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TOWARDS SUSTAINABLE TRANSPORTATION: MODELING AND SIMULATION OF PV PANEL IMPLEMENTATION ON NATIONAL HIGHWAYS FOR CHARGING ELECTRIC VEHICLES WHICH LEADS TO MITIGATE CARBON EMISSION

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Efficient land use is increasingly critical due to rising land costs. In the realm of solar photovoltaic energy, this entails exploring innovative areas for panel installation. A study examined the feasibility of erecting roof structures along national highways to harness the adjacent land for energy production. This approach allows land utilization without substantial additional expenses. By implementing photovoltaic panels along a 200 km stretch of the Bucharest-Constanta national highway, with 2 meters on each side, and incorporating an electric car charging station in the middle, we promote electric vehicle adoption, curbing fossil fuel emissions. Our initiative addresses charging concerns and fosters clean energy sharing, thus reducing carbon footprints.

Keywords: Photovoltaic, National Highways, Carbon Emission, Electric Vehicles, Green Energy, Renewable Energy

1. Introduction

Solar energy is an important renewable energy source that has the potential to replace fossil fuels without emitting carbon. Besides its environmental advantages, PV systems can yield significant returns on investment that are competitive with fossil fuels and can meet global energy consumption requirements[1][2]. The global solar PV market has grown at a 50% annual rate over the last ten years [3]. Furthermore, the International Energy Agency indicates that PV systems will contribute 16% of global electricity by 2050.

However, some challenges remain that prevent the widespread use of PV systems. One obvious issue is the low efficiency of a solar PV panel, which converts

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only a percentage of solar energy into a usable form of energy (e.g., electricity), while the remainder is lost.

The typical efficiency range of solar PV systems is 15-20% [4]. In recent years, significant efforts have been made to overcome technical limitations, resulting in some studies reporting conversion efficiencies of over 40% [5]. However, higher efficiency solar panels come with a higher cost. Additionally, large installation areas are required for PV systems, which can be a limitation [6]. Demands for optimal use of available land increase as land costs rise over time. Installing integrated PV systems in densely populated urban areas is one method of overcoming the issues of limited space, high land prices, and matching these areas' energy requirements[7]. Nowadays, rather than large and centralized solar power plants, "distributed generation" with a solar PV system on plentiful rooftops is gaining popularity, providing onsite electricity generation for nearby customers with small capacities in building sectors. However, there are several issues with building-integrated PV systems, including owner relocation, renovation, and health and safety concerns[8].

Installing PV systems along national highways is a promising option due to various advantages they offer. Highways are usually public lands that are not in use, and their linear shape allows for economies of scale in installation. Being close to roads also lowers project and logistical costs. Moreover, highways have fewer obstacles such as trees and buildings that could block sunlight, and most extensions avoid densely populated or protected areas, which reduces the likelihood of civil complaints and environmental harm [9]. Although solar panel installation can be economically advantageous, it is a laborious and expensive process to locate suitable installation sites. Moreover, there are potential safety risks for surveyors working in areas with heavy traffic [10].

2. Literature Research

Transport plays an important role in people's lives, providing access to jobs, services, education, and relaxation while also boosting economic growth. As a result, transportation plays an important role in achieving some of the SDGs, such as improving urban and rural access, improving safety, and reducing air pollution[11]. The European Environment Agency states that transportation is the primary contributor to carbon emissions in Europe, responsible for 27% of the EU's total CO2 emissions. Cars and vans are responsible for over two-thirds of these emissions, according to the EEA [12]. The only industry where emissions have increased since 1990 is transportation, which accounts for a portion of the rise in emissions across the EU in 2015. In 2016, transportation-related emissions grew even more, and in 2017, EU oil consumption a reliable indicator of transportation CO_2 rose at its quickest rate since 2001 [13].

Since then, CO2 emission reduction strategies have dominated the global policy agenda, with a focus on the transportation sector. Oil dependence and climate change are highly contested issues among states and international decision-makers (UN Framework on Climate Change, UN-UNECE, European Commission); the car sector is challenged to enhance the environmental performance of its products, municipal governments, particularly those in the metropolitan level, are challenged by the mitigating the negative effects of the increasing demand for road transportation [13].

2.1 The software programs.

Among various software programs, MATLAB, and Meteonorm provide access to historical irradiation, temperature, humidity, precipitation, and wind time series. Meteonorm provides a comprehensive software platform that enables access to all the necessary meteorological data required for planning solar applications. This includes typical years, monthly averages, and hourly time series data [14]. Another software used in this study MATLAB is the engineering language. We used MATLAB script to write a program that can calculate the production power and cost.

2.2 Area of study and site specification

Installation of solar panels on both sides of the road linking the cities of Bucharest and Constanta in Romania with a length of 200 km 46.4N/26.1E, 95m. These panels can provide electric power for cars and road lighting and feed the national grid. The radiