power plant with a power of 74 kW and consists of 260 of polycrystalline photovoltaic panels with a single power of 285 W. Three EV charging stations was installed. The electrical energy that is producing by this PV plant is used to power the facility, while excess energy is stored in batteries with a capacity of 100 kWh (Energetski portal, 2020).

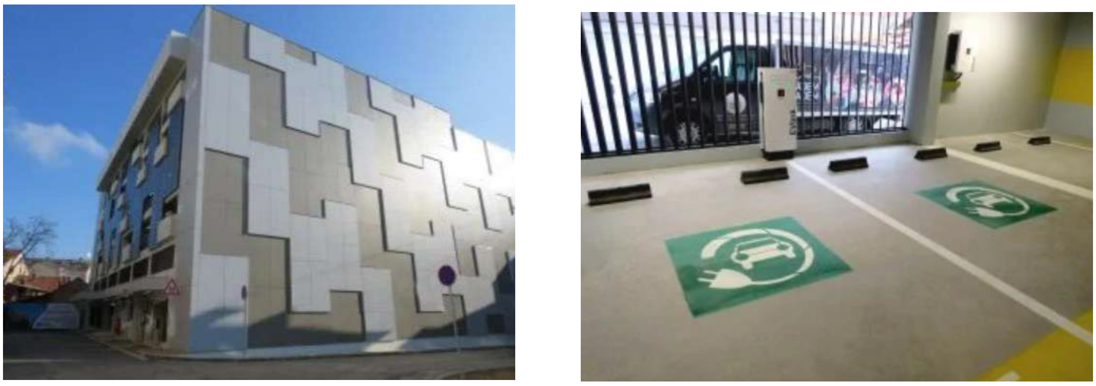

Figure 2: Public garage in Kragujevac, Kneza Miloša street (Energetski portal, 2020)

On public parking lots, state of art is that there is not one PV carport installed yet, even in cases when there are installed charging stations for electric vehicles (EV). On the other side, a few public garages in major Serbian cites have already installed PV plants on rooftops and this is becoming a trend. The main reason for this could be complicated permitting procedure in Serbia for PV carport over 20m2 (a building permit is required), opposite to rooftop PV installations where this procedure is simplified. Other reason could be found in specific investment costs (EUR/MW) that are almost double compered to investment cost for rooftop PV installations.

2.3 Potential for parking lot PV in Serbia

The development of industry and competitive market of photovoltaic systems and wind turbines led to a drastic reduction in investments and operating costs for these technologies. According to International Renewable Energy Agency, costs of electricity production from photovoltaic energy plants reduced almost 10 times between 2010 and 2022. The levelized cost of energy (LCOE) in solar and wind power plants primarily depends on potential wind and solar energy and in many regions, they are already very competitive with conventional power plants. The advancement of technologies and incentive systems has led to intensive construction of wind and solar power plants globally. Consequently, the competitiveness of renewable power generation technologies increased significantly especially for solar photovoltaics and onshore wind. Energy security benefits of renewable power were also highlighted. The 2022 fossil fuel price crisis in Europe had global implications for energy prices. In Europe, the renewable capacity added since 2010 reduced electricity generation costs by USD 176 compared to what they would have been without it (IRENA, 2023).

It is estimated that Serbia would need about 300 MW installed in wind power farms and about 250 MW installed in photovoltaic power plants to be at the average level for a country power system in Europe (Đurišić & Škrbic, 2022).

For designing and implementing PV system it is very important to calculate Sun radiation potentials for the location. utilizing analytical data from accessible measurement databases like the Photovoltaic Geographical Information System (PVGIS) is adequate.

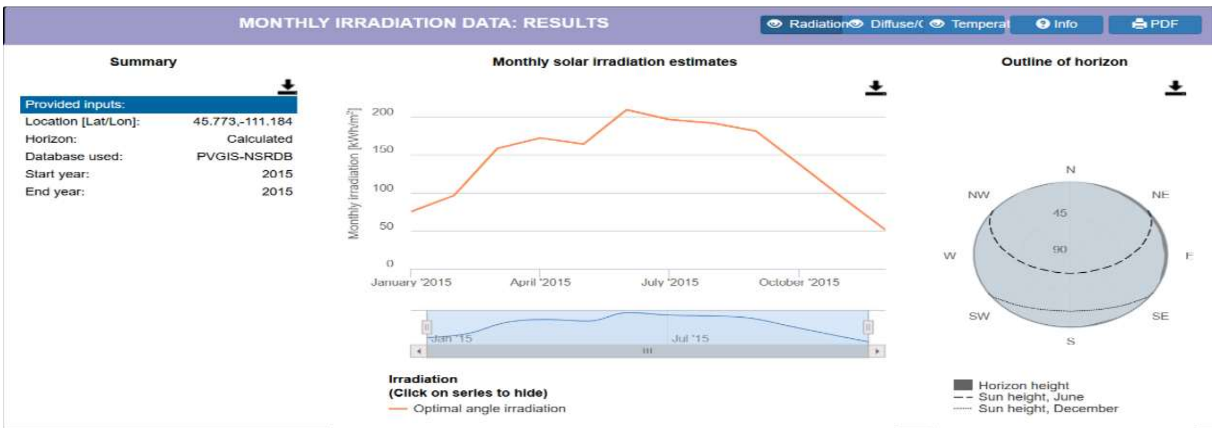

Figure 3: Monthly solar Irradiation estimates for Belgrade (Serbia) from Source: (PVGIS, n.d.)

The energy potential of solar radiation in Serbia is approximately 30% greater than in Central Europe, with some of the highest solar radiation intensities in Europe. Due to its latitude, positioned between 42 and 45.5 degrees North, Serbia experiences significantly higher global solar radiation during the summer months. (Mikić & Jovanović, 2017) with long periods of daylight, including direct sunlight and diffused sunlight. During the winter levels of radiation are much lower, and daylight hours are shorter.

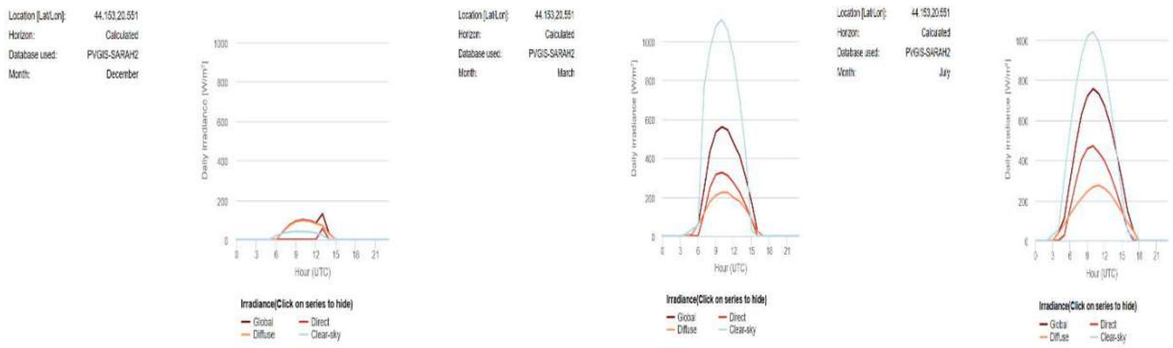

Figure 4: Daily average irradiance in different season in Serabia (module angle 41°). Source: (PVGIS, n.d.)

The average daily energy received from global radiation in Serbia, on a flat surface, during winter varies from 1.1 kWh/m2 in the north to 1.7 kWh/m2 in the south. In summer, this range increases from 5.4 kWh/m2 in the north to 6.9 kWh/m2 in the south (Mikić & Jovanović, 2017). The annual average solar radiation energy varies from 1,200 kWh/m² in the northwest of Serbia to 1,550 kWh/m² in the southeast. The central region has an average of approximately 1,400 kWh/m² per year, indicating a significant energy potential. ("Službeni glasnik RS", 2015).

The technical solar potential in Serbia is estimated at approx. 24 GWp, with roughly half of that on rooftops. Estimated annual production of electricity from solar capacity is about 30.5 TWh (Đurišić & Škrbic, 2022).

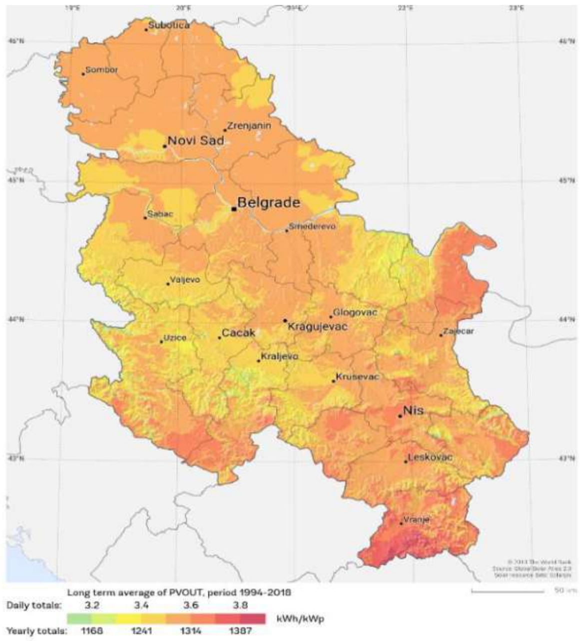

Figure 5: Photovoltaic Electricity Potential in Serbia. Source: (solargis.com, 2018)

Solar energy is available at any location and has significantly less spatial variability compared to wind energy. The main limitation in the installation of photovoltaic systems is the relatively low specific power per area unit, which requires large areas.

There are two basic approaches for the construction of photovoltaic systems: installations on the roofs of industrial, commercial, residential and other buildings and installations on structures on the ground. Expected annual production of photovoltaic panels in Serbia on roof surfaces ranges from 1.100 to 1.300 MWh/MWp, Table 1, depending on the orientation of roof surfaces, the presence of shadows and the region where the panel is installed (Đurišić & Škrbic, 2022)

Table 1: Full Load Hours of PV systems on rooftop (h) in Serbia by regions (Đurišić & Škrbic, 2022)

Region no.	Region	Full Load Hours of PV systems on rooftop (h)
1.	Western Bačka region	1175
2.	North Bačka region	1179
3.	North Banat region	1178
4.	Southern Bačka region	1184
5.	Middle Banat region	1185
6.	Srem region	1177
7.	South Banat region	1187
8.	Mačva region	1169
9.	Belgrade region	1186
10.	Kolubara region	1162
11.	Danube region	1178
12.	Braničevo region	1183
13.	Zlatibor region	1228
14.	Morava region	1178
15.	Šumadija region	1182
16.	Pomoravlje region	1187
17.	Bor region	1227
18.	Raška region	1196
19.	Rasina region	1188
20.	Nišava region	1224
21.	Zaječar region	1247
22.	Toplica area	1251
23.	Jablanica region	1220
24.	Pirot area	1248
25.	Pčinj region	1268
	SERBIA (without Kosovo)	**1198**

Structures placed on the ground are positioned for optimization their azimuth and tilt angle, resulting in higher expected annual production per unit of installed capacity compared to the average roof installations, ranging from 1.400 to 1.500 MWh/MWp, Table 2, depending on installation region (Đurišić & Škrbic, 2022).

Table 2: Full Load Hours for ground mounted PV systems (h) in Serbia by regions (Đurišić & Škrbic, 2022)

Region no.	Region	Full Load Hours for ground mounted PV systems (h)
1.	Western Bačka region	1412
2.	North Bačka region	1417
3.	North Banat region	1416
4.	Southern Bačka region	1423
5.	Middle Banat region	1424
6.	Srem region	1413
7.	South Banat region	1426
8.	Mačva region	1399
9.	Belgrade region	1418
10.	Kolubara region	1416
11.	Danube region	1402
12.	Braničevo region	1423
13.	Zlatibor region	1459
14.	Morava region	1411
15.	Šumadija region	1415
16.	Pomoravlje region	1426
17.	Bor region	1483
18.	Raška region	1412
19.	Rasina region	1408
20.	Nišava region	1472
21.	Zaječar region	1479
22.	Toplica area	1469
23.	Jablanica region	1473
24.	Pirot area	1494
25.	Pčinj region	1526
	SERBIA (without Kosovo)	**1436**

In this paper rooftop PV installations on public garages are considered, as well as PV installations on carports on public parking lots. The latter have certain features from both approaches. The certain position and size of the parking lots and surrounding buildings has a great influence in the planning of these power plants, but on the other hand, we build and plan the construction ourselves, on the ground, and are not conditioned by the orientation, load-bearing capacity and shape of the roof.

When considering rooftop photovoltaic systems and their potential installed power, it's essential to assess factors such as module efficiency, roof orientation and slope, available space, and local energy infrastructure to determine the optimal design and capacity for a specific location. In terms of geometry, the basic division of rooftop photovoltaic systems is related to the pitch of the roof surface, distinguishing between flat and sloped roof surfaces. For flat roof surfaces, the entire area can be technically used for installing photovoltaic panels. In the case of sloped roofs, parts of the roof surface that are oriented south are usually suitable and economically justified for installing photovoltaic panels.

The most commonly used solar modules are monocrystalline (Sc-Si) or polycrystalline (Mc-Si) silicon. In commercial application solar panels made of Sc-Si modules have efficiency level 13-21% and Mc-Si PV panels 11%-15% at standard test conditions (STC) (Hartung Katalin, 2014). Further development of photovoltaic conversion technologies can lead to an increase in efficiency, which would allow better utilization of roof surfaces for the solar power plants production.

Public parking lots Serbia refers to the publicly accessible parking spaces available in Serbia. These parking lots and public garages are typically managed by local governments or private companies and are open for use by the public. They may be located in various urban areas, such as city centers, shopping malls, residential neighborhoods, and near public transportation hubs. The availability, pricing, and regulations for using public parking lots and garages in Serbia can vary depending on the specific location and the managing entity. Some may be free to use, while others may require payment through meters, mobile apps, or other methods.

Advantage for these locations is that electrical infrastructure in urban areas is capable of absorbing significantly larger amounts of energy from photovoltaic systems compared to rural areas with weak distribution networks. In Belgrade there are 19 public parking lots on the total area of 83.967,9 m2 and 9 public garages with average roof area about 400 m2 managed by city company “Parking servis” Belgrade (Biljana Vlajić "Parking servis" Beograd, 2024). Novi Sad has 3 garages, and more than 7 parking lots managed by JKP “Parking servis” Novi Sad. It is similar in all other cities in Serbia, but number and surfaces of parking lots and garages varies in correlation with the size of the cities.

Assuming that it is possible to install a PV carport on half of the area (because of the shape and the micro location of the parking lots, the access lanes, etc.), the total installed power of PV power plants, only on the public parking lots managed by “Parking servis” Belgrade, would be close to 9 MW with yearly PV energy production around 11.250 MWh, Figure 6.

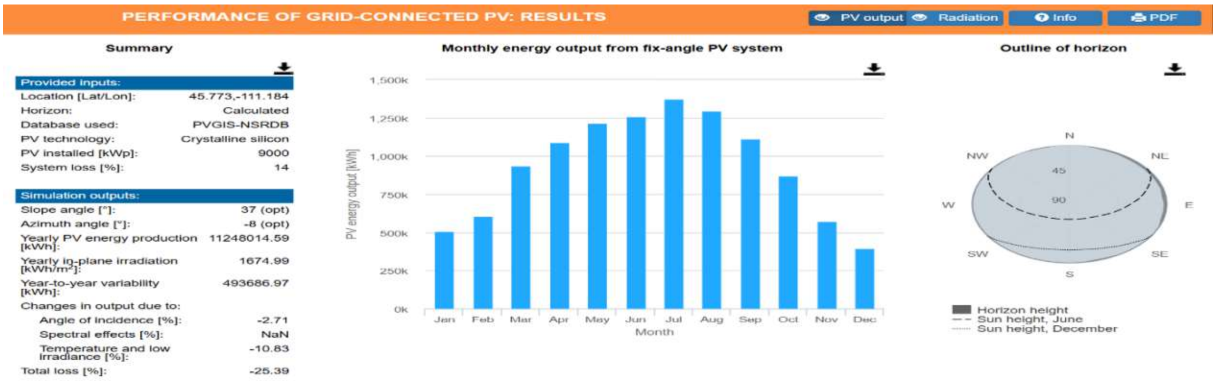

Figure 6: Performance of grid connected PV carports total installed power 9 MW in Belgrade. Source: (PVGIS, n.d.)

2.4 Potential for the Electric Vehicle Charging Stations on parking lots and garages in Serbia

Battery electric vehicles (BEVs) are gaining popularity thanks to their environmental benefits and improvements in battery technology. They run on electricity stored in a large traction battery pack, which powers an electric motor. To recharge, battery needs to be connected to a wall outlet or charging station, called electric vehicle supply equipment (EVSE). This charging infrastructure is crucial for the broad acceptance of electric vehicles and plays a key role in supporting sustainable transport.

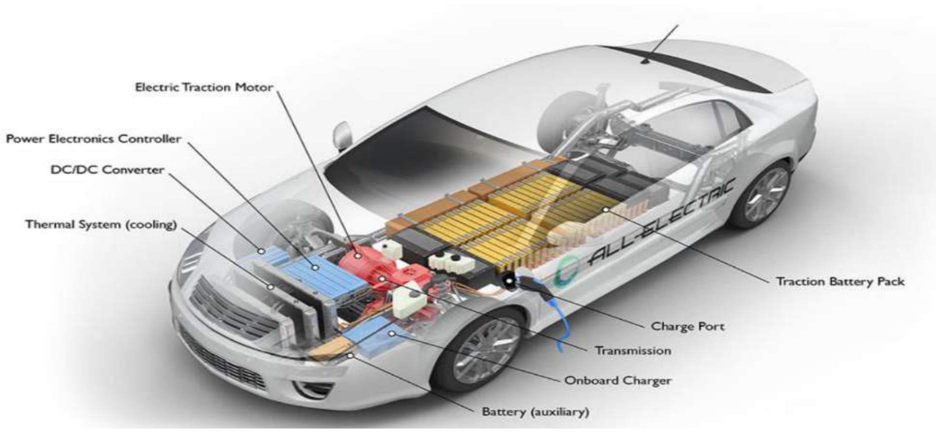

Figure 7: Battery electric vehicles (BEV). Source: (U.S. Department of Energy, n.d.)

BEVs usually can't travel that far on a single charge as traditional vehicles do on a full tank of gas. However, as new models with better batteries and faster charging technology become available, this difference is decreasing. Efficiency and the range of electric vehicles can vary depending on factors such as driving conditions and external temperature. Electric cars are more efficient in city driving because they can take advantage of frequent stops for regenerative braking (U.S. Department of Energy, n.d.).

Consumers considering electric vehicles need access to charging stations. For most drivers, this begins with home charging. The availability of charging stations at workplaces and public destinations can help strengthen the market acceptance by offering more versatile charging options at at locations people often visit.

The EU Commission has established ambitious CO2 reduction goals for the transport sector with the "Fit for 55 Package," introduced in July 2021. The EU's goal is to cut emissions by at least 55% by 2030 from 1990 levels, striving to become the world's first climate-neutral continent by 2050. The transport sector, accounting for nearly 20% of the EU's total greenhouse gas emissions, is expected to play a key role in achieving these reductions. New regulations include a 55% CO2 emissions reduction target for passenger cars and trucks by 2030, with a 30% reduction target for trucks reviewed in 2022. To achieve these objectives, a substantial share of new passenger and commercial vehicles sold by 2030 must be electric vehicles (EVs), necessitating the development of an electric vehicle charging infrastructure in Europe (ACEA, 2022). The EU needs to install an average of 6,000 public charging points per week from 2021 to 2030 to meet these goals. Last year, France and Germany were leading in installing public electric vehicle chargers in the European Union, but EU is still falling short of the required rate for charger installation (McKinsey, 2022).

Serbia is also obliged to develop policies for sustainable mobility. Key tasks for municipalities and cities are promotion of electric mobility and creating a strategic e-mobility plan. For switching to zero-emission electric transport planning and installing appropriate EV charging infrastructure is a key step.

The number of electric vehicles in Serbia is slowly increasing. As of February 20, 2024, a total of 2.699 BEVs and about 18.000 hybrid vehicles were registered in Serbia. The percentage of electric vehicles in Serbia is still low, around one percent of the total vehicle fleet, which indicates that the country lags the EU average of 12 to 14%. The infrastructure for charging these vehicles in Serbia is still developing and is very much behind countries like Norway, Germany, Slovenia and Croatia by the number of public charging points per 100.000 inhabitants. Although there are between 120 and 130 public chargers in Serbia, this is considered insufficient for the existing number of electric vehicles in Serbia, especially when considering the foreign drivers of electric vehicles passing through the country (Bloomberg Adria, 2024). Using the assumption from EV industry that there should be 1 public AC charger per 10 electric vehicles and 1 public DC charger per 100 electric vehicles (CleanTechnica, 2017), in this moment, Serbia needs at least to double the number of installed EV chargers.

To improve EV charging infrastructure, the number of public chargers should increase, with ensuring operation 24/7, enabling easy payment options, providing different types of connectors at charging stations and high-power chargers installed. Recent legislation mandates that a certain percentage of parking spaces in residential and commercial buildings must have electric chargers.

Different types of EV users have different charging needs, with around 80% of charging in the world is typically done at home. Workplace charging is also important. In 2021, 42% of European EV owners in cities did not have these possibilities for charging and instead relied on public chargers (McKinsey, 2022). In Serbia, 70% EV owners are relying on public chargers. The challenge is the high cost of public charging, which is typically 30 to 200% more expensive than private charging. To ensure a fair transition to an all-electric Europe, it is essential to have an equitable rollout of public chargers in all neighborhoods and fair pricing for those without private access. Public charging networks should offer convenient locations and fast charging options, such as 22 kW charging stations, Combined Charging System (CCS) and CHArge de MOve (CHAdeMO) DC fast chargers for optimal use (CleanTechnica, 2017).

There are some concerns regarding public charging. Drivers often struggle to locate chargers. The creation of real-time dashboards with centralized information could be an effective approach. Accessing chargers can be difficult due to plug incompatibility and availability issues. To address this, enforcing restrictions and using time-based restrictions are recommended to avoid chargers' occupancy by fully charged vehicles. Standardizing billing costs, payment methods, regarding safety and comfort of charging point location, could reduce consumer anxiety and improve the interoperability of charging stations (McKinsey, 2022).

As mentioned in chapter 2.3 public parking lots and garages in Serbia are managed objects, usually in dents urban areas, publicly accessible 24/7 and should be very much considered as locations for public EV charging stations.

The development and maintenance of charging infrastructure requires careful planning, cost analysis and operational support to ensure an efficient and reliable service for electric vehicle users. The costs and revenue sources associated with EV charging infrastructure is essential for developing sustainable business models in this sector.

Setting up a charging infrastructure involves:

1. Fixed costs:
 - Site selection, approvals and contracts required.
 - Construction works for connecting to the network and installing chargers.
 - Chargers - AC chargers cost around 500 EUR for private use and 1.500+ EUR for public use; Fast DC chargers cost over 25,000 EUR each, with installation costs potentially reaching 40.000 EUR (CleanTechnica, 2017).
 - Charges for electricity connection (fee paid to the DSO based on the kW power connection) can significantly affect the total costs.

2. Variable costs:
 - Energy costs.
 - Maintenance - IT software and on the physical unit.
 - Operations (billing, invoicing, customer support) - crucial for the smooth operation of a charging service business and require significant resources and personnel.

Revenues from EV charging station:

1. Charge for energy or time in combination with the utilization of the charger.
2. Advertising on the charging station. (CleanTechnica, 2017)

Table 3: Example of the costs vs revenue. Source: (CleanTechnica, 2017)

	Scenario					Profitability	
Fast charger (DC)	Initial investment	Customer facing price in kWh	Costs of electricty	Utilization scenario	Daily utilisation in hours (lifetime average)	NPV (Net Present Value)	IRR (Internal Rate of Return)
low prices and utilisation	€25 000	€0,26	€0,18	50%	2,4	-€7 927	2%
medium prices and utilisation	€25 000	€0,34	€0,18	100%	4,8	€19 321	25%
high prices and utilisation	€25 000	€0,43	€0,18	150%	7,2	€47 551	44%
Standard charger (AC)							
low prices and utilisation	€2 500	€0,20	€0,18	50%	3,8	-€1 962	-14%
medium prices and utilisation	€2 500	€0,25	€0,18	100%	7,6	€4 918	39%
high prices and utilisation	€2 500	€0,30	€0,18	150%	11,5	€17 532	87%

Adjusting electricity price for EVs and utilization will help developing sustainable business model as we can see from Table 3.

"*Smart charging is a data-driven model of communication between an electric vehicle and a charging station that provides the parties involved with insights into the charging process and energy use.*" (Yalantis, 2024).

Smart technology solutions, such as real-time monitoring, adaptive load management and dynamic energy distribution systems, improve the efficiency of electric vehicle charging infrastructure by optimizing energy use and minimizing waste, Figure 8.

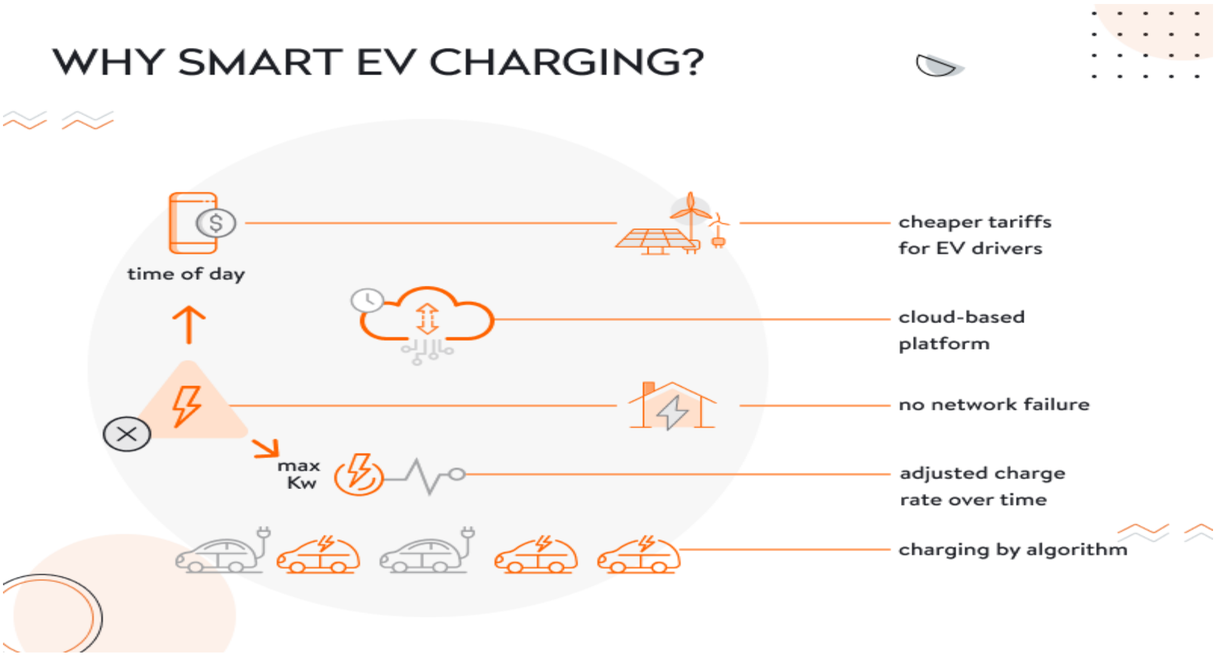

Figure 8: EV smart charging schematic picture. Source: (Yalantis, 2024)

2.5 Grid capability in Serbia

Electric networks (grids) are an essential part of electro power system, which includes production, transmission and distribution of electricity to end consumers. These consumers include various direct recipients of electricity, such as lighting, motor drives, thermal receivers, chemical industry receivers, households, etc. The grids ensure a continuous supply electricity to consumers and consist of interconnected objects and conductors at the same rated voltage. They are composed of electrical conductors equipped with devices for connection, disconnection, measurement, protection and transformers that increase or decrease the voltage in the transmission and distribution of electricity (Brankovic, 1999).

In electrical networks, there are standard voltage supply values, which are:

- Low voltage networks (380/220 V)

- Medium voltage networks (3.6, 10, 20, 35 kV)

- High voltage networks (110 and 220 kV)

- Very high voltage networks (400 kV)

Depending on the function in the electro power system there are:

- Transmission networks - transmit high power over long distances (hundreds and thousands of kilometers), on high and very high voltage networks. They usually terminate at main transformer stations (e.g. 400/110 kV).

- Power supply networks - transmit power at high voltage, from main transformer stations to individual consumption cores, i.e. substations (e.g. 110 kV/10 kV). The lengths of lines in this case are up to several tens of kilometers.

- Distribution networks - distribute power within consumption areas, all the way to consumers, on medium and low voltage networks.

- Consumer networks - directly power consumers, i.e. various electrical appliances of small ones, such as household appliances, or slightly higher powers, such as industrial plants. They are in direct contact with users and operate at low voltages (3 kV, 6 kV, 10 kV) to ensure a high level of protection.

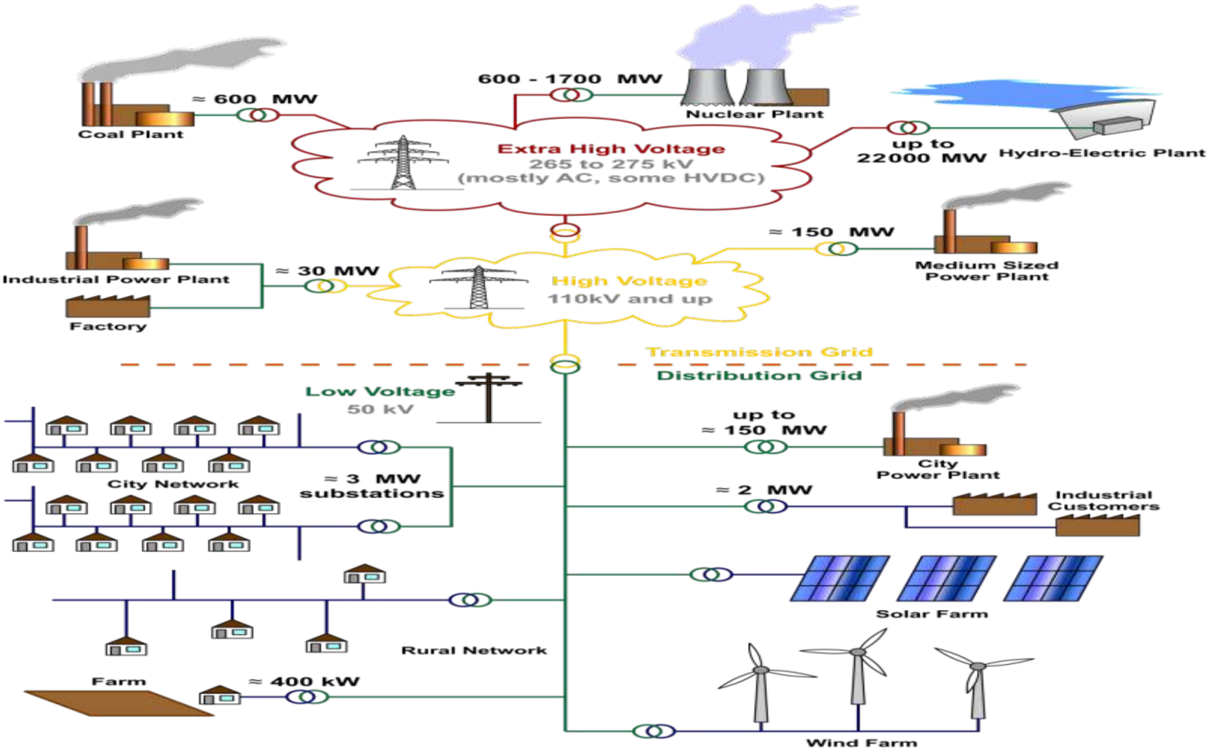

Figure 9: Electricity grid schematic picture. Source: (creativecommons, n.d.)

In 1958 the transmission of electrical energy in Serbia was defined as a separate electro-technical activity with specific technology and technical equipment by the Government. In early 1958, the electrical transmission network in Serbia was 1.815,5 km long with an installed power of 286,5 megavolt-amperes. Over time, the installed capacity in the transmission system increased to over 17.000 megavolt-amperes, whereby the high-voltage transmission network is now more than 9.800 km long (Elektroenergetika, 2018).

The development of the transmission network in Serbia began after World War II, with the construction of larger power plants and increased demand for electricity. The establishment of the specialized electricity transmission company “Elektroistok” helped unify the regional systems in Serbia into an integrated power system. Significant advances were made in transmission technology, including the establishment of a 220 kV transmission line in 1960 and the later introduction of a 400 kV transmission network. The construction of the 400 kV network marked a turning point in the modernization and expansion of the electricity transmission system, which led to an increase in security and connectivity with other European energy systems (Elektroenergetika, 2018).

„*Main purpose of the transmission system, along with the distribution system, is to enable reliable transmission of electricity from production facilities to end customers, as well as the international electricity exchange*” (EMS RS, 2024).

Similar to other parts of Balkan, the grid in Serbia is still not ready to handle with renewable electricity production systems. As the country has been relying on conservative, “baseload”, technology of coal-fired power generation for years and considering the bad economic situation in the country caused by sanctions and wars during the nineties, not enough has been invested in the maintenance of the existing network for years. This has been changing for the last twenty years and, in the efficiency of the transmission, network has significantly improved. Transmission system losses have declined from approximately 4% in 1998-99 to 2.8% in 2007, but building a modern grid ready to handle the loads of unpredictable renewable generations requires serious time, effort and financial resources

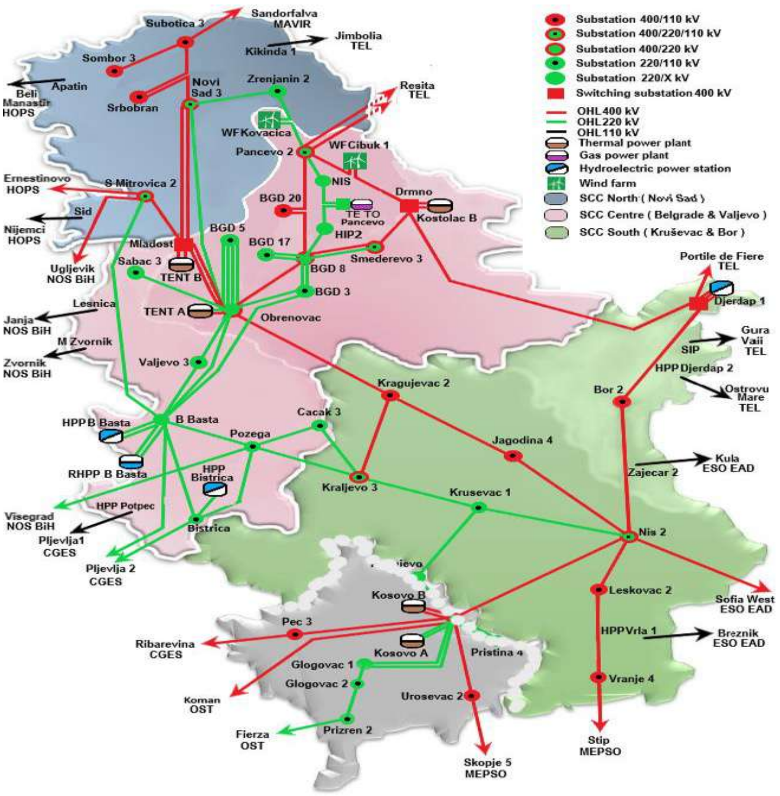

Figure 10: Transmission system in the Republic of Serbia plus Kosovo[1]. Source: (EMS RS, 2024)

Public company “Elektromreža Srbije” is operating transmission system in the Republic of Serbia that includes overhead power lines, cables, substations and switching stations at 400 kV, 220 kV levels and 110 kV, with the exception of 110 /x kV substations as they are part of the distribution system, (EMS RS, 2024), Figure 10.

[1] *This designation is without prejudice to positions on status and is in line with UNSCR 1244 and ICJ Opinion on the Kosovo Declaration of Independence*

In this paper, focus will be on distribution system in the Republic of Serbia, because this part of grid is much more affected, and their capacities are important for the technologies described.

Distribution system in the Republic of Serbia is operated by company “Elektrodistribucija Srbije” d.o.o. (EDS). The electric distribution activity is conducted through 33 branches, distributed on a territorial principle: Novi Sad, Belgrade, Kraljevo, Niš and Kragujevac, Figure 11. The total length of the medium-voltage network of EDS (35, 20 and 10 kV) at the end of 2023 was 52.243 km, while the low-voltage network reached 115.045 km (EDS, 2024) .

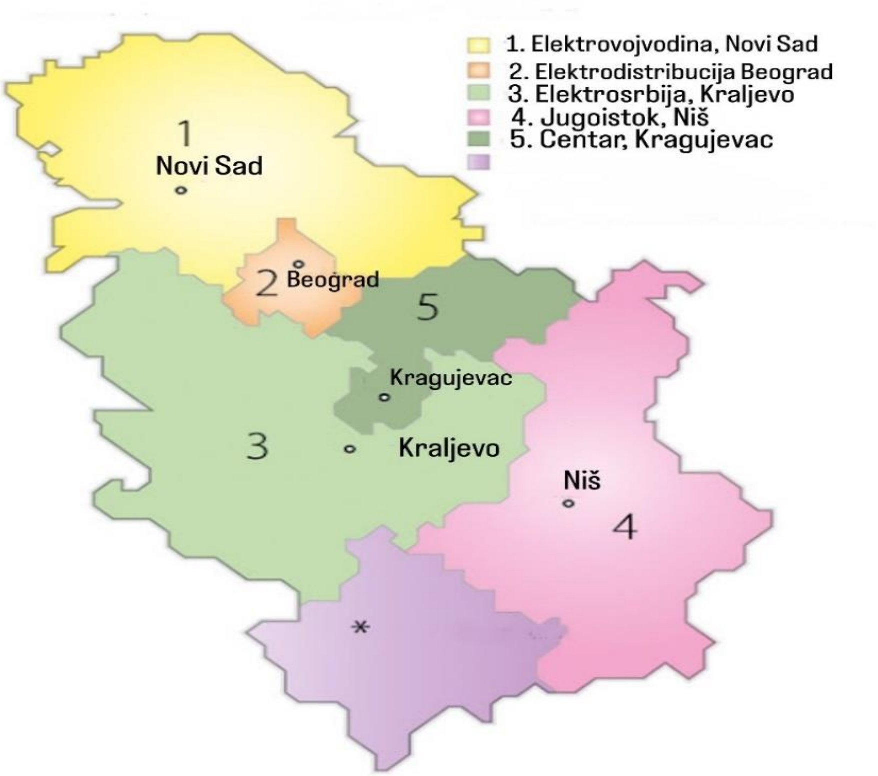

Figure 11: EDSs 5 distribution regions. Source: (Popivoda, 2014)

In

Table 4 and Table 5, characteristics of the network of EDS, are presented.

Table 4: Characteristics of the network of “Elektrodistribucija Srbije”. Source: (EDS, 2024)

SURFACE	77.472 km²
NUMBER OF INHABITANTS	6.641.197
TOTAL NUMBER OF USERS	3.801.937
ANNUAL ENERGY RECEIVED	29.509 GWh
MAXIMUM CONSUMER POWER	4.879 MW
TOTAL NUMBER OF HOUSEHOLDS	3.371.236
AVERAGE ANNUAL HOUSEHOLD CONSUMPTION	3.859 kWh
AVERAGE MONTHLY HOUSEHOLD CONSUMPTION	322 kWh
AVERAGE ANNUAL CONSUMPTION PER CAPITA	4.443 kWh

Table 5: Technical characteristics of the network of "Elektrodistribucija Srbije". Source: (EDS, 2024)

NUMBER OF TS 110/X kV	201
REMOTE CONTROLLED TS 110/X kV	198
INSTALLED POWER TS 110/X kV	11.142 MVA
NUMBER OF TS 35/X kV	582
REMOTE CONTROLLED TS 35/X kV	448
INSTALLED POWER TS 35/X kV	6.646 MVA
LENGTH OF DISTRIBUTION LINES 35kV	6.956 km
NUMBER OF TS 20/0.4 kV	9.169
INSTALLED POWER TS 20/0.4 kV	3.546 MVA
LENGTH OF LINES 20 kV	10.870 km
NUMBER OF TS 10/0.4 kV	26.799
INSTALLED POWER TS 10/0.4 kV	10.381 MVA
LENGTH OF LINES 10 kV	34.417 km
LENGTH OF LINES 0.4 kV	115.045 km
TOTAL LENGTH OF MEDIUM VOLTAGE LINES AND LOW VOLTAGE NETWORK	167.288 km

During the distribution of electrical energy to end-users, Electro distribution of Serbia took over 29.509.125 MWh of electrical energy in 2023, with 13.008.211 MWh (44.08%) being delivered to users in the category of "Households," and 13.298.084 MWh (45.06%) being delivered to users in the category of "Other." Distribution losses of electrical energy amounted to 3.202.830 MWh or 10.85% of the total quantities taken over (EDS, 2024).

The System Average Interruption Frequency Index (SAIFI) is indicator of power supply continuity. SAIFI measures the average annual number of service interruptions a customer experience. In 2020, countries with the most reliable power supply had a SAIFI of less than 0,25, while those with the least reliability had a SAIFI exceeding 1,0 (ACEA, 2022). In 2023 SAIFI in Serbia was 7,92. There is correlation between the amount of investments needed for grid upgrades and continuity of power supply index and this number speaks for itself. Inadequate maintenance dynamics (such as the high average age of distributive network components, in particular, large transformers with an average age of over 30 years) due to insufficient investment in the distribution system over the years, primarily because of the poor economic situation in the 90s and slow renewal in subsequent decades due to limited financial resources, impacts the level of technical losses in the distributive network and disruptions in supply.

In previous years, EDS invested significantly in the automation of the distribution system at all voltage levels which led to a major increase in facilities and elements of the distribution system incorporated in the remote monitoring and control system (SCADA). The process of automation has progressed the most concerning the most important elements of the distribution system, like the 110 kV substations. Out of a total of 208 objects in this category, 198 are integrated into SCADA. Regarding the 35 kV substations and switching stations, out of a total of 638.448 are integrated into SCADA. The process of automating the remaining elements of the distribution system is underway, with 2.387 different elements/objects (substation 20(10)/0.4 kV, reclosers, and sectionalizes) integrated into SCADA, distributed throughout the network (EDS, 2024).

Smart charging solutions can help reduce peak loads on the grid, which in turn can lower the need for grid reinforcements. By managing charging times for vehicles parked for extended periods in public garages and parking lots, smart charging can balance the grid and prevent peak energy demands. This can minimize the required grid investments, especially for public fast chargers connected to the medium-voltage grid.

The integration of electric vehicle (EV) charging stations with solar energy, could be a key step towards a sustainable future. By directly charging electric vehicles using solar photovoltaic (PV) systems, optimize the use of solar electricity, and lessens the load on the power grid, reducing the need for fossil fuel backup plants and contributing to energy security and climate change (WWF-UK, n.d.).

Power system designers are increasingly focusing on the integration of large numbers of electric vehicles and intermittent renewable energy sources (RES) to move towards modern microgrids. However, challenges such as increased power losses, thermal load, voltage deviation and overall system cost may arise.

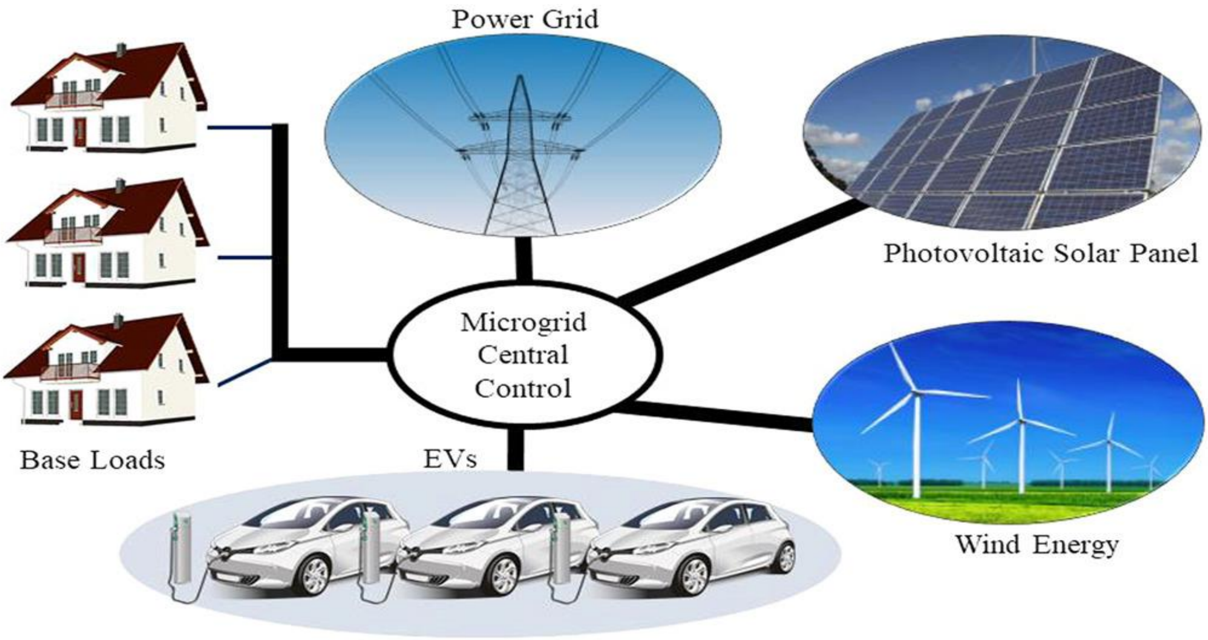

Figure 12: Architecture of modern microgrids. Source: (Ali Asaad, 2022)

The researchers found that the optimal integration of EV charging stations and renewable energy sources with a controlled charging and discharging strategy significantly reduces voltage deviation, undelivered energy and total cost compared to other scenarios. Optimal planning techniques should be used to identify suitable locations and sizes for EV charging stations with controlled charging and hybrid wind and photovoltaic systems in multi-microgrids (Ali Asaad, 2022), Figure 12.

3 ASSESSMENT, ANALYSIS AND DISCUSSION OF THE PROPOSED APPLICATION

3.1 Method of approach

Similar method of approach was conducted as in Section 2 research from various literature sources (scientific literature, industry reports, government websites, company websites, online forums and communities) and consulting experts from the industry. Economic projection was based on NPV and LRGC calculation.

The research included several steps:

- Identifying available technologies,
- Evaluation the performance of technology: efficiency, reliability and performance of technology,
- Estimation of capital costs, operating costs and Long Run Electricity Generation Costs (LRGC) for each technology, based on expected plant size and operating conditions,
- Making recommendations on how to design and operate the plant to optimize performance and efficiency based on assessment and analysis,
- Net present value calculation was performed to assess the economic viability of investing in PV power plants in combination with EV chargers on the rooftop of public garage “Obilicev Venac” and PV canopy over the public parking lot “Novi Beograd” in Belgrade.

3.2 Technological overview, description and efficiency of the PV installations

Photovoltaic (PV) effect means the direct conversion of short-wave solar irradiance into electricity at the atomic level. It is performed on solar cells that are made of semiconductor materials. When short-wave solar irradiance hits a solar cell, electrons are stripped from atoms and if electrical conductors are attached to the positive and negative sides to form an electrical circuit, the electrons are captured in the form of an electrical current - electricity that can be used to power a load (Fechner, 2023).

The efficiency of photovoltaic systems depends on multiple factors like the type of semiconductor material used in the solar cells and the impurities present and the cell formation technology (Milosavljević, 2013).

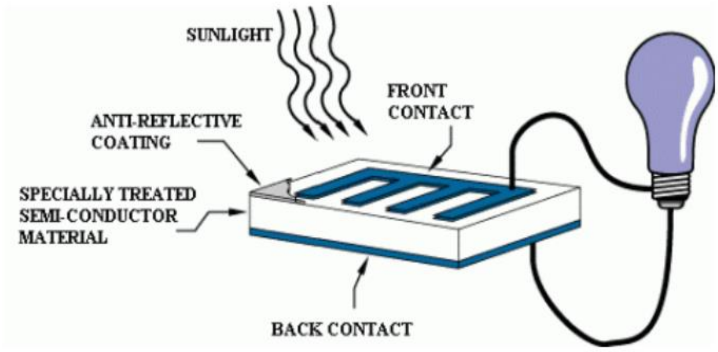

Figure 13: Converting sunlight into electricity. Source: (Knier, 2008)

Photovoltaic solar systems connected to the electrical distribution network consist of solar modules, DC/AC converters (inverters), cables, connectors, current meters and connection lines for connecting the solar system to the electrical distribution network. It is the same for utility-scale solar power plants and low-power solar power plants installed on private houses, residential and other buildings. There are also stand-alone systems (off-grid PV system) with and without energy storage (batteries and chargers) but they are not considered in this paper.

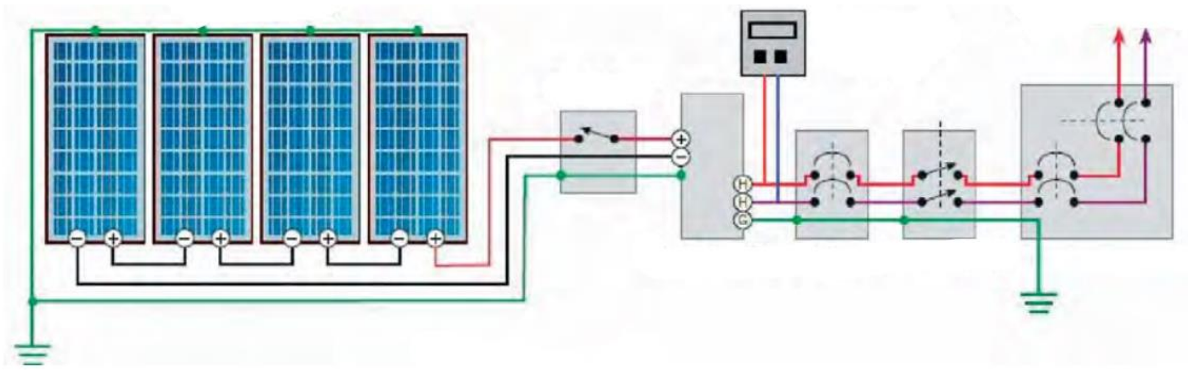

Figure 14: Schematic representation of the PV power plant. Source: (Hartung Katalin, 2014)

A photovoltaic module consists of a number of pre-wired cells in series and mounted in frame. Top of the modules are covered with glass and on the back with glass or plastic. can be wired in series to increase voltage and in parallel to increase current Multiple modules connected together form an array, they can be wired in series to increase voltage and in parallel to increase current. PV system design is deciding how modules should be connected to deliver the projected energy (Hartung Katalin, 2014). The electricity produced is in direct correlation with the surface area of the module or array, larger it is, more electricity will be produced. They are then placed on to mounting structures and form solar PV system.

Table 6 and shows module properties, the number of cells per modules, panel size (meters), module power (W), and panel yield (W/m2) for rooftop installation on public garage “Obilicev

Venac". These properties are taken from business case of company "Parking servis" Belgrade. Table 7 shows module properties for PV carport on "Novi Beograd" parking lot.

Table 6: Module properties for rooftop installation on public garage "Obilicev Venac". Source: (Biljana Vlajić "Parking servis" Beograd, 2024)

Module properties	
Number of cells	60 (6 x 10)
Panel size (mm)	**1640 x 990** x 0,035 (with Frame)
Nominal Modul power (W)	280
Panel yield (W/m2)	172,5

Table 7: Module properties for PV carport on "Novi Beograd" parking lot. Case study

Module properties	
Number of cells	132 (6 x 22)
Panel size (mm)	**2382 x 1134** x 0,035 (with Frame)
Nominal Modul power (W)	620
Panel yield (W/m2)	233,96

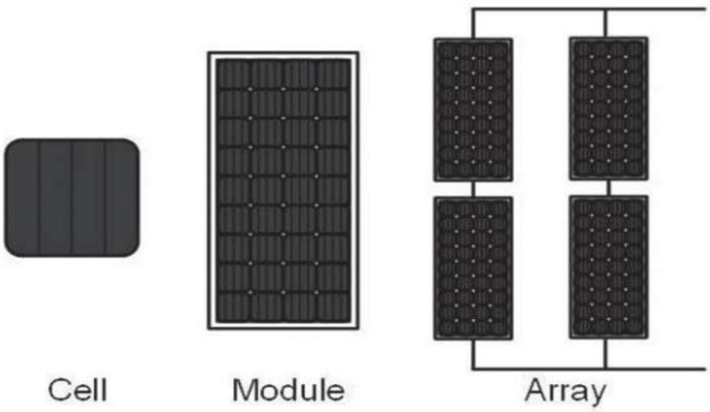

Figure 15: Photovoltaic cells, modules, and arrays. Source: (Hartung Katalin, 2014)

The most commonly used solar modules are monocrystalline (Sc-Si) and polycrystalline (Mc-Si) silicon. These two types of PV cell technology represent roughly 90% of new installations world-wide (IRENA, 2016). There are also modules made of thin-film materials, such as amorphous silicon (a-Si), copper indium gallium selenide (CIGS), and cadmium telluride (CdTe) but efficiencies of this modules are lower than Sc-Si and Mc-Si modules, usually less than 10% (Hartung Katalin, 2014).

Monocrystalline silicon solar cells come from a single silicon crystal, called an ingot, which is cut into thin silicon wafers, are then used in the solar modules. In commercial application solar panels made of Sc-Si modules have efficiency level 13-21% at standard test conditions (STC) and usually have a nice design but their price is higher than Mc-Si panels price . Polycrystalline solar cells are also made of silicon, but in their production the cooling process is different, which causes multiple crystals to form, as opposed to one. Mc-Si PV panels are cheaper than monocrystalline panels, but they are less efficient (11%-18%) and less aesthetically pleasing (Hartung Katalin, 2014).

For the purpose of this paper, systems with Sc-Si modules will be considered for PV canopy over “Novi Beograd” parking lot scale 0,3 MW and Mc-Si modules for rooftop PV installation on “Obilicev Venac” garage, scale 50,4 kW.

There are various possibilities for solar PV Installations:

- Ground mounted solar installations, placed mainly on the barren land;
- Roof top solar installations, placed on the roofs of buildings (capacity to 100 kW) and the sides of buildings;
- Offshore solar projects, a good feature is less land occupation and better cooling of the panels;
- Floating solar projects are appropriate for all water surfaces: rivers, lakes, fishponds, etc. The efficiency coefficient of these panels is 11% higher compared to the other (Alok Sahu, 2016).

Mounting structures is important part of solar PV system. Depending on the conditions of the location, fixed, uniaxially and biaxially rotating solar power plants are installed. Fixed solar power plants are the most common. Single and double axis mounting allow solar tracking, and this increases the amount of radiation captured but also significantly increases the cost of a solar PV system. A fixed solar power plant means a power plant where the solar modules are placed on fixed metal supports at an optimal angle in relation to the horizontal plane with orientation towards the south. For Serbia (latitude 43°- 44°) optimal angle for installing fixed solar modules is 41° (this is for spring and autumn, for summer optimal angle is 16° and for winter 68°), (Solar Angle Calculator, 2019).

For PV canopy, fixed mounting systems has been developed for various photovoltaic modules, customized to fit into the parking lot and designed according to specific requirements. The PV carport system can provide protection for vehicles against damage from sunshine, wind, rainwater, and snow. Mounting structures for PV canopy comes in different designs and are made from different materials but most common are carbon steel mounting structure and aluminium, Figure 16, Figure 17.

Figure 16: Carbon steel mounting structure PV canopy. Source: (KSENG, 2024)

Carbon steel solar canopies offer high strength and durability, making them suitable for various weather conditions and providing long-term vehicle protection. Additionally, these canopies are customizable to meet specific project requirements, allowing for efficient use of available space, Figure 16.

Figure 17: Aluminium mounting structure PV canopy. Source: (KSENG, 2024)

Aluminium is a durable, corrosion-resistant material that ensures the longevity of commercial solar carports. They require minimal maintenance, reducing operating costs and maximizing return on investment, Figure 17.

An inverter is a device that converts the direct voltage obtained by the solar power plant into an alternating voltage of 220 V. Converter efficiency ranges up to 97%. When selecting an inverter, it is important to take into account the output voltage of solar modules, the strength of the field of solar modules, the parameters of the municipal network and the method of solar energy management. With solar power plants, a number of lower power inverters or one or two higher power inverters can be used.

The solar power plant should have monitoring system that consists of a central control unit for monitoring the operating mode of the power plant. Sensors and software are used in the monitoring system, to obtain the different data: daily, monthly and annual electricity production, CO_2 reduction, change of system parameters, recording of events after failure, etc.

Through transformers the electrical energy obtained by the solar power plant is handed over to the electrical distribution network.

Sun radiation potentials for the location is described in Chapter 2.3, Figure 3. For most applications it is sufficient to use analytic data from available measurements data bases such as Photovoltaic Geographical Information System (PVGIS).

Efficiency is defined as the ratio of output energy from the module to input energy from the Sun. The efficiency of a solar power plant depends on several factors, like the spectrum and intensity of the incident sunlight, the temperature of the solar cell, purity of modules (dirt and dust), shading, mismatch and DC losses, MPP tracing losses, inverter losses, AC losses, etc. Beside rated efficiency of module, other evaluation criteria for energy appraisal of PV system is performance ratio (PR). It does not depend of the alignment of the solar power plant and global solar radiation. The performance ratio is the ratio between the actual energy output and the theoretical potential energy output of the photovoltaic system (Fechner, 2023).

Arrays should be formed by modules that are as identical as possible before installation because modules in a string are always oriented to the module with the lowest power.

Module temperature is very important to consider for efficiency rates. Every Celsius degree rise in temperature of Sc-Si cell yields a loss of 0,5% efficiency. Ventilation needs to be considered when installing solar PV modules. Backing ventilation level should be approximately 10 cm (Fechner, 2023).

As mentioned above, systems with Sc-Si modules will be considered for PV canopy case study and Mc-Si module for rooftop installation in this paper. Sc-Si modules come at a higher price point than Mc-Si modules but their efficiency level goes up to 21%. Mc-Si cells are cheaper, but the lower efficiency rate makes them a less desirable option for PV system.

Inverter efficiency ranges up to 97%, and that is only a small part of overall system losses. Purity of modules (dirt and dust), mismatch and DC losses, MPP tracing losses, losses, AC losses, etc. also gives a fractions of overall system losses each and all together they effect the system performance ratio. For PV canopy over “Novi Beograd” parking lot the assumed rated electrical efficiency is 23% and for PV installation on public garage “Obilicev Venac”, 17%. Performance ratio is assumed 80% for both plants.

Full load hours for PV canopy over “Novi Beograd” parking lot is assumed to be 1.250 h, Table 1, Table 2, and for rooftop PV installation on public garage “Obilicev Venac” 1.186 h, Table 1.

In Table 8 is given a summary of data for rated efficiency and capacity rates and full load hours.

Table 8: Rated Electric Efficiency, Performance Ratio, Rated Capacity, and Full Load Hours

Plant	PV Canopy “Novi Beograd”	Rooftop PV installation “Obilicev Venac” garage
Rated Efficiency	23%	17%
Performance Ratio	80%	80%
Rated Capacity (kW)	387,5	50,4
Full Load Hours (h)	1250	1186

Practice has shown that the energy efficiency of a solar power plant drops from 0.5 to 1% annually. The lifetime of solar modules depends on the technology of making solar cells. For solar cells made of monocrystalline silicon manufacturers give a 10/90 and 30/80 guarantee, which means that a ten-year guarantee is given that the solar module will function with more than 90% of the nominal power and more than 30 years with 80% of the nominal power. The lifetime of solar modules made of monocrystalline silicon is about 30 years (Milosavljević, 2013).

3.3 Technological overview and description of the Electric Vehicle Charging Stations

Electric Vehicle Charging Station is facility that supply electric power to EVs. There are different levels of charging systems available for electric cars.

The charging infrastructure industry has adopted a common standard called the Open Charge Point Interface (OCPI) protocol, that defines a a hierarchy for charging stations. This hierarchy includes location, EV charging port and connector. A station location is a place where one or more electric vehicle charging points are located, for example in a parking garage or parking lot. An EV charging port provides power for charging one vehicle at a time and can have multiple connectors. Connectors are attached to vehicles to charge them (U.S. Department of Energy, n.d.).

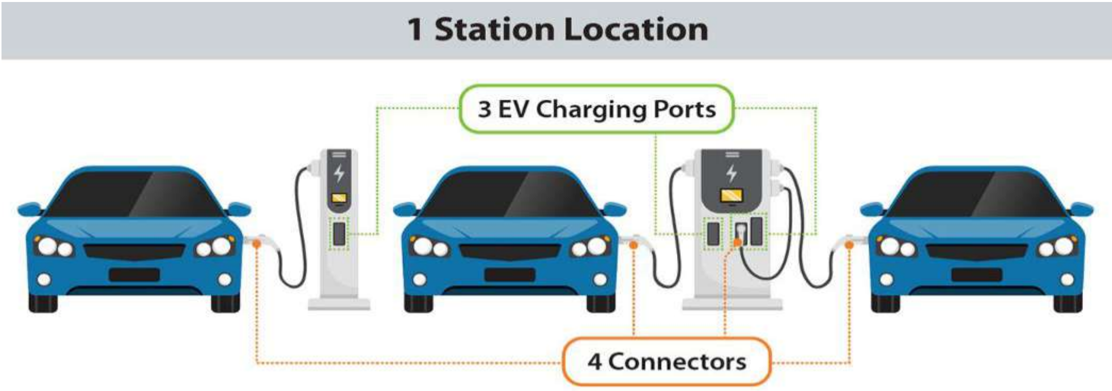

Figure 18: A station location with 3 EV charging ports and 4 connectors. Source: (U.S. Department of Energy, n.d.)

Charging equipment varies in speed based on factors such as EV battery capacity and the type of charger used. Charging times can range from less than 20 minutes with DC fast chargers to over 20 hours with AC 4-9 kW chargers,Table 9. Factors such as networking capabilities and payment options are important to consider when choosing charging equipment.

Table 9: Charging times for different EV chargers.

Charger	Charging time
AC 4 – 9 kW	Relatively slow alternating-current (AC) chargers wired to home's electricity supply for overnight charging
AC 10 – 22kW	Public AC charging stations typically on locations where vehicles are parked for longer periods of time
DC 25 kW, DC 150 kW, DC 350 kW	Standalone fast charging stations – these can range from 25 kW to 350 kW, and charge for a range of ~100-200 km in ~10-20 minutes depending on the charger and the vehicle
DC 500+ kW	Standalone fast charging stations currently ~500 kW are ready for commercial use (trucks)

The most commonly used electric vehicle (EV) charging connectors are:

- Type 2 (IEC 62196) connector: This is the most common connector in Europe for both slow AC charging and fast AC charging. It has become the standard connector for EV charging in many European countries.
- CCS and Combo 2 connector: The Combo Charging System (CCS) is a standard for fast DC charging. The CCS Combo 2 combines a Type 2 AC charging input with additional DC pins for high power DC charging. Commonly used for DC fast charging in Europe.

- CHAdeMO connector: Although less common in Europe compared to Asia, some charging stations still support the CHAdeMO connector for fast DC charging.

Needs of community members must be considered when planning the installation of charging infrastructure. Understanding factors such as travel patterns, EV ownership, charging times, and the expected number and types of EVs at location is critical to determining the appropriate number and type of charging infrastructure for a project. However, these installations require extensive work. Permits are required for all commercial electric vehicle charging installations, usually including building or electrical permits. These complex projects involve landscape changes, parking lot alterations and structural adjustments and the expertise of engineers, architects, and electrical design consultants is necessary. Installation costs can be minimized if charging equipment is placed near an appropriately sized PV plant (OPR, Ben Rubin, 2013).

The cost of installing electric vehicle charging infrastructure for public sector charging can vary significantly based on several factors. These include charger type, existing electrical infrastructure, facility characteristics, permit considerations, preferred charger location, power requirements, complexity of the installation and any additional equipment or features. The price of charger hardware will also depend on features and design preferences. Installation costs depend on factors such as distance from the electrical panel, whether additional wiring or electrical upgrades are required, and any permit requirements. In the relation with mentioned above, installation cost can widely range, Table 10 (OPR, Ben Rubin, 2013).

Table 10: Capital Costs of Electric Vehicle Supply Equipment. Source: (Brennan Borlaug, 2020)

Charger	Equipment ($)	Installation ($)	Total Cost ($)
AC 4 – 9 kW	550/plug	1.280/plug	1,830/plug
AC 10 – 22kW	3.500/plug	2.500/plug	6.000/plug
DC 50 kW	38.000/plug	20.000/plug	58.000/plug
DC 150 kW	90.000/plug	60.000/plug	150.000/plug

EV charger specifications should be considered when choosing an electric vehicle charger. Hardware specifications cover aspects such as mounting options (stand or wall), cable management strategies, number of charging ports/types, anti-theft systems, input power ratings, and operating condition limitations related to temperature and humidity. Software, considerations include features such as network capabilities, remote control access, cross-vendor hardware compatibility, network communication protocol, demand response capability to adjust output power based on network demand, and data reporting capabilities available (California Energy Commission, 2018).

For installation in public garage "Obilicev Venac", EV chargers type wall mounted AC – 22 kW with Type 2 connector will be considered, and for parking lot "Novi Beograd", two types of chargers will be considered: freestanding AC – 22 kW with Type 2 connector and DC – 60 kW with Combo 2 and CHAdeMO connector.

Planning the installation of multiple charging stations traditionally led to anticipation that all stations will be in use at the same time, affecting electrical demand. Using energy management software by monitoring and controlling, can help reduce the additional load from PEV charging.

3.4 Canopy over mid-size public parking lot New Belgrade – Case study

This study should determine economic potential for converting a public parking lots to a solar energy farm comprised of PV canopies. A sensitivity analysis will be performed on the price per unit (EUR/MW) power installed including differential cost of solar canopies and different electricity rates (EUR/kWh). Case study is used to investigate economic, ecological and social effect of installing solar canopies on public parking lots in Serbia. The results are presented and discussed.

Public parking lot “Novi Beograd” is situated in Belgrade, Serbia, in very dense urban area, surrounded with the administrative building of the municipality of New Belgrade, main police station building of the New Belgrade Police Department and few residential buildings. Parking lies in a lot size of 3.196 m², with 122 parking spaces.

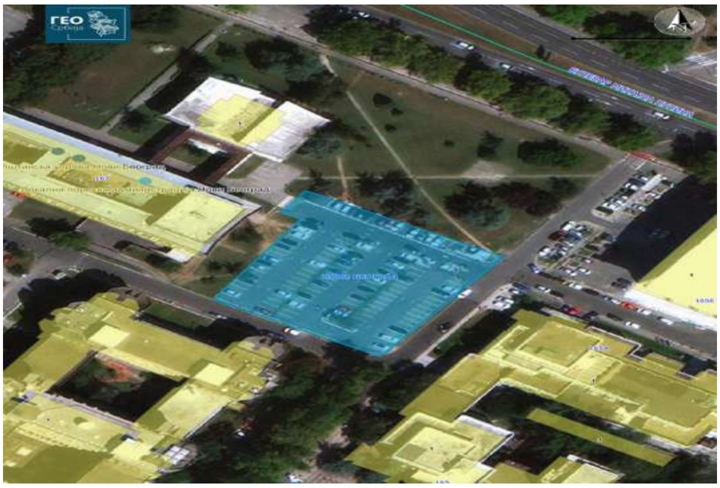

Figure 19: Parking lot „Novi Beograd “. Source: (Geosrbija)

Based on the constructed object project sketch, Figure 20, it is possible to construct a canopy over all 122 parking spaces plus over the paying station. Dimensions of one parking space are 2,5 m x 5 m. Five canopies would be built over the parking spaces, total area of 1.563,5 m².

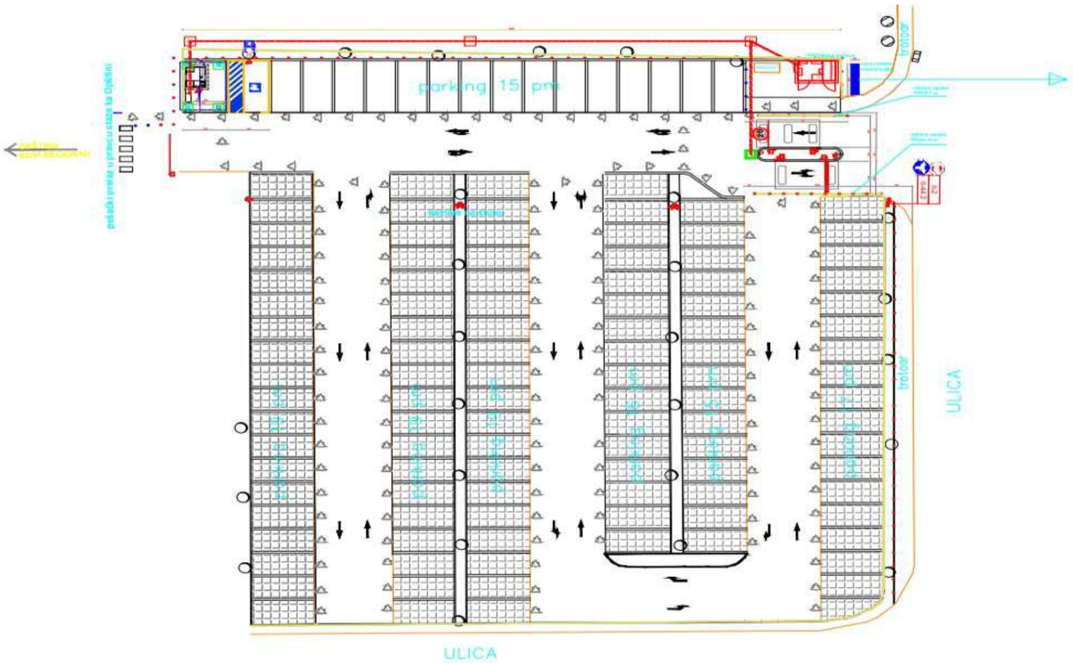

Figure 20: Sketch of the constructed project of parking lot "Novi Beograd". Source (Biljana Vlajić "Parking servis" Beograd, 2024)

Over each parking space it is possible to instal five monocrystalline, bifacial PV panels, rated power 620 W, size 2382 mm x 1134 mm and panel yield 233,96 W/m², Table 7. Total number of panels is 625 and rated capacity of PV plant installed is 387,5 kW.

Table 11: Electrical data of PV module. Source (www.luxor.solar, 2024)

Rated power (W)	620,00
Rated power (W) range to	626,49
Rated current (A)	15,42
Rated voltage (V)	40,22
Short-circuit current (A)	16,30
Open-circuit voltage (V)	48,69
Efficiency at STC[2] up to (%)	23,19
Efficiency at 200 W/m² (%)	22,72

[2] Specification as per STC (Standard test conditions): irradiance 1000 W/m2 | module temperature 25°C | AM = 1,5

PV canopy will be connected to the public grid and solar batteries. This system could be defined as hybrid solar system. The electricity generated by PV canopy will be primarily used to fulfil the immediate power needs of parking lot infrastructure. Two lithium battery systems, 48 v, 1.000 Ah - 48 kwh, will be included, to store energy from solar panels to use in night or during periods of overcast weather. When solar panels are not generating electricity, the system will switch to use stored energy from solar batteries to power the load. Excess electricity produced by solar system, will be stored in batteries to be used when the solar system's output does not meet demand. The surplus energy produced beyond that will be automatically sent to the grid. During periods when solar system is not generating enough electricity, the electricity requirements will be supplied from grid.

As mentioned above in Chapter 2.4, Serbia should at least double the existing number of EV charging stations to meet the needs in this moment. Public parking lots represent ideal location for installing public EV chargers. For the case study, 3 freestanding AC – 22 kW with Type 2 connector and 1 DC – 60 kW with Combo 2 and CHAdeMO connector EV chargers will be installed. Installed PV Carport will not just mitigate new electricity demand for EVs charging but will also offer shade from the sun and protection from the rain to the car owners that uses this parking lot.

The DC – 60 kW charging station can provide full charge for most electric vehicles in 20 – 30 minutes, and AC – 22 kW charging station can fully charge an electric vehicle in 2-3 hours, Table 9. The connected battery storage should shift the load from peak-load hours to off-peak-load hours which would have, beside economic benefit, also benefit local grid.

In Chapter 3.8 sensitivity analysis is conducted in corelation with Specific Investment Costs and electricity prices, and the results are presented and discussed.

3.5 Roof top PV installation on public parking garage “Obilicev venac” – Case study

Public parking garage “Obilicev Venac” is situated in the very centre of the city, right in “the heart of Belgrade”, in the street with the same name, next to the pedestrian zone of the city, Figure 22. There are 805 parking spaces spread over the ground floor and seven levels.

Figure 21: Public garage “Obilicev Venac”. Source: (Belgrade, "Parking Servis", 2024)

Figure 22: Parking garage "Obilicev Venac", location. Source: (Geosrbija)

On the rooftop of public garage "Obilicev Venac", solar power plant, rated capacity 50,4 kW, was installed as part of the reconstruction in 2018, which now supply the facility with electricity,

Figure 1. Gel batteries (2 V, 1000 Ah) was added as a storage. This plant produces electricity for the electricity needs in the garage, which means that the produced electricity is consumed by consumers within the object (balkangreenenergynews.com, 2019).

The main objective for installing PV power plant was generating green electricity to facilitate electric vehicle chargers that were installed at the same time, and to offset part of electricity costs.

Table 12: Monthly electricity consumption in public garage "Obilicev Venac" in 2021. Source: (Biljana Vlajić "Parking servis" Beograd, 2024)

January	February	March	April	May	June	July	August	September	October	November	December	Annual
38.460 kWh	29.700 kWh	24.480 kWh	27.180 kWh	25.680 kWh	25.860 kWh	27.600 kWh	27.960 kWh	27.780 kWh	30.780 kWh	30.548 kWh	37.140 kWh	353.168 kWh

Three AC – 22 kW chargers with Type 2 connectors were installed, with real-time monitoring, adaptive load management and dynamic energy distribution systems, which makes it possible, if too many vehicles are connected, to limit the total consumption and perform charging prioritization.

Full load hours (FLHs) for the proposed location are assumed to be 1.186 h, Table 1. Based on FLHs and rated capacities of PV plant, Yearly Generation was calculated to be 59.774,40 kWh, or 17% of annual consumption of electricity in the object,Table 12.

Solar panels are installed across the entire width of the roof in a horizontal position. The distance between the rows on the structure is 65 cm for easier access for the maintenance.

Polycrystalline solar panels are placed in 4 rows of 45 pieces, rated power 280 W, size 1.640 mm x 990 mm and panel yield 172,5 W/m². Table 6. Total rated capacity of installed solar panels is: 180 pcs x 0.28 kW = 50.4 kW.

Table 13: Electrical data of PV module. Source: (cdn.enfsolar, 2024)

Rated power (W)	280,00
Rated power (W) range to	286,49
Rated current (A)	9,13
Rated voltage (V)	30,76
Short-circuit current (A)	9,69
Open-circuit voltage (V)	38,12
Efficiency at STC up to (%)	17,26
Efficiency at 200 W/m² (%)	16,74

The solar power plant operates in parallel with the distribution system. During the day, priority consumers receive energy from solar power plant. In the event of a power outage, these consumers receive electricity from battery storage, until the batteries are discharged. The system also has a smart meter device managing the inverter's operation (Biljana Vlajić "Parking servis" Beograd, 2024).

In Chapters 3.6, 3.6, and 3.7 ecological, social and economic appraisal will be given for PV power plant installed.

3.6 Ecological appraisal of the selected / proposed applications / installations

The potential of solar energy accounts for 16.7% of Serbia's total exploitable potential of RES, offering an environmentally friendly energy alternative (Mikić & Jovanović, 2017)

Life cycle assessment LCA represents the process of analyzing the materials, energy, emissions, and waste that "produces" a product or system, through the entire life cycle from creation, starting with the exploitation of the material, until the final disposal and possible environmental impact.

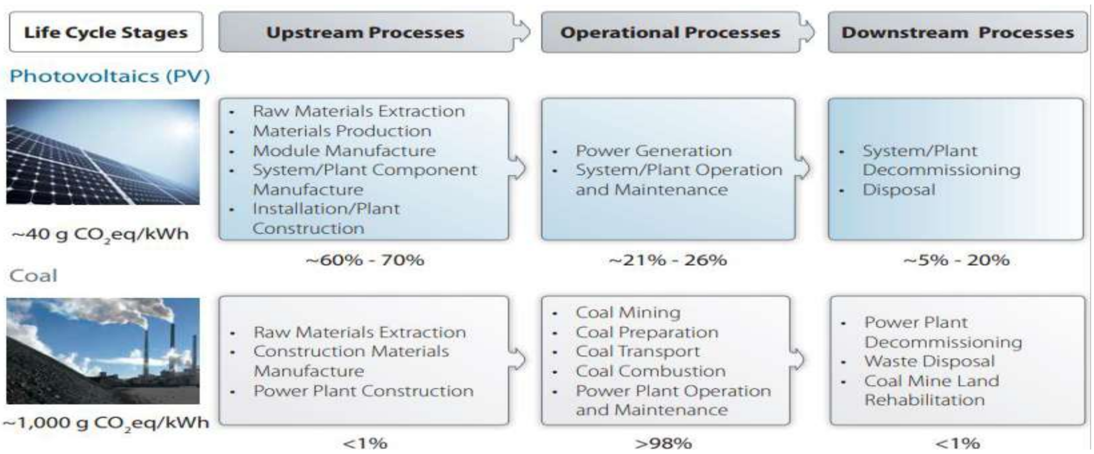

Figure 23: LCA of Energy Systems. Source: **(NREL, 2012)**

LCA for PV power plants brings to conclusion that the majority of GHG emissions occur upstream of operation during module manufacturing and in materials. There is also minor impact from end-of-life activities and almost no impact from the operation (Fechner, 2023). This is in direct contrast to fossil and nuclear power plants, which emit the majority emissions during operations operation and fuel supply (IEA-PVPS, 2020).

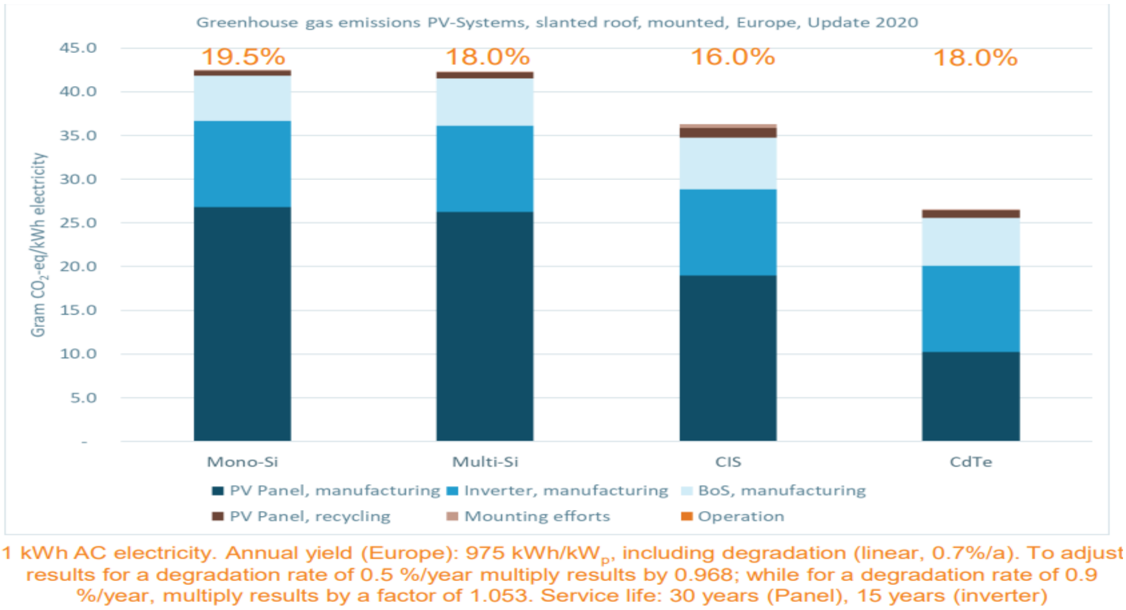

Figure 24: GH gas emissions PV Systems, 2020. Source: (IEA-PVPS, 2020)

Figure 24 shoves that greenhouse gas (GHG) emissions from Sc-Si PV system is about 41,2 grCO2eq/kWh electricity. Compared to the GHG emissions from coal that are about 1.000 grCO2 eq/kWh there is a significant saving of CO2 with solar PV.

“Energy payback time (in years) is the period needed for PV system to generate the same amount of energy with the energy used to produce the system and consumed throughout PV life cycle.”, (IEA-PVPS, 2020). In this case it is 1,2 years.

End of a life cycle for PV systems should be plant decommissioning and disposal. Recycling and repurposing the PV panels on the end of their lifetime (30 years) could unlock a large stock of raw materials, especially glass which is the main component of PV modules (IRENA I.-P. , 2016).

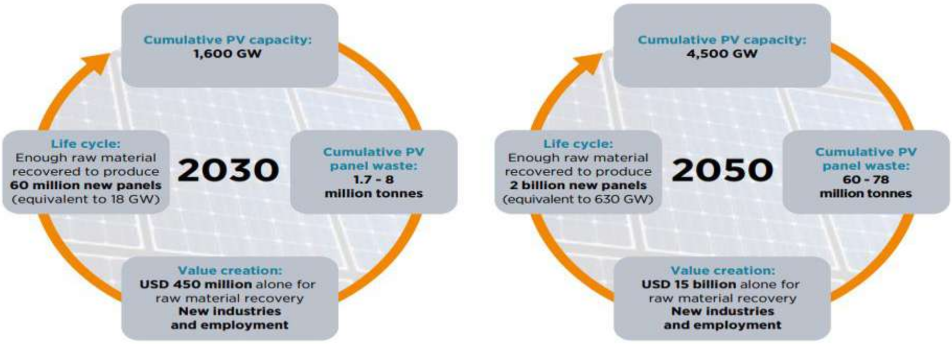

Figure 25: Potential value creation through PV end-of-life management. Source: (IRENA I.-P. , 2016)

There is one other important environmental impact that should be considered when examining the ecological influences of solar PV plants, land use. A cautious estimate for the land footprint of solar development suggests that approximately 4.5 hectares are required to generate 1 MW of electricity. This calculation includes the area needed for solar arrays, and additional space for maintenance and site access (Jessi Wyatt, 2021). As the industry grows the land necessary for solar projects will become increasingly valuable. Large scale solar PV systems on quality land, forests, useable farmland, or pastures has negative affect at the environment. Cutting down trees that help to absorb CO2 is not good for the environment. Proposed PV canopy structures and PV rooftop installations makes it possible to use the space above parking lot and garages and turn them into solar farms without sacrificing additional land surface to install a solar energy system. Solar canopies essentially turn the parking lot into a solar farm, creating a clean, renewable energy from the existing footprint, helping to preserve green spaces and avoiding additional impact on the environment.

Reducing Urban Heat Island effects is another ecological benefit of PV canopy. PV canopies, in parking lots reduce solar heat flow to the ground and lower pavement surface temperatures. The findings of the study “A comparative study of the thermal and radiative impacts of photovoltaic canopies on pavement surface temperatures” by J.S. Golden et al., suggest that pavement surfaces covered by conventional and PV canopies have lower maximum surface temperatures compared to unshaded pavement. The PV canopy has seen a 70% reduction in diurnal temperature variation, which can help reduce Urban Heat Island effects. While urban forestry can also help reduce surface temperatures of pavement, PV canopies offer greater benefits during peak solar radiation by generating electricity and better space utilisation for the basic parking lot function, vehicle parking. This is why the use of PV canopies as a thermal mitigation strategy would be most appropriate on these objects (Jay S. Golden, 2006).

Table 14: Mean pavement surface temperatures for various types of coverage. Source: (Jay S. Golden, 2006)

Pavement coverage	Mean maximum temperature	Mean minimum temperature	Mean average temperature
Fully exposed pavement (Ψ_{sky} 0.90)	146.2 °F/63.5 °C	83.3 °F/28.5 °C	110.5 °F/43.6 °C
Under conventional canopy (Ψ_{sky} 0.11)	99.9 °F/37.7 °C	81.1 °F/27.3 °C	90.3 °F/32.4 °C
Under PV modified canopy (Ψ_{sky} 0.11)	98.7 °F/37.0 °C	81.9 °F/27.7 °C	89.7 °F/32.1 °C

Phoenix, Arizona, 17 June 2004.

Under the canopy, vehicles are protected from the sun and time elements, and that results having cooler cars and reduced fuel consumption by reducing air conditioning use by drivers, that also lessen GHG emissions in transportation.

3.7 Social appraisal of the proposed installations

Solar carports are an innovative solution that combines technology with practicality, enhancing urban aesthetics, while providing functional benefits.

Installing solar carports demonstrates a commitment to sustainability by reducing carbon footprint and promoting the use of the renewable energy. As mentioned before, in Serbia, public parking lots are usually managed by public companies (state or municipality owned), and with this installations, local governments can showcase their values and sustainability efforts. The high visibility of solar carports in the parking lot serves as a unique renewable feature that promotes sustainability. This is a great PR value. Every time someone drives past a PV carport, can see the commitment to sustainability companies that menages parking lots with PV carports.

Solar carports and PV rooftop installations provide energy resilience against power outages and interruptions. Integrated battery storage gives the option to store excess solar power for use during high demand hours or power outages, providing reliable backup power generation.

They also offer benefits for costumers, such as shaded parking and electric vehicle charging infrastructure. Providing these benefits can improve satisfaction for parking users and, at the same time, support the transition to environmentally friendly transport, Figure 26.

Figure 26: EV charging infrastructure on PV carport. Source: (Stumbraite, 2024)

Good architectural design of solar canopies can enhance the visual appeal of parking lots making them more attractive, Figure 27. The use of nanotechnology-based films enables solar panels in a variety of colours, maintaining design integrity while incorporating renewable energy solutions. Same comes with PV on the rooftop of public garage. Installing solar gives the opportunity to refresh and improve the design of the roof.

Figure 27: Architectural design of solar canopies. (Lumos sola, 2024)

The integration of solar canopies can significantly raise property values. They provide shelter and optimize space what makes them a smart solution for modern urban planning. Solar canopies could significantly contribute to global renewable energy objectives in the future.

Currently, public parking managing companies in Serbia are not registered for electricity sale, their financial revenues come from savings on the electricity bills. This companies are installing EV charging station in their objects in public interest for developing EVs charging infrastructure and for overall parking users' satisfaction. To charge EV battery on public parking lots and garages in Serbia is free, vehicle owners just pay time spent on parking lot or garage by hour as any other user. This makes all previously mentioned benefits even more significant.

3.8 Economic appraisal of the proposed installations

In this Chapter, economic projection, based on NPV and LRGC calculation, is given, for case studies presented in Chapter 3.4 and Chapter 3.5. For PV canopy, sensitivity analysis is conducted in corelation with Specific Investment Costs and different Electricity rates, and the results are presented.

All installations supply generated electricity to the national power grid under the Power Purchase Agreements (PPAs) with the Electric Power Industry of Serbia (EPS) and receive payment based on the Feed-in Tariffs (Dragović, 2019), or auction prices (premium market) or as prosumers, making savings on electricity bill.

Electricity price for commercial customers in Serbia is 119,67 EUR/MWh (EDS, 2024). This price is used to calculate revenues as saving on electricity bill as one of scenarios for case studies on both objects.

Energy sector in Serbia is dependent on imports of crude-oil and natural gas and its own reserves of lignite but is endowed with the potential of renewable energy sources. Serbia has a strategy to lower greenhouse gas emissions in the energy sector and to boost the proportion of RES in total energy production. The national renewable energy action plan (NREAP) targets a 36.6% share of renewable energy in the electricity supply by 2025. The success of these objectives depends on governmental support, ("Službeni glasnik RS", 2015).

For solar power plants in Serbia, rated capacity under 0,5 MW, there is a feed-in tariff for generated electricity, and it is 20,941 eurocents – 9,383 eurocents x rated electrical power (MW)/kWh (energetskiportal.rs, n.d.) and that is 173,05 EUR/MWh for proposed installation on public parking lot “Novi Beograd”. Eq (1)

. This price is used for sensitivity analysis and scenarios.

$$\begin{aligned} EPfeedTpv\left[\frac{€cent}{kWel}\right] &= 20,941\left[\frac{€cent}{kWel}\right] - \left(9,383\left[\frac{€cent}{kWel}\right] \times RCel[MWel]\right) \\ &= 20,941\left[\frac{€cent}{kWel}\right] - 3,636\left[\frac{€cent}{kWel}\right] = 17,305\left[\frac{€cent}{kWel}\right] \end{aligned} \tag{1}$$

EPfeed in Tpv [€cent/kWh] - Electricity Price (feed in tariff for roof top solar installation rated electric capacity up to 0,5 MW)
RC [MW] - Rated capacity for electricity

Table 15: The cost of charging electric vehicles at home across Europe. Source: (Archer, 2024)

COUNTRY	PRICE (EUR/kWH)
Ireland	0,379
Belgium	0,378
Denmark	0,355
Italy	0,335
Austria	0,275
France	0,259
Finland	0,240
Spain	0,350
Croatia	0,148
Hyngary	0,113
Serbia	0,105
Montenegro	0,097

In Table 15 we can see the prices of charging EVs at home in different European countries. In Serbia it is 0,105 EUR/kWh. The cost of electricity for EVs at public chargers can go up to 60% more than rates at home (Archer, 2024), but currently the average price in EU is in range 0,38 – 0,45 EUR/kWh (Platini, 2024). NPV sensitivity analysis is conducted with different electricity rates, including 380 EUR/MWh and 450 EUR/MWh, and different Specific Investment Costs. In dynamic investment calculation, electricity rate 380 EUR/MWh is used for both PV plants.

Investment cost for PV carport systems can significantly vary depending on the cost of material used for building a carport (aluminium, stainless steel) and the local labour cost for the construction, and even if ordering premanufactured PV carport, different manufacturers have different prices. Specific Investment Costs are in the range of 1.000.000 EUR/MW – 1.900.000 EUR/MW, which includes the cost of labour, wiring, solar equipment, and carport structure in addition to solar panels, (Futr., 2024) (ENF, 2024), (Solar Electric Supply, Inc., 2024).

Specific Investment Cost (Cinv) of 1.300.000 EUR/MW was assumed for net present value (NPV), annuity (α), long run generation calculation costs (LRGC), and for the sensitivity analysis for parking lot "Novi Beograd". The range of Specific Investment Costs mentioned above will be used for sensitivity analysis and for setting scenarios.

Specific Investment Cost for the rooftop PV plant is assumed to be 925 EUR/kWh. Although advisory expert from the industry says that prices for PV rooftop systems in this scale dropped significantly (today Specific Investment Costs are in the range 500.000 – 600.000 EUR/MW), this installation is set in 2018, and from that reason we go conservatively with the price.

Full load hours (FLHs) for the proposed location for PV carport are assumed to be 1250 h/y, and for PV rooftop installation 1.186h/y, Table 1, Table 2.

Yearly generation in Table 16 was calculated based on FLHs and rated capacities of PV plants, Eq. (2):

$$Pel = FLHel * RCel \quad (2)$$

Pel [MWh] - Yearly electrical generation
RCel [MWl] - Rated capacity for electricity

Table 16: Rated capacity, FLH (h), Yearly Generation (MWh). (Own calculation)

Rated Capacity (MW)	FLH (h/y)	Yearly Electricity Generation(MWh)
0,3875	1250	**484.38**
0,0504	1186	**59,77**

Operation and maintenance (O&M) costs was assumed to be 34 EUR/MWh (Petrović, 2019). Inverter should be replaced after 10-15 year of operation and this replacement costs were calculated to be 9% of the investment costs for the PV canopy and 10% of the investment costs for the PV rooftop plant. There is no fuel cost because solar irradiance is free.

For PV canopy, two NPV and sensitivity analysis were conducted. For the first NPV analysis, into the revenue stream were counted electricity sales (savings) and CO2 certificates (carbon credits). For the second, only electricity savings or sale were counted into the revenue stream. Dynamic sensitivity analysis without CO2 revenues was conducted because companies in Serbia are not obliged to pay for CO2 emissions yet, but starting the end of 2025 year, they will be. For PV rooftop system, electricity savings and green certificates were counted. The CO2 emissions were calculated by multiplying the produced net electrical energy with the CO2 emission factor for electricity, Eq (3). The CO2 emission factor for electricity[3] (CO2ef el) is usually prescribed by the relevant ministry.

$$CO2 = Pel * CO2efCO2 \tag{3}$$

CO2 [t] - CO2 emission savings
CO2ef el [tCO2/MWh] - Emission factor for electricity
Pel [MWh] - Yearly electrical generation

Table 17: CO2 emission calculation (PV) (own calculation)

CO2 Emiss. Factor Electricity (kg CO2/kWh)	0,708	
	System 50,4 kW	**System 387,5 kW**
Yearly Electricity Generation(MWh)	**59,77**	**484,38**
CO2 (t)	**42**	**342,94**

Investment horizon (y) for NPV, LRGC and Annuity Analysis is 25 years.

Table 18: Input Values for NPV and Annuity Analysis for PV rooftop plant on public garage "Obilicev Venac"[4] (own calculation)

[3] It depends on electricity mix in the country.
[4] * 25 YR EURIRS 2,4% on 23.8.2024, plus equity risk premium
** Assumption for a normalized long term inflation rate

Input Description	50,4 kW
Discount rate (%) *	5,40%
Rated Capacity MW	0,0504
Full Load Hours	1.186
Specific Investment Costs (EUR/MW)	925.000
Inverter replacement (EUR)	4.862
Investment Horizon (Years)	25
Electricity Price (EUR/MWh)	380
Inflation (%) **	3,00%
O&M costs (EUR/MW)	35
Yearly Electricity Generation (MWh)	59,77
Battery cost (EUR)	2.000
Yearly credits CO2 (t)	42,32
Green certificate (EUR/tCO2)	50
Investment Costs (EUR)	48.620
Residual value (EUR)	38.896

NPV, LRGC and Annuity (α) for PV rooftop plant on public garage "Obilicev Venac" were calculated based on Input Values in Table 18 and Eq (4), Eq (5) and Eq (7).

$$NPV = \sum_{t=1}^{T} \frac{Ct}{(1+r)^t} - C \qquad (4)$$

$$\alpha = NPV * \frac{r*(1+r)^T}{(1+r)^T - 1} \qquad (5)$$

$$\frac{r*(1+r)^T}{(1+r)^T - 1} = CRF \qquad (6)$$

$$\text{LRGC} = \frac{Annuity\ of Costs}{Yearly\ Electricity\ Generation} = \frac{NPV\ of\ costs * CRF}{Pel} \qquad (7)$$

T - Investment Horizon [y]
t – year – count
Ct – Cash flow in ear t [€]
r – Discount rate
C – Initial investment cost [€]
CRF – Capital recovery factor
Pel – Yearly Electricity Generation [MWh]
LRGC - Long run generation costs [€/MWH]
α - Annuity [€]

Table 19: Summary of Dynamic Investment Calculation, PV rooftop plant on public garage "Obilicev Venac. (own calculation)

PV rooftop plant on public garage "Obilicev Venac",	50,4 kW
NPV (EUR)	268.961
LRGC (incl.Cost Escal.) (EUR/MWh)	110,21
Annuity (EUR)	19.856

Dynamic Investment Calculation shows that PV rooftop plant on the garage in these scales are economically favorable given the positive NPV and annuity making the investment profitable. Return on investment is expected in 2 years and 3 months. High profitability of the project is primarily due to the high electricity prices for EVs.

Input Values, including CO2 revenues, for NPV, LRGC and Annuity Analysis for PV canopy on public parking lot "Novi Beograd" is given in Table 20.

Table 20: Input Values, including CO2 revenues, for NPV, LRGC and Annuity Analysis for PV canopy on public parking lot "Novi Beograd".[5] (own calculation)

Input Description	387,5 kW
Rated Capacity MW	0,3875
Full Load Hours	1.250
Specific Investment Costs (EUR/MW)	1.300.000
Inverter replacement (EUR)	47.138
Investment Horizon (Years)	25
Electricity Price (EUR/MWh)	380
Inflation (%) **	3,00%
O&M costs (EUR/MW)	35
Yearly Electricity Generation (MWh)	484,38
Battery cost (EUR)	20.000
Yearly CO2 (t)	324,94
Green certificate (EUR/tCO2)	50
Investment Costs (EUR)	523.750
Residual value (EUR), 80%	419.000

[5] * 25 YR EURIRS 2,4% on 23.8.2024, plus equity risk premium 3%
** Assumption for a normalized long term inflation rate

Input Values, without CO2 revenues, for NPV, LRGC and Annuity Analysis for PV canopy on public parking lot “Novi Beograd” is given in Table 21.

Table 21: Input Values, without CO2 revenues, for NPV, LRGC and Annuity Analysis for PV canopy on public parking lot “Novi Beograd”. (own calculation)

Input Description	387,5 kW
Rated Capacity MW	0,3875
Full Load Hours	1.250
Specific Investment Costs (EUR/MW)	1.300.000
Inverter replacement (EUR)	47.138
Investment Horizon (Years)	25
Electricity Price (EUR/MWh)	380
Inflation (%) **	3,00%
O&M costs (EUR/MW)	35
Yearly Electricity Generation (MWh)	484,38
Battery cost (EUR)	20.000
Yearly CO2 (t)	324,94
Green certificate (EUR/tCO2)	0
Investment Costs (EUR)	523.750
Residual value (EUR), 80%	419.000

Table 22: Summary of Dynamic Investment Calculation for PV canopy on public parking lot “Novi Beograd” (own calculation)

PV canopy on public parking lot “Novi Beograd”		
	With CO2 revenues	Without CO2 revenues
NPV (EUR)	2.092.183	1.872.104
LRGC (incl.Cost Escal.) (EUR/MWh)	130,58	130,58
Annuity (EUR)	154.452	138.205

PV plant shows positive NPVs making project highly financially profitable with or without CO2 revenues. Thus, it can be concluded that under ceteris paribus conditions an investment into PV canopy is profitable. Under current planning assumptions, 1.300.000 EUR/MW specific investment cost, green certificate remuneration 50 EUR/tCO2, electricity price 380 EUR/MWh (the average cost of electricity for EVs in EU), time to return on investment is 3 years and 2 months.

4 DISCUSSION OF THE RESULTS

In Chapters 3.6, 3.7 and 3.8 ecological, social and economic appraisal of technology and possibilities installing PV plants on public parking lots and garages in Serbia's cites are presented, based on two case studies.

To evaluate environmental impacts, the GHG emissions were calculated yearly for both PV plants presented in paper and compared with coal fired power plant.

$$GHGy = GHGemiss * Pel \tag{8}$$

1 kg = 1000gr
1MWh=1000kWh

GHGy [kgCO2eq] - GHG emissions yearly
GHGemiss [grCO2eq/kWh] - Technology generation emissions (based on LCA)
Pel [MWh] - Yearly electrical generation

Table 23: GHG emissions (own calculation)

	PV Canopy	PV rooftop	Coal fired power plant	
Rated Capacity (MW)	0,3875	0,0504	-	-
Yearly Generation (Mwelh)	484,38	59,77	484,38	59,77
GHG emissions (grCO2eq/kWh)	41,2	41,2	1.000	1.000
Yearly GHG emissions (kgCO2eq)	19.956,46	2.462,52	484.380	59.770

As a generation technology with a very low CO2 footprint (about 41,2 grCO2eq/kWh), Figure 24, with the majority of GHG emissions upstream of operation and a little impact from end-of-life activities (LCA) comparing to fossil fueled power generations, it makes huge GHG emission savings on generation, Table 23.

Efficient land use is achieved by multipurpose the existing objects and reducing Urban Heat Island effect as other ecological benefits of installing PV carport, Chapter 3.6.

The most valuable social impacts of the technologies are highly visible demonstration of commitment to sustainability and support the transition to low carbon transportation. As mentioned in Chapter 2.4, Serbia is far behind EU countries in transport electrification and needs to significantly accelerate development of EVs charging infrastructure in order to catch up, and public parking lots and garages represent ideal locations for this infrastructure to be used by EV vehicle owners that does not have the possibility to charge their vehicles at home or work. Combining PV plants with the EV chargers lead to cost saving by reducing electricity costs while contributing to a healthier environment.

Multiple scenarios are set in order to investigate profitability of investing in this project in Serbia.

Two scenarios are set for PV plant on the rooftop of public garage “Obilicev Venac”, and first is presented and evaluated in Chapter 3.8. As mentioned in Chapter 3.7 public parking managing companies in Serbia are not registered for electricity production/sale, their financial revenues come currently from savings on the electricity bills. The reason for this may be that at the moment there are very few PV plants, with small rated capacities installed on their facilities, Chapter 2.2, and they do not have interest in applying for permits and registering for the production/sale of electricity, beside their core business. First scenario was set under assumption that with an increase in installed capacity, this companies will be motivated to register for electricity production/sale, since it is three times more profitable for them.

Second scenario is considering current situation. Investing in PV rooftop plant as a prosumer was investigated and evaluated, considering all the same parameters except electricity price which in this scenario is set on 119,67 EUR/MWh (electricity price for commercial customers in Serbia), Table 24. Economic projection was based on NPV and LRGC calculation, Table 25.

Table 24: Input Values for NPV and Annuity Analysis for PV rooftop plant on public garage “Obilicev Venac”[6], second scenario. (own calculation)

Input Description	50,4 kW
Discount rate (%) *	5,40%
Rated Capacity MW	0,0504
Full Load Hours	1.186
Specific Investment Costs (EUR/MW)	925.000
Inverter replacement (EUR)	4.862
Investment Horizon (Years)	25
Electricity Price (EUR/MWh)	119,67
Inflation (%) **	3,00%
O&M costs (EUR/MW)	35
Yearly Electricity Generation (MWh)	59,77
Battery cost (EUR)	2.000
Yearly production CO2 (t)	42,32
Green certificate (EUR/tCO2)	50
Investment Costs (EUR)	48.620
Residual value (EUR)	38.896

Table 25: Summary of Dynamic Investment Calculation, PV rooftop plant on public garage “Obilicev Venac, second scenario. (own calculation)

PV rooftop plant on public garage “Obilicev Venac", 50,4 kW	
NPV (EUR)	58.189
LRGC (incl.Cost Escal.) (EUR/MWh)	110
Annuity (EUR)	4.296

[6] * 25 YR EURIRS 2,4% on 23.8.2024, plus equity risk premium 3% VIDI GORE STA SAM TI NAPISAO
** Assumption for a normalized long term inflation rate

Positive NPV and annuity shows that investing in PV plants as a prosumer in Serbia, and even without incentives for reducing Investment Costs that R. of Serbia is offering, brings significant savings on electricity bill, and is economically viable. Return on investment is expected in 9 years and 1 month. NPV sensitivity analysis showed that break-even electricity price for this installation is 47,8 EUR/MWh, Table 26.

Table 26: NPV and LRGC sensitivity analysis for PV rooftop on "Obilicev Venac" garage. (own calculation)

Co2 = EUR 50				
Canopy	NPV	119,67	380	BE
Specific investment cost	925.000	58.189	268.961	47,80
Specific investment cost				
Specific investment cost				
Specific investment cost				
		150,36%	694,98%	
Canopy	LRGC	119,67	380	
Specific investment cost	925.000	110,21	110,21	
Specific investment cost	-			
Specific investment cost	-			
Specific investment cost	-			

Economic evaluation for PV canopy on parking lot "Novi Beograd" is given conducting NPV and LRGC sensitivity analysis, setting 32 different scenarios, assuming different (Cinv) and different electricity prices, including and excluding CO2 revenues and results are in Table 27, and Table 27.

These scenarios are set in order to investigate profitability of investing in this project in Serbia.

Table 27: NPV and LRGC sensitivity analysis, including CO2 revenues, in relation with Investment Costs* and Electricity price*, (own calculation).[7]

Co2 = EUR 50		Electricity price			
Canopy	NPV	119,67	173,05	380	450
Specific investment cost	1.000.000	453.316	803.559	2.161.427	2.620.720
Specific investment cost	1.300.000	384.072	734.316	2.092.183	2.551.477
Specific investment cost	1.600.000	314.829	665.073	2.022.940	2.482.233
Specific investment cost	1.900.000	245.586	595.829	1.953.697	2.412.990
		Electricity price			
Canopy	LRGC	119,67	173,05	380	450
Specific investment cost	1.000.000	112,06	112,06	112,06	112,06
Specific investment cost	1.300.000	130,58	130,58	130,58	130,58
Specific investment cost	1.600.000	149,10	149,10	149,10	149,10
Specific investment cost	1.900.000	167,62	167,62	167,62	167,62

[7] All values in EUR

Table 28: NPV and LRGC sensitivity analysis, excluding CO2 revenues, in relation with Investment Costs* and Electricity price*, (own calculation).[8]

Co2 = EUR 0		Electricity price			
Canopy	NPV	119,67	173,05	380	450
Specific investment cost	1.000.000	233.236	583.480	1.941.348	2.400.641
Specific investment cost	1.300.000	163.993	514.237	1.872.104	2.331.397
Specific investment cost	1.600.000	94.750	444.994	1.802.861	2.262.154
Specific investment cost	1.900.000	25.506	375.750	1.733.618	2.192.911
		Electricity price			
Canopy	LRGC	119,67	173,05	380	450
Specific investment cost	1.000.000	112,06	112,06	112,06	112,06
Specific investment cost	1.300.000	130,58	130,58	130,58	130,58
Specific investment cost	1.600.000	149,10	149,10	149,10	149,10
Specific investment cost	1.900.000	167,62	167,62	167,62	167,62

Sensitivity analysis shows that NPV is going down with Cinv increasing and electricity price decreasing but stays highly positive with or without CO2 revenues included making this investment financially profitable, Figure 28.

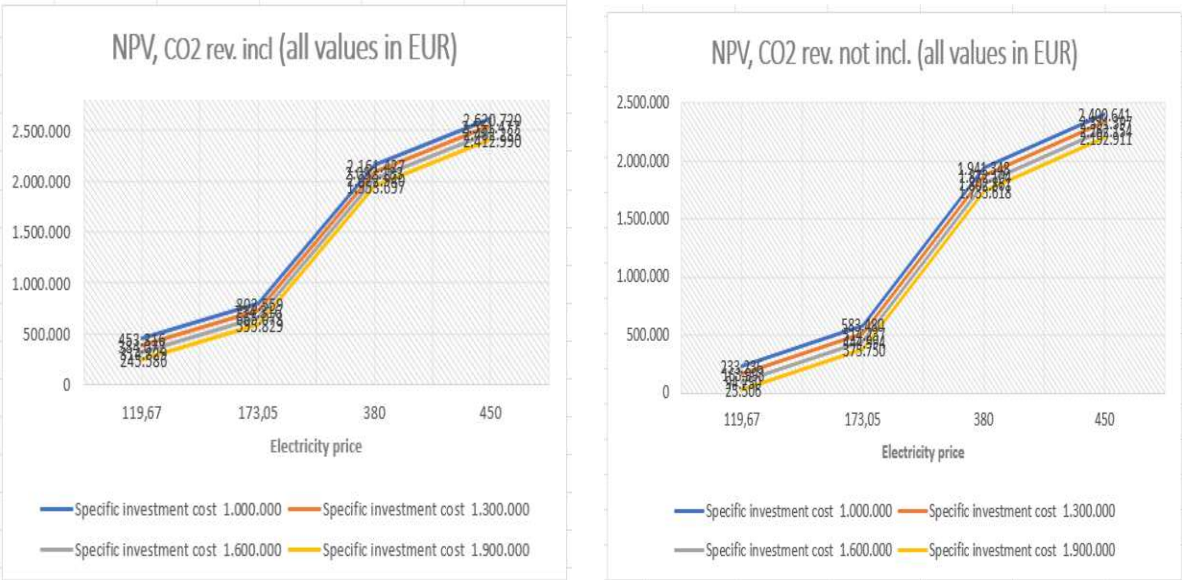

Figure 28: NPV sensitivity analysis, including and excluding CO2 revenues.

[8] All values in EUR

Table 29: Break-even electricity price (EUR/MW) (NPV = 0), (own calculation).[9]

Co2 = EUR 50		
Canopy	NPV	BE
Specific investment cost	1.000.000	50,58
Specific investment cost	1.300.000	61,13
Specific investment cost	1.600.000	71,69
Specific investment cost	1.900.000	82,24

Co2 = EUR 0		
Canopy	NPV	BE
Specific investment cost	1.000.000	84,12
Specific investment cost	1.300.000	94,68
Specific investment cost	1.600.000	105,23
Specific investment cost	1.900.000	115,78

In Table 29 was calculated minimum required electricity prices that gives positive NPV, with and without CO2 revenues and different Cinv.

Sensitivity analysis for LRGC shows that LRGC is very sensitive on Cinv changes in a way that, higher the Cinv, LRGC is also higher, Figure 29.

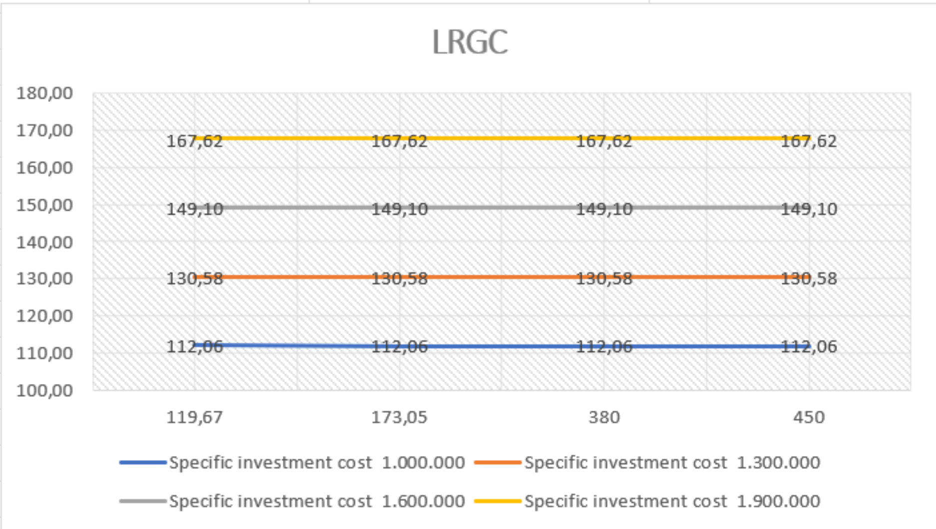

Figure 29: LRGC sensitivity analysis.

Based on these scenarios for evaluation financial rentability of installing PV canopy on public parking lots one can conclude the following:

- Under all scenarios an investment into PV canopy is financially profitable. The higher the price per MWh, and the lower the investment costs, the higher the profitability both under a 0 EUR and 50 EUR green certificate remuneration.

- Even in a scenario with electricity price 119,67 EUR/MW (scenario set for calculating savings on electricity bills), and the highest specific investment cost (1.900.000 EUR/MW), the

[9] All values in EUR

electricity price is higher than the break-even price per MWh (3,36% in case of 0 EUR/tCO2, respectively 45,51% in case of 50 EUR/tCO2).

5 CONCLUSION

Energy transition and implementing renewable generation technologies in Serbia started just a few years ago, but now the country is on a good track. Ambitious goals have been established in terms of renewable energy sources, energy efficiency and reduction of GHG emissions. In order to achieve these goals, Government has established a legal framework to encourage investments in renewable projects. Based on the Integrated national energy and climate plan (INECP) municipalities are encouraged to create their local strategies and involve on developing different sustainability projects.

Sustainable transportation refers to using modes of transportation that are environmentally friendly, energy-efficient, and affordable. This includes vehicles powered by electricity.

Serbia is far behind EU countries in transport electrification and needs to significantly accelerate development of EVs charging infrastructure in order to catch up, and public parking lots and garages represent ideal locations for this infrastructure to be used by EV vehicle owners that do not have the possibility to charge their vehicles at home or work.

Even though Serbia, for the moment, is one of the most affordable places in Europe to charge an electric vehicle (Archer, 2024), drivers have not been enticed to switch, and sales of electric vehicles remain low. New incentives and purchase subsidies have been put in place to encourage more people to start using electric vehicles.

But beside subsides, in order for drivers in Serbia switch to EVs, it is essential to develop a good EV charging infrastructure. That brings another question, if EVs in Serbia are charging their batteries on the current Serbia ‘s electricity mix with 70% of electricity coming from fossil fuels power plants, from sustainability point of view, this is worse than having vehicles powered with fossil fuels.

From that reason, integrating renewable energy production into electric vehicle charging infrastructure is crucial. Long-term planning and investments in EV charging infrastructure in combination with renewable energy generation is vital to ensure the economic and ecological viability of electric vehicles mobility. Adoption of solar energy can lead to cost saving by reducing electricity costs while contributing to a healthier environment. In Serbia, actual price of generating electricity from coal according to EBRD 2022 method, is 207 EUR/MWh (Kalmar Z., Batas-Bjelić, I., Molnar D, 2021), and that is much above any LRGC calculated in the paper, even in scenario with the highest Specific Investment Costs, and that brings to conclusion that even putting ecological and social benefits of the model presented in the paper aside, just economic reasons should encourage introducing solar generation in EV infrastructure.

Serbia´s grid infrastructure is not yet fully ready to handle the loads of unpredictable renewable generations. Smart charging solutions can help reduce peak loads, thus minimizing the need for grid reinforcements. Integrating EV charging stations with solar energy can optimize solar electricity use and ease the load on the power grid. This would result reducing reliance on backup fossil fuel plants and contributing to energy security and climate change mitigation.

This study showcased that implementing solar canopies with EV charging stations on public parking lots and PV plants on rooftops of public garages in Serbia could be a beneficial model.

These technologies are not just highly economically viable, they can provide an opportunity to address multiple urban challenges like energy safety and independence, promotion of sustainable transport, thermal mitigation, efficient use of the land and aesthetics improvement. And, taking into account the visibility of PV canopies, this would send a very loud message on commitment to sustainability of municipalities that are introducing these technologies.

This paper is focusing on public parking lots and garages, although this model could be appropriate for any other parking lots regardless of whether they are managed by public entities or private.

REFERENCES

Republic of Serbia Ministry of Mining and Energy. (2016). Energy Sector Development Strategy of the Republic of Serbia for the period by 2025 with projections by 2030. Preuzeto sa arhiva.mre.gov.rs: https://arhiva.mre.gov.rs/doc/efikasnost-izvori/23.06.02016%20ENERGY%20SECTOR%20DEVELOPMENT%20STRATEGY%20OF%20THE%20REPUBLIC%20OF%20SERBIA.pdf

U.S. Department of Energy. (n.d.). U.S. Department of Energy. Preuzeto sa U.S. Department of Energy's Vehicle Technologies Office: https://afdc.energy.gov/fuels/electricity-basics

"Službeni glasnik RS". (2015, December 8). Стратегија развоја енергетике Републике Србије до 2025. године са пројекцијама до 2030. године - 101/2015. Preuzeto sa pravno-informacioni-sistem.rs: https://pravno-informacioni-sistem.rs/eli/rep/sgrs/skupstina/ostalo/2015/101/1

(2018). Preuzeto sa solargis.com: https://solargis.com/maps-and-gis-data/download/serbia

ACEA. (2022, 03). European Electric Vehicle Charging Infrastructure Masterplan. Preuzeto sa www.acea.auto: https://www.acea.auto/files/Research-Whitepaper_A-European-EV-Charging-Infrastructure-Masterplan.pdf

Ali Asaad, A. A. (2022). Multi-objective optimal planning of EV charging stations and renewable energy resources for smart microgrids. Energy Science & Engineering, Volume 11, Issue 3 p. 1202-1218. Preuzeto sa Energy Science & EngineeringVolume 11, Issue 3 p. 1202-1218: https://scijournals.onlinelibrary.wiley.com/doi/10.1002/ese3.1385

Alok Sahu, N. Y. (2016). Floating photovoltaic power plant: A review. Renewable and Sustainable Energy Reviews , 815-824.

Archer, E. (2024). Switcher.ie. Preuzeto sa The cost of charging an electric car across Europe: https://switcher.ie/car-insurance/cost-of-charging-electric-car-europe/

balkangreenenergynews. (2023, July 12). Solar canopy for 15-hectare parking lot in France. Preuzeto sa balkangreenenergynews.com: https://balkangreenenergynews.com/solar-canopy-for-15-hectare-parking-lot-in-france/

balkangreenenergynews.com. (2019, January). Preuzeto sa Tendering maintenance of solar power system other garage facilities: https://balkangreenenergynews.com/tendering-maintenance-of-solar-power-system-other-garage-facilities/

Belgrade, "Parking Servis". (2024). www.parking-servis.co.rs. Preuzeto sa https://www.parking-servis.co.rs/garaza-obilicev-venac

Biljana Vlajić "Parking servis" Beograd. (2024, Jun 26). Email - Podaci Parking servis. Beograd, Serbia.

Bloomberg Adria. (2024, May). Električni punjači u Srbiji: Manje od 150, Hrvatska već preko 1.000. Preuzeto sa rs.bloombergadria.com: https://rs.bloombergadria.com/ostalo/opste/59230/elektricni-punjaci-u-srbiji-manje-od-150-hrvatska-vec-preko-1000/news/

Brankovic, S. (1999). Električne mreže i dalekovodi: Za III razred elektrotehničke škole. Beograd: енка Бранковић, Завод за уџбенике и наставна средства (Београд). Branković, SeZavod za udžbenike i nastavna sredstva. ISBN 978-86-17-06911-5.

Brennan Borlaug, S. S. (2020). Levelized Cost of Charging Electric Vehicles in the United States. Joule, Volume 4, Issue 7, Pages 1470-1485.

California Energy Commission. (2018). Electric Vehicle Charger Selection Guide. Preuzeto sa afdc.energy.gov: https://afdc.energy.gov/files/u/publication/EV_Charger_Selection_Guide_2018-01-112.pdf

cdn.enfsolar. (2024). Preuzeto sa https://cdn.enfsolar.com/z/pp/7a6h09wx6iu/59704ce0a720a.pdf

CleanTechnica. (2017, 11). Electric Vehicle Charging Infrastructure: Guidelines for Cities. Preuzeto sa CleanTechnica: https://cleantechnica.com/wp-content/uploads/2024/02/EV-Charging-Infrastructure-Guidelines-for-Cities.pdf

creativecommons. (n.d.). Preuzeto sa https://creativecommons.org/compatiblelicenses

Dragović, N. M. (2019). POTENTIALS AND PROSPECTS FOR IMPLEMENTATION OF RENEWABLE ENERGY SOURCES IN SERBIA. THERMAL SCIENCE, Vol. 23, No. 5B, 2895-2907.

Đurišić, Ž., & Škrbic, B. (2022). Solar and Wind Energy Potential for Strategic Planning of Decarbonisation of Electricity Production in Serbia. EEE, energija, ekonomija, ekologija, no. 4, str. 10.46793/EEE22-4.01D.

EDS. (2024). elektrodistribucija.rs. Preuzeto sa elektrodistribucija.rs/o-nama/tehnicki-podaci-o-konzumu: https://elektrodistribucija.rs/o-nama/tehnicki-podaci-o-konzumu

Elektroenergetika. (2018). elektroenergetika.info. Preuzeto sa https://www.elektroenergetika.info/m/blogceli.php?sifra=220&puta=

EMS RS. (2024). Preuzeto sa ems.rs/en/organisation-3: https://ems.rs/en/organisation-3

EMS RS. (2024). Preuzeto sa ems.rs/en/description-and-capacities: https://ems.rs/en/description-and-capacities/

Energetski portal. (2020, December). OTVORENA PRVA "ZELENA GARAŽA" U KRAGUJEVCU. MAGAZIN ENERGETSKOG PORTALA, str. 32-33.

energetskiportal.rs. (n.d.). https://energetskiportal.rs/ministarstvo/fid-in-tarife/. Preuzeto sa energetskiportal.rs: https://energetskiportal.rs/ministarstvo/fid-in-tarife/

ENF. (2024). www.enfsolar.com. Preuzeto sa Solar Mounting System Directory: https://www.enfsolar.com/pv/mounting-system

Enphase Energy. (2023, November 30). sustainable-ev-charging-solar-powered-evs. Preuzeto sa enphase.com: https://enphase.com/ev-chargers/learn/sustainable-ev-charging-solar-powered-evs

EUROSTAT. (2024, April). ec.europa.eu. Preuzeto sa Electricity prices for non-household consumers: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Electricity_price_statistics#Electricity_prices_for_non-household_consumers

Fechner, H. (2023). U Module 3 - Solar Energy, Solar Heating & Photovoltaics. TU WIEN Continuing Education Center.

Futr. (2024, June). futr.energy. Preuzeto sa Are Solar Carports Worth Investing in? : https://futr.energy/knowledge/are-solar-carports-worth-investing/

Geosrbija. (n.d.). Preuzeto sa file:///C:/Users/dusic/Downloads/5ddcc6e569b9c9b894f9746f31daf34c3d425fb5.pdf

GreenWay Infrastructure s. r. o. (2018). ev4cities.greenwaynetwork.com. Preuzeto sa greenwaynetwork.com: https://ev4cities.greenwaynetwork.com/

Hartung Katalin, H. R. (2014). Regional impacts of different photovoltaic systems. IDResearch Kft. / Publikon Kiadó, Pécs.

IEA. (2024). Preuzeto sa Global EV Outlook 2024: https://www.iea.org/reports/global-ev-outlook-2024/trends-in-electric-cars

IEA-PVPS, T. (2020). Environmental life cycle assessment of electricity from PV systems. IEA-PVPS , Task12. Preuzeto sa https://iea-pvps.org/fact-sheets/factsheet-environmental-life-cycle-assessment-of-electricity-from-pv-systems/

IRENA. (2016). The Power to change: Solar and Wind cost reduction potential to 2025. IRENA.

IRENA. (2016). The Power to change: Solar and Wind cost reduction potential to 2025. IRENA.

IRENA. (2023). Renewable power generation costs in 2022. Abu Dhabi: International Renewable Energy Agency.

IRENA, I.-P. (2016). End of life management Solar Photovoltaic Panels.

Jay S. Golden, J. C. (2006, December). A comparative study of the thermal and radiative impacts of photovoltaic canopies on pavement surface temperatures. Preuzeto sa www.sciencedirect.com: https://keep.lib.asu.edu/system/files/2022-05/1-s2.0-s0038092x06002908-main_0.pdf

Jessi Wyatt, M. K. (2021). GREAT PLAINS INSTITUTE. Preuzeto sa https://betterenergy.org/: https://betterenergy.org/blog/the-true-land-footprint-of-solar-energy/

Kalmar Z., Batas-Bjelić, I., Molnar D. (2021). Stvarna cena struje iz uglja u Srbiji. Preuzeto sa CEKOR: https://www.cekor.org/documents/pages/718_1.pdf

Knier, G. (2008). The Edge of Sunshine. Preuzeto sa NASA SCIENCE: https://science.nasa.gov/science-news/science-at-nasa/2002/solarcells/

KSENG. (2024). Preuzeto sa https://www.ksengsolar.com/OEM-Custom-High-Strength-Carbon-Steel-Solar-Carport-Manufacturer-pd715998888.html

Lumos sola. (2024). Preuzeto sa Beautiful Solar Carports Ideal for Shade & Clean Energy Production!: https://lumossolar.com/beautiful-solar-carports-ideal-for-shade-clean-energy-production/

McKinsey. (2022, November 4). Europe's EV opportunity—and the charging infrastructure needed to meet it. Preuzeto sa www.mckinsey.com: https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/europes-ev-opportunity-and-the-charging-infrastructure-needed-to-meet-it

Mikić, M. J. (2017). Potencijali obnovljivih izvora energije i sunčane energije u Srbiji. Zbornik MeđUnarodne Konferencije O Obnovljivim Izvorima ElektričNe Energije – MKOIEE (str. 4(1), 319-326). https://izdanja.smeits.rs/index.php/mkoiee/article/view/2682.

Mikić, M., & Jovanović, I. (2017). Renewable Energy and Solar Energy Potential in Serbia. Proceedings of the 4th International Conference on Renewable Electrical Power Sources IV MKOIEE (str. 319-326). Belgrade: izdanja.smeits.rs. Preuzeto sa www.gps-coordinates.net: https://www.gps-coordinates.net/

Milosavljević, D. D. (2013). PROUČAVANJE ENERGETSKE EFIKASNOSTI SOLARNIH ELEKTRANA U REPUBLICI SRBIJI I REPUBLICI SRPSKOJ. Preuzeto sa www.pmf.ni.ac.rs: www.pmf.ni.ac.rs/download/doktorati/dokumenta/disertacije/2013/2013-11-21-md.pdf

Nenadović, A. (2024, 04.). Privrednici čekaju pojeftinjenje struje, pojedinci već dobijaju „nepristojne ponude“. Preuzeto sa Nova ekonomija: https://novaekonomija.rs/vesti-iz-zemlje/privrednici-cekaju-pojeftinjenje-struje-pojedinci-vec-dobijaju-nepristojne-ponude

NREL. (2012). Life Cycle Greenhouse Gas Emissions from Solar Photovoltaics. Preuzeto sa National Renewable Energy Laboratory: https://www.nrel.gov/docs/fy13osti/56487.pdf

OPR, Ben Rubin. (2013). Zero-Emission Vehicles in California: COMMUNITY READINESS GUIDEBOOK. Preuzeto sa Governor's Office of Planning and Research, State of California: https://opr.ca.gov/docs/ZEV_Guidebook.pdf

Petrović, T. (2019). Komparativna analiza troškova proizvodnje električne energije. Preuzeto sa https://repozitorij.efzg.unizg.hr/urn:nbn:hr:148:57253

Platini, I. (2024). Mobility Portal Europe. Preuzeto sa From the least to the most expensive: In which EU countries is recharging an EV most cost-effective?: https://mobilityportal.eu/eu-countries-recharging-ev/

Popivoda, Ž. (2014). zeljko.popivoda.com. Preuzeto sa https://zeljko.popivoda.com/potrosnja-struje/

PVGIS. (n.d.). Preuzeto sa PVGIS: https://re.jrc.ec.europa.eu/pvg_tools/en/#TMY

Solar Angle Calculator. (2019). Preuzeto sa www.solarelectricityhandbook.com: http://www.solarelectricityhandbook.com/solar-angle-calculator.html

Solar Electric Supply, Inc. (2024). Preuzeto sa Commercial Solar Carport Systems: https://www.solarelectricsupply.com/commercial-solar-systems/solar-carport

Stumbraite, R. (2024, June). solar explain. Preuzeto sa Turning Parking into Powerhouses: Solar Carports: https://solarexplain.eu/turning-parking-into-powerhouses-solar-carports/

Winton, N. (2024, April). Forbes. Preuzeto sa Europe To Buy Nearly 9 Million Fewer EVs By 2030 Than Expected: Repor: https://www.forbes.com/sites/neilwinton/2024/04/08/europe-to-buy-nearly-9-million-fewer-evs-by-2030-than-expected-report/

WWF-UK. (n.d.). How do I charge my electric car with renewable-energy. Preuzeto sa wwf.org.uk: https://www.wwf.org.uk/updates/how-do-i-charge-my-electric-car-renewable-energy

www.luxor.solar. (2024). Preuzeto sa https://www.luxor.solar/files/luxor/download/datasheets/LX_EL_N-Type_GG_BIF_SW_M132_600-620W_182R_EN.pdf

www.mre.gov.rs. (2023). www.mre.gov.rs/tekst/1115. Preuzeto sa www.mre.gov.rs: https://www.mre.gov.rs/tekst/1115/-integrisani-nacionalni-energetski-i-klimatski-plan-republike-srbije-za-period-do-2030-sa-vizijom-do-2050-godine.php

Yalantis. (2024). Understanding EV charging standards in the US and Europe. Preuzeto sa yalantis.com: https://yalantis.com/blog/ev-charging-standards/

Republic of Serbia Ministry of Mining and Energy. (2016). Energy Sector Development Strategy of the Republic of Serbia for the period by 2025 with projections by 2030. Preuzeto sa arhiva.mre.gov.rs: https://arhiva.mre.gov.rs/doc/efikasnost-izvori/23.06.02016%20ENERGY%20SECTOR%20DEVELOPMENT%20STRATEGY%20OF%20THE%20REPUBLIC%20OF%20SERBIA.pdf

U.S. Department of Energy. (n.d.). U.S. Department of Energy. Preuzeto sa U.S. Department of Energy's Vehicle Technologies Office: https://afdc.energy.gov/fuels/electricity-basics

"Službeni glasnik RS". (2015, December 8). Стратегија развоја енергетике Републике Србије до 2025. године са пројекцијама до 2030. године - 101/2015. Preuzeto sa pravno-informacioni-sistem.rs: https://pravno-informacioni-sistem.rs/eli/rep/sgrs/skupstina/ostalo/2015/101/1

(2018). Preuzeto sa solargis.com: https://solargis.com/maps-and-gis-data/download/serbia

ACEA. (2022, 03). European Electric Vehicle Charging Infrastructure Masterplan. Preuzeto sa www.acea.auto: https://www.acea.auto/files/Research-Whitepaper_A-European-EV-Charging-Infrastructure-Masterplan.pdf

Ali Asaad, A. A. (2022). Multi-objective optimal planning of EV charging stations and renewable energy resources for smart microgrids. Energy Science & Engineering, Volume 11, Issue 3 p. 1202-1218. Preuzeto sa Energy Science & EngineeringVolume 11, Issue 3 p. 1202-1218: https://scijournals.onlinelibrary.wiley.com/doi/10.1002/ese3.1385

Alok Sahu, N. Y. (2016). Floating photovoltaic power plant: A review. Renewable and Sustainable Energy Reviews , 815-824.

Archer, E. (2024). Switcher.ie. Preuzeto sa The cost of charging an electric car across Europe: https://switcher.ie/car-insurance/cost-of-charging-electric-car-europe/

balkangreenenergynews. (2023, July 12). Solar canopy for 15-hectare parking lot in France. Preuzeto sa balkangreenenergynews.com: https://balkangreenenergynews.com/solar-canopy-for-15-hectare-parking-lot-in-france/

balkangreenenergynews.com. (2019, January). Preuzeto sa Tendering maintenance of solar power system other garage facilities: https://balkangreenenergynews.com/tendering-maintenance-of-solar-power-system-other-garage-facilities/

Belgrade, "Parking Servis". (2024). www.parking-servis.co.rs. Preuzeto sa https://www.parking-servis.co.rs/garaza-obilicev-venac

Biljana Vlajić "Parking servis" Beograd. (2024, Jun 26). Email - Podaci Parking servis. Beograd, Serbia.

Bloomberg Adria. (2024, May). Električni punjači u Srbiji: Manje od 150, Hrvatska već preko 1.000. Preuzeto sa rs.bloombergadria.com: https://rs.bloombergadria.com/ostalo/opste/59230/elektricni-punjaci-u-srbiji-manje-od-150-hrvatska-vec-preko-1000/news/

Brankovic, S. (1999). Električne mreže i dalekovodi: Za III razred elektrotehničke škole. Beograd: енка Бранковић, Завод за уџбенике и наставна средства (Београд). Branković, SeZavod za udžbenike i nastavna sredstva. ISBN 978-86-17-06911-5.

Brennan Borlaug, S. S. (2020). Levelized Cost of Charging Electric Vehicles in the United States. Joule, Volume 4, Issue 7, Pages 1470-1485.

California Energy Commission. (2018). Electric Vehicle Charger Selection Guide. Preuzeto sa afdc.energy.gov: https://afdc.energy.gov/files/u/publication/EV_Charger_Selection_Guide_2018-01-112.pdf

cdn.enfsolar. (2024). Preuzeto sa https://cdn.enfsolar.com/z/pp/7a6h09wx6iu/59704ce0a720a.pdf

CleanTechnica. (2017, 11). Electric Vehicle Charging Infrastructure: Guidelines for Cities. Preuzeto sa CleanTechnica: https://cleantechnica.com/wp-content/uploads/2024/02/EV-Charging-Infrastructure-Guidelines-for-Cities.pdf

creativecommons. (n.d.). Preuzeto sa https://creativecommons.org/compatiblelicenses

Dragović, N. M. (2019). POTENTIALS AND PROSPECTS FOR IMPLEMENTATION OF RENEWABLE ENERGY SOURCES IN SERBIA. THERMAL SCIENCE, Vol. 23, No. 5B, 2895-2907.

Đurišić, Ž., & Škrbic, B. (2022). Solar and Wind Energy Potential for Strategic Planning of Decarbonisation of Electricity Production in Serbia. EEE, energija, ekonomija, ekologija, no. 4, str. 10.46793/EEE22-4.01D.

EDS. (2024). elektrodistribucija.rs. Preuzeto sa elektrodistribucija.rs/o-nama/tehnicki-podaci-o-konzumu: https://elektrodistribucija.rs/o-nama/tehnicki-podaci-o-konzumu

Elektroenergetika. (2018). elektroenergetika.info. Preuzeto sa https://www.elektroenergetika.info/m/blogceli.php?sifra=220&puta=

EMS RS. (2024). Preuzeto sa ems.rs/en/organisation-3: https://ems.rs/en/organisation-3

EMS RS. (2024). Preuzeto sa ems.rs/en/description-and-capacities: https://ems.rs/en/description-and-capacities/

Energetski portal. (2020, December). OTVORENA PRVA "ZELENA GARAŽA" U KRAGUJEVCU. MAGAZIN ENERGETSKOG PORTALA, str. 32-33.

energetskiportal.rs. (n.d.). https://energetskiportal.rs/ministarstvo/fid-in-tarife/. Preuzeto sa energetskiportal.rs: https://energetskiportal.rs/ministarstvo/fid-in-tarife/

ENF. (2024). www.enfsolar.com. Preuzeto sa Solar Mounting System Directory: https://www.enfsolar.com/pv/mounting-system

Enphase Energy. (2023, November 30). sustainable-ev-charging-solar-powered-evs. Preuzeto sa enphase.com: https://enphase.com/ev-chargers/learn/sustainable-ev-charging-solar-powered-evs

EUROSTAT. (2024, April). ec.europa.eu. Preuzeto sa Electricity prices for non-household consumers: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Electricity_price_statistics#Electricity_prices_for_non-household_consumers

Fechner, H. (2023). U Module 3 - Solar Energy, Solar Heating & Photovoltaics. TU WIEN Continuing Education Center.

Futr. (2024, June). futr.energy. Preuzeto sa Are Solar Carports Worth Investing in? : https://futr.energy/knowledge/are-solar-carports-worth-investing/

Geosrbija. (n.d.). Preuzeto sa file:///C:/Users/dusic/Downloads/5ddcc6e569b9c9b894f9746f31daf34c3d425fb5.pdf

GreenWay Infrastructure s. r. o. (2018). ev4cities.greenwaynetwork.com. Preuzeto sa greenwaynetwork.com: https://ev4cities.greenwaynetwork.com/

Hartung Katalin, H. R. (2014). Regional impacts of different photovoltaic systems. IDResearch Kft. / Publikon Kiadó, Pécs.

IEA. (2024). Preuzeto sa Global EV Outlook 2024: https://www.iea.org/reports/global-ev-outlook-2024/trends-in-electric-cars

IEA-PVPS, T. (2020). Environmental life cycle assessment of electricity from PV systems. IEA-PVPS , Task12. Preuzeto sa https://iea-pvps.org/fact-sheets/factsheet-environmental-life-cycle-assessment-of-electricity-from-pv-systems/

IRENA. (2016). The Power to change: Solar and Wind cost reduction potential to 2025. IRENA.

IRENA. (2016). The Power to change: Solar and Wind cost reduction potential to 2025. IRENA.

IRENA. (2023). Renewable power generation costs in 2022. Abu Dhabi: International Renewable Energy Agency.

IRENA, I.-P. (2016). End of life management Solar Photovoltaic Panels.

Jay S. Golden, J. C. (2006, December). A comparative study of the thermal and radiative impacts of photovoltaic canopies on pavement surface temperatures. Preuzeto sa www.sciencedirect.com: https://keep.lib.asu.edu/system/files/2022-05/1-s2.0-s0038092x06002908-main_0.pdf

Jessi Wyatt, M. K. (2021). GREAT PLAINS INSTITUTE. Preuzeto sa https://betterenergy.org/: https://betterenergy.org/blog/the-true-land-footprint-of-solar-energy/

Kalmar Z., Batas-Bjelić, I., Molnar D. (2021). Stvarna cena struje iz uglja u Srbiji. Preuzeto sa CEKOR: https://www.cekor.org/documents/pages/718_1.pdf

Knier, G. (2008). The Edge of Sunshine. Preuzeto sa NASA SCIENCE: https://science.nasa.gov/science-news/science-at-nasa/2002/solarcells/

KSENG. (2024). Preuzeto sa https://www.ksengsolar.com/OEM-Custom-High-Strength-Carbon-Steel-Solar-Carport-Manufacturer-pd715998888.html

Lumos sola. (2024). Preuzeto sa Beautiful Solar Carports Ideal for Shade & Clean Energy Production!: https://lumossolar.com/beautiful-solar-carports-ideal-for-shade-clean-energy-production/

McKinsey. (2022, November 4). Europe's EV opportunity—and the charging infrastructure needed to meet it. Preuzeto sa www.mckinsey.com: https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/europes-ev-opportunity-and-the-charging-infrastructure-needed-to-meet-it

Mikić, M. J. (2017). Potencijali obnovljivih izvora energije i sunčane energije u Srbiji. Zbornik MeđUnarodne Konferencije O Obnovljivim Izvorima ElektričNe Energije – MKOIEE (str. 4(1), 319-326). https://izdanja.smeits.rs/index.php/mkoiee/article/view/2682.

Mikić, M., & Jovanović, I. (2017). Renewable Energy and Solar Energy Potential in Serbia. Proceedings of the 4th International Conference on Renewable Electrical Power Sources IV MKOIEE (str. 319-326). Belgrade: izdanja.smeits.rs. Preuzeto sa www.gps-coordinates.net: https://www.gps-coordinates.net/

Milosavljević, D. D. (2013). PROUČAVANJE ENERGETSKE EFIKASNOSTI SOLARNIH ELEKTRANA U REPUBLICI SRBIJI I REPUBLICI SRPSKOJ. Preuzeto sa www.pmf.ni.ac.rs: www.pmf.ni.ac.rs/download/doktorati/dokumenta/disertacije/2013/2013-11-21-md.pdf

Nenadović, A. (2024, 04.). Privrednici čekaju pojeftinjenje struje, pojedinci već dobijaju „nepristojne ponude". Preuzeto sa Nova ekonomija: https://novaekonomija.rs/vesti-iz-zemlje/privrednici-cekaju-pojeftinjenje-struje-pojedinci-vec-dobijaju-nepristojne-ponude

NREL. (2012). Life Cycle Greenhouse Gas Emissions from Solar Photovoltaics. Preuzeto sa National Renewable Energy Laboratory: https://www.nrel.gov/docs/fy13osti/56487.pdf

OPR, Ben Rubin. (2013). Zero-Emission Vehicles in California: COMMUNITY READINESS GUIDEBOOK. Preuzeto sa Governor's Office of Planning and Research, State of California: https://opr.ca.gov/docs/ZEV_Guidebook.pdf

Petrović, T. (2019). Komparativna analiza troškova proizvodnje električne energije. Preuzeto sa https://repozitorij.efzg.unizg.hr/urn:nbn:hr:148:57253

Platini, I. (2024). Mobility Portal Europe. Preuzeto sa From the least to the most expensive: In which EU countries is recharging an EV most cost-effective?: https://mobilityportal.eu/eu-countries-recharging-ev/

Popivoda, Ž. (2014). zeljko.popivoda.com. Preuzeto sa https://zeljko.popivoda.com/potrosnja-struje/

PVGIS. (n.d.). Preuzeto sa PVGIS: https://re.jrc.ec.europa.eu/pvg_tools/en/#TMY

Solar Angle Calculator. (2019). Preuzeto sa www.solarelectricityhandbook.com: http://www.solarelectricityhandbook.com/solar-angle-calculator.html

Solar Electric Supply, Inc. (2024). Preuzeto sa Commercial Solar Carport Systems: https://www.solarelectricsupply.com/commercial-solar-systems/solar-carport

Stumbraite, R. (2024, June). solar explain. Preuzeto sa Turning Parking into Powerhouses: Solar Carports: https://solarexplain.eu/turning-parking-into-powerhouses-solar-carports/

Winton, N. (2024, April). Forbes. Preuzeto sa Europe To Buy Nearly 9 Million Fewer EVs By 2030 Than Expected: Repor: https://www.forbes.com/sites/neilwinton/2024/04/08/europe-to-buy-nearly-9-million-fewer-evs-by-2030-than-expected-report/

WWF-UK. (n.d.). How do I charge my electric car with renewable-energy. Preuzeto sa wwf.org.uk: https://www.wwf.org.uk/updates/how-do-i-charge-my-electric-car-renewable-energy

www.luxor.solar. (2024). Preuzeto sa https://www.luxor.solar/files/luxor/download/datasheets/LX_EL_N-Type_GG_BIF_SW_M132_600-620W_182R_EN.pdf

www.mre.gov.rs. (2023). www.mre.gov.rs/tekst/1115. Preuzeto sa www.mre.gov.rs: https://www.mre.gov.rs/tekst/1115/-integrisani-nacionalni-energetski-i-klimatski-plan-republike-srbije-za-period-do-2030-sa-vizijom-do-2050-godine.php

Yalantis. (2024). Understanding EV charging standards in the US and Europe. Preuzeto sa yalantis.com: https://yalantis.com/blog/ev-charging-standards/

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List of abbreviations and symbols

kW	Kilowatt
MW	Megawatt
kWh	Kilowatt hours
MWh	Megawatt hours
IAE	International Energy Agency
EU	European Union
RS	Republic of Serbia
RES	Renewable Energy Sources
EPS	Electric Power Industry of Serbia
EDS	Electric Distribution of Serbia
PV	Photovoltaics
EV	Electric Vehicle
BEV	Battery Electric Vehicle
CO2ef el	Emission factor for electricity
Ct	Cash flow in year t
CRF	Capital recovery factor
α	Annuity
r	Discount rate
C	Investment Cost
Cinv	Specific Investment Cost
LRGC	Long Run Generation Costs
CO2	Carbon Dioxide
gr	Gram
kg	Kilogram
t	Ton
gr	Gram
NREAP	National renewable energy action plan
NPV	Net present value
EPRI	Electric Power Research Institute
LCA	Life cycle assessment
O&M	Operation & Maintenance
AC	Alternating current
DC	Direct current
Sc-Si	Monocrystalline
Mc-Si	Polycrystalline
STC	Standard test conditions
FLH	Full load hours
PPA	Power Purchase Agreements
EVSE	Electric vehicle supply equipment
CCS	Combined Charging System
CHAdeMO	CHArge de MOve
SAIFI	System Average Interruption Frequency Index
PR	Performance ratio
GHG	Greenhouse gas
SIC	Specific Investment Cost

APPENDICES

Appendix 1.1: **50,4 kW PV rooftop plant “Obilicev Venac”, Dynamic Investment Calculation, scenario 1**

#	Input Description	50,4 kW			
3	Rated Capacity MW	0,0504			
4	Full Load Hours	1.186			
5	Specific Investment Costs (EUR/MW)	925.000			
6	Inverter replacement (EUR)	4.862	10%	268.961	NPV
7	Investment Horizon (Years)	25		110,21	LRGC (incl. Cost Escal.)
8	Electricity Price (EUR/MWh)	380			
9	Inflation (%) **	3,00%			
10	O&M costs (EUR/MW)	35			
11	Yearly Electricity Generation (MWh)	59,77			
12	Battery cost (EUR)	2.000			
13	Yearly production CO2 (t)	42,32			
14	Green certificate (EUR/tCO2)	50			
15	Investment Costs (EUR)	48.620			
16	Residual value (EUR)	38.896	80%		
17	* 25 YR EURRS 2,4% on 23.8.2024, plus equity risk premium 3%				
18	** Assumption for a normalised long term inflation rate				
19					

#	Year	0	1	2	3	4	5	6	7	8	9	10	11	12
21	Investment Costs (EUR)	48.620	-	-	-	-	-	-	-	-	-	-	-	-
22	Revenue Electricity		22.713	22.713	22.713	22.713	22.713	22.713	22.713	22.713	22.713	22.713	22.713	22.713
23	Revenue CO2		2.116	2.116	2.116	2.116	2.116	2.116	2.116	2.116	2.116	2.116	2.116	2.116
24	**Total revenue**		**24.829**	**24.829**	**24.829**	**24.829**	**24.829**	**24.829**	**24.829**	**24.829**	**24.829**	**24.829**	**24.829**	**24.829**
25	Inverter replacement (EUR)		-	-	-	-	-	-	-	-	-	-	-	-
26	O&M costs (EUR/MW)		2.092	2.155	2.219	2.286	2.355	2.425	2.498	2.573	2.650	2.730	2.811	2.896
27	**Total costs**		**2.092**	**2.155**	**2.219**	**2.286**	**2.355**	**2.425**	**2.498**	**2.573**	**2.650**	**2.730**	**2.811**	**2.896**
28	Residual value (EUR)													
29	**Total cash flow**	**- 48.620**	**22.737**	**22.674**	**22.609**	**22.543**	**22.474**	**22.403**	**22.331**	**22.256**	**22.179**	**22.099**	**22.017**	**21.933**
30														
31	Discounted CF	- 48.620	21.572	20.410	19.309	18.266	17.277	16.341	15.453	14.612	13.816	13.061	12.346	11.668
32	NPV	268.961												
33	Discounted cost	48.620	1.985	1.940	1.895	1.852	1.810	1.769	1.729	1.689	1.651	1.613	1.576	1.541
34	Sum discounted cost	89.232												
35														
36	CRF	0,074												
37	LRGC (incl. Cost Escal.)	110,21												
38														
39	Annuity (B)	- 3.589												
40	Annuity	19.856												
41														
42	Cumulative CF	- 48.620	- 27.048	- 6.638	12.671	30.937	48.214	64.555	80.008	94.621	108.436	121.497	133.843	145.511
43	Years to Break even		0,0	0,0	2,3	3,3	4,4	5,4	6,4	7,5	8,5	9,5	10,5	11,5
44	Absolute CF	48.620	27.048	6.638	12.671	30.937	48.214	64.555	80.008	94.621	108.436	121.497	133.843	145.511
45	Absolute cumulative CF two periods		75.668	33.686	19.309	43.608	79.152	112.770	144.564	174.629	203.057	229.933	255.340	279.354
46	Monthy 2 year CF		6.306	2.807	1.609	3.634	6.596	9.397	12.047	14.552	16.921	19.161	21.278	23.279
47	Months calc	-	- 4	- 2	8	9	7	7	7	7	6	6	6	6
48														
49	BE 119,67	9,1												
50	BE 380	2,3												

#	Year	13	14	15	16	17	18	19	20	21	22	23	24	25	
21	Investment Costs (EUR)	-	-	-	-	-	-	-	-	-	-	-	-	-	
22	Revenue Electricity	22.713	22.713	22.713	22.713	22.713	22.713	22.713	22.713	22.713	22.713	22.713	22.713	22.713	
23	Revenue CO2	2.116	2.116	2.116	2.116	2.116	2.116	2.116	2.116	2.116	2.116	2.116	2.116	2.116	
24	**Total revenue**	**24.829**	**24.829**	**24.829**	**24.829**	**24.829**	**24.829**	**24.829**	**24.829**	**24.829**	**24.829**	**24.829**	**24.829**	**24.829**	
25	Inverter replacement (EUR)	4.862	-	-	-	-	-	-	-	-	-	-	-	-	
26	O&M costs (EUR/MW)	2.983	3.072	3.164	3.259	3.357	3.458	3.561	3.668	3.778	3.892	4.008	4.129	4.253	
27	**Total costs**	**7.845**	**3.072**	**3.164**	**3.259**	**3.357**	**3.458**	**3.561**	**3.668**	**3.778**	**3.892**	**4.008**	**4.129**	**4.253**	
28	Residual value (EUR)													81.440	Nominal CF
29	**Total cash flow**	**16.984**	**21.757**	**21.664**	**21.569**	**21.472**	**21.371**	**21.267**	**21.160**	**21.050**	**20.937**	**20.820**	**20.700**	**102.016**	572.402
31	Discounted CF	8.573	10.419	9.843	9.298	8.782	8.293	7.830	7.391	6.976	6.583	6.211	5.859	27.394	
33	Discounted cost	3.960	1.471	1.438	1.405	1.373	1.342	1.311	1.281	1.252	1.224	1.196	1.169	1.142	
42	Cumulative CF	154.084	164.502	174.346	183.644	192.425	200.718	208.547	215.939	222.915	229.497	235.708	241.567	268.961	
43	Years to Break even	12,5	13,5	14,5	15,5	16,5	17,5	18,5	19,5	20,5	21,5	22,5	23,5	24,5	
44	Absolute CF	154.084	164.502	174.346	183.644	192.425	200.718	208.547	215.939	222.915	229.497	235.708	241.567	268.961	
45	Absolute cumulative CF two periods	299.594	318.586	338.848	357.989	376.069	393.143	409.265	424.486	438.853	452.412	465.206	477.275	510.528	
46	Monthy 2 year CF	24.966	26.549	28.237	29.832	31.339	32.762	34.105	35.374	36.571	37.701	38.767	39.773	42.544	
47	Months calc	6	6	6	6	6	6	6	6	6	6	6	6	6	

Appendix 1.2 : **50,4 kW PV rooftop plant "Obilicev Venac", Dynamic Investment Calculation, scenario 2**

1	Input Description	50,4 kW																											
3	Rated Capacity MW		0,0504																										
4	Full Load Hours		1.186																										
5	Specific Investment Costs (EUR/MW)		925.000																										
6	Inverter replacement (EUR)		4.862	10%		#VALUE!	NPV																						
7	Investment Horizon (Years)		25			110,21	LRGC (incl. Cost Escal.)																						
8	Electricity Price (EUR/MWh)		119,67																										
9	Inflation (%) **		3,00%																										
10	O&M costs (EUR/MW)		35																										
11	Yearly Electricity Generation (MWh)		59,77																										
12	Battery cost (EUR)		2.000																										
13	Yearly production CO2 (t)		42,32																										
14	Green certificate (EUR/tCO2)		50																										
15	Investment Costs (EUR)		48.620																										
16	Residual value (EUR)		38.896	80%																									
17	* 25 YR EURIRS 2,4% on 23.8.2024, plus equity risk premium 3%																												
18	** Assumption for a normalised long term inflation rate																												
19																													
20	Year		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	
21	Investment Costs (EUR)		48.620	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
22	Revenue Electricity			#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	
23	Revenue CO2			2.116	2.116	2.116	2.116	2.116	2.116	2.116	2.116	2.116	2.116	2.116	2.116	2.116	2.116	2.116	2.116	2.116	2.116	2.116	2.116	2.116	2.116	2.116	2.116	2.116	
24	**Total revenue**			#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	
25	Inverter replacement (EUR)			-	-	-	-	-	-	-	-	-	-	-	-	4.862	-	-	-	-	-	-	-	-	-	-	-	-	
26	O&M costs (EUR/MW)			2.092	2.155	2.219	2.286	2.355	2.425	2.498	2.573	2.650	2.730	2.811	2.896	2.983	3.072	3.164	3.259	3.357	3.458	3.561	3.668	3.778	3.892	4.008	4.129	4.253	
27	**Total costs**			**2.092**	**2.155**	**2.219**	**2.286**	**2.355**	**2.425**	**2.498**	**2.573**	**2.650**	**2.730**	**2.811**	**2.896**	**7.845**	**3.072**	**3.164**	**3.259**	**3.357**	**3.458**	**3.561**	**3.668**	**3.778**	**3.892**	**4.008**	**4.129**	**4.253**	
28	Residual value (EUR)																									81.440	Nominal CF
29	**Total cash flow**		**48.620**	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!
30																													
31	Discounted CF		48.620	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	
32	NPV	#VALUE!																											
33	Discounted cost		48.620	1.985	1.940	1.895	1.852	1.810	1.769	1.729	1.689	1.651	1.613	1.576	1.541	3.960	1.471	1.438	1.405	1.373	1.342	1.311	1.281	1.252	1.224	1.196	1.169	1.142	
34	Sum discounted cost		89.232																										
35																													
36	CRF		0,074																										
37	LRGC (incl. Cost Escal.)		110,21																										
38																													
39	Annuity (B)		3.589																										
40	Annuity	#VALUE!																											
41																													
42	Cumulative CF		48.620	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	
43	Years to Break even			#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	
44	Absolute CF		48.620	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	
45	Absolute cumulative CF two periods			#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	
46	Monthy 2 year CF			#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	
47	Months calc			#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	
48																													
49	BE 119,67		9,1																										
50	BE 380		2,3																										

Appendix 1.3: **50,4 kW PV canopy plant “Novi Beograd”, Dynamic Investment Calculation, CO2 revenues included.**

Input Description				
Inverter replacement (EUR)	47.138	9%	2.092.183	NPV
Investment Horizon (Years)	25		130,58	LRGC (incl. Cost Escal.)
Electricity Price (EUR/MWh)	380			
Inflation (%) **	3,00%			
O&M costs (EUR/MW)	35			
Yearly Electricity Generation (MWh)	484,38			
Battery cost (EUR)	20.000			
Yearly production CO2 (t)	324,94			
Green certificate (EUR/tCO2)	50			
Investment Costs (EUR)	523.750			
Residual value (EUR)	419.000	80%		

* 25 YR EURIRS 2,4% on 23.8.2024, plus equ

** Assumption for a normalised long term i

Year	0	1	2	3	4	5	6	7	8	9	10	11	12
Investment Costs (EUR)	523.750	-	-	-	-	-	-	-	-	-	-	-	-
Revenue Electricity		184.064	184.064	184.064	184.064	184.064	184.064	184.064	184.064	184.064	184.064	184.064	184.064
Revenue CO2		16.247	16.247	16.247	16.247	16.247	16.247	16.247	16.247	16.247	16.247	16.247	16.247
Total revenue		**200.311**	**200.311**	**200.311**	**200.311**	**200.311**	**200.311**	**200.311**	**200.311**	**200.311**	**200.311**	**200.311**	**200.311**
Inverter replacement (EUR)		-	-	-	-	-	-	-	-	-	-	-	-
O&M costs (EUR/MW)		16.953	17.462	17.986	18.525	19.081	19.654	20.243	20.850	21.476	22.120	22.784	23.467
Total costs		**16.953**	**17.462**	**17.986**	**18.525**	**19.081**	**19.654**	**20.243**	**20.850**	**21.476**	**22.120**	**22.784**	**23.467**
Residual value (EUR)													
Total cash flow	**523.750**	**183.358**	**182.850**	**182.326**	**181.786**	**181.230**	**180.658**	**180.068**	**179.461**	**178.835**	**178.191**	**177.528**	**176.844**
Discounted CF	523.750	173.964	164.593	155.713	147.298	139.325	131.769	124.610	117.827	111.401	105.313	99.545	94.081
NPV	2.092.183												
Discounted cost	523.750	16.085	15.718	15.361	15.011	14.669	14.335	14.009	13.690	13.378	13.073	12.776	12.485
Sum discounted cost	856.776												
CRF	0,074												
LRGC (incl. Cost Escal.)	130,58												
Annuity (β)	38.665												
Annuity	154.452												
Cumulative CF	523.750	- 349.786	- 185.193	- 29.479	117.819	257.144	388.913	513.523	631.350	742.751	848.063	947.608	1.041.690
Years to Break even		0,0	0,0	0,0	3,2	4,3	5,4	6,4	7,4	8,5	9,5	10,5	11,5
Absolute CF	523.750	349.786	185.193	29.479	117.819	257.144	388.913	513.523	631.350	742.751	848.063	947.608	1.041.690
Absolute cumulative CF two periods		873.536	534.978	214.672	147.298	374.963	646.057	902.436	1.144.873	1.374.101	1.590.814	1.795.672	1.989.298
Monthy 2 year CF		72.795	44.582	17.889	12.275	31.247	53.838	75.203	95.406	114.508	132.568	149.639	165.775
Months calc		- 5	- 4	- 2	10	8	7	7	7	6	6	6	6

Year	13	14	15	16	17	18	19	20	21	22	23	24	25	
Investment Costs (EUR)	-	-	-	-	-	-	-	-	-	-	-	-	-	
Revenue Electricity	184.064	184.064	184.064	184.064	184.064	184.064	184.064	184.064	184.064	184.064	184.064	184.064	184.064	
Revenue CO2	16.247	16.247	16.247	16.247	16.247	16.247	16.247	16.247	16.247	16.247	16.247	16.247	16.247	
Total revenue	**200.311**	**200.311**	**200.311**	**200.311**	**200.311**	**200.311**	**200.311**	**200.311**	**200.311**	**200.311**	**200.311**	**200.311**	**200.311**	
Inverter replacement (EUR)	47.138	-	-	-	-	-	-	-	-	-	-	-	-	
O&M costs (EUR/MW)	24.171	24.896	25.643	26.413	27.205	28.021	28.862	29.728	30.620	31.538	32.484	33.459	34.463	
Total costs	**71.309**	**24.896**	**25.643**	**26.413**	**27.205**	**28.021**	**28.862**	**29.728**	**30.620**	**31.538**	**32.484**	**33.459**	**34.463**	
Residual value (EUR)													877.293	Nominal CF
Total cash flow	**129.003**	**175.415**	**174.668**	**173.899**	**173.106**	**172.290**	**171.450**	**170.584**	**169.692**	**168.773**	**167.827**	**166.853**	**1.043.142**	**4.696.08[illegible]**
Discounted CF	65.113	84.004	79.360	74.963	70.798	66.854	63.120	59.583	56.235	53.065	50.064	47.224	280.110	
NPV														
Discounted cost	35.993	11.923	11.651	11.386	11.127	10.873	10.626	10.384	10.147	9.916	9.690	9.470	9.254	
Sum discounted cost														
CRF														
LRGC (incl. Cost Escal.)														
Annuity (β)														
Annuity														
Cumulative CF	1.106.803	1.190.807	1.270.167	1.345.130	1.415.928	1.482.782	1.545.902	1.605.486	1.661.721	1.714.786	1.764.850	1.812.074	2.092.183	
Years to Break even	12,5	13,5	14,5	15,5	16,5	17,5	18,5	19,5	20,5	21,5	22,5	23,5	24,5	
Absolute CF	1.106.803	1.190.807	1.270.167	1.345.130	1.415.928	1.482.782	1.545.902	1.605.486	1.661.721	1.714.786	1.764.850	1.812.074	2.092.183	
Absolute cumulative CF two periods	2.148.492	2.297.609	2.460.973	2.615.297	2.761.058	2.898.711	3.028.685	3.151.388	3.267.206	3.376.507	3.479.636	3.576.924	3.904.257	
Monthy 2 year CF	179.041	191.467	205.081	217.941	230.088	241.559	252.390	262.616	272.267	281.376	289.970	298.077	325.355	
Months calc	6	6	6	6	6	6	6	6	6	6	6	6	6	

Appendix 1.4: **50,4 kW PV canopy plant “Novi Beograd”, Dynamic Investment Calculation, CO2 revenues not included.**

1	Input Description				
6	Inverter replacement (EUR)	47.138	9%	1.872.104	NPV
7	Investment Horizon (Years)	25		130,58	LRGC (incl. Cost Escal.)
8	Electricity Price (EUR/MWh)	380			
9	Inflation (%) **	3,00%			
10	O&M costs (EUR/MW)	35			
11	Yearly Electricity Generation (MWh)	484,38			
12	Battery cost (EUR)	20.000			
13	Yearly production CO2 (t)	324,94			
14	Green certificate (EUR/tCO2)	0			
15	Investment Costs (EUR)	523.750			
16	Residual value (EUR)	419.000	80%		
17	* 25 YR EURIRS 2,4% on 23.8.2024, plus equ				
18	** Assumption for a normalised long term i				
19					

20	Year	0	1	2	3	4	5	6	7	8	9	10	11	12
21	Investment Costs (EUR)	523.750	-	-	-	-	-	-	-	-	-	-	-	-
22	Revenue Electricity		184.064	184.064	184.064	184.064	184.064	184.064	184.064	184.064	184.064	184.064	184.064	184.064
23	Revenue CO2		-	-	-	-	-	-	-	-	-	-	-	-
24	**Total revenue**		**184.064**	**184.064**	**184.064**	**184.064**	**184.064**	**184.064**	**184.064**	**184.064**	**184.064**	**184.064**	**184.064**	**184.064**
25	Inverter replacement (EUR)		-	-	-	-	-	-	-	-	-	-	-	-
26	O&M costs (EUR/MW)		16.953	17.462	17.986	18.525	19.081	19.654	20.243	20.850	21.476	22.120	22.784	23.467
27	**Total costs**		**16.953**	**17.462**	**17.986**	**18.525**	**19.081**	**19.654**	**20.243**	**20.850**	**21.476**	**22.120**	**22.784**	**23.467**
28	Residual value (EUR)													
29	**Total cash flow**	**523.750**	**167.111**	**166.603**	**166.079**	**165.539**	**164.983**	**164.411**	**163.821**	**163.214**	**162.588**	**161.944**	**161.281**	**160.597**
30														
31	Discounted CF	523.750	158.549	149.969	141.838	134.134	126.834	119.919	113.367	107.160	101.280	95.710	90.435	85.438
32	NPV	1.872.104												
33	Discounted cost	523.750	16.085	15.718	15.361	15.011	14.669	14.335	14.009	13.690	13.378	13.073	12.776	12.485
34	Sum discounted cost	856.776												
35														
36	CRF	0,074												
37	LRGC (incl. Cost Escal.)	130,58												
38														
39	Annuity (B)	38.665												
40	Annuity	138.205												
41														
42	Cumulative CF	523.750	- 365.201	- 215.232	- 73.394	60.740	187.574	307.493	420.859	528.019	629.300	725.010	815.445	900.883
43	Years to Break even		0,0	0,0	0,0	3,5	4,2	5,4	6,4	7,4	8,5	9,5	10,5	11,5
44	Absolute CF	523.750	365.201	215.232	73.394	60.740	187.574	307.493	420.859	528.019	629.300	725.010	815.445	900.883
45	Absolute cumulative CF two periods		888.951	580.433	288.626	134.134	248.313	495.067	728.352	948.879	1.157.319	1.354.309	1.540.455	1.716.327
46	Monthy 2 year CF		74.079	48.369	24.052	11.178	20.693	41.256	60.696	79.073	96.443	112.859	128.371	143.027
47	Months calc		- 5	- 4	- 3	5	9	7	7	7	7	6	6	6
48														

20	Year	13	14	15	16	17	18	19	20	21	22	23	24	25	
21	Investment Costs (EUR)	-	-	-	-	-	-	-	-	-	-	-	-	-	
22	Revenue Electricity	184.064	184.064	184.064	184.064	184.064	184.064	184.064	184.064	184.064	184.064	184.064	184.064	184.064	
23	Revenue CO2	-	-	-	-	-	-	-	-	-	-	-	-	-	
24	**Total revenue**	**184.064**	**184.064**	**184.064**	**184.064**	**184.064**	**184.064**	**184.064**	**184.064**	**184.064**	**184.064**	**184.064**	**184.064**	**184.064**	
25	Inverter replacement (EUR)	47.138	-	-	-	-	-	-	-	-	-	-	-	-	
26	O&M costs (EUR/MW)	24.171	24.896	25.643	26.413	27.205	28.021	28.862	29.728	30.620	31.538	32.484	33.459	34.463	
27	**Total costs**	**71.309**	**24.896**	**25.643**	**26.413**	**27.205**	**28.021**	**28.862**	**29.728**	**30.620**	**31.538**	**32.484**	**33.459**	**34.463**	
28	Residual value (EUR)													877.293	Nominal CF
29	**Total cash flow**	**112.756**	**159.168**	**158.421**	**157.652**	**156.859**	**156.043**	**155.203**	**154.337**	**153.445**	**152.526**	**151.580**	**150.606**	**1.026.895**	**4.289.911**
30															
31	Discounted CF	56.913	76.223	71.979	67.959	64.153	60.550	57.138	53.908	50.851	47.957	45.218	42.625	275.747	
32	NPV														
33	Discounted cost	35.993	11.923	11.651	11.386	11.127	10.873	10.626	10.384	10.147	9.916	9.690	9.470	9.254	
34	Sum discounted cost														
35															
36	CRF														
37	LRGC (incl. Cost Escal.)														
38															
39	Annuity (B)														
40	Annuity														
41															
42	Cumulative CF	957.795	1.034.019	1.105.997	1.173.956	1.238.110	1.298.660	1.355.798	1.409.707	1.460.558	1.508.515	1.553.732	1.596.357	1.872.104	
43	Years to Break even	12,5	13,5	14,5	15,5	16,5	17,5	18,5	19,5	20,5	21,5	22,5	23,5	24,5	
44	Absolute CF	957.795	1.034.019	1.105.997	1.173.956	1.238.110	1.298.660	1.355.798	1.409.707	1.460.558	1.508.515	1.553.732	1.596.357	1.872.104	
45	Absolute cumulative CF two periods	1.858.678	1.991.814	2.140.016	2.279.954	2.412.066	2.536.770	2.654.458	2.765.505	2.870.264	2.969.072	3.062.247	3.150.090	3.468.462	
46	Monthy 2 year CF	154.890	165.984	178.335	189.996	201.006	211.397	221.205	230.459	239.189	247.423	255.187	262.507	289.038	
47	Months calc	6	6	6	6	6	6	6	6	6	6	6	6	6	
48															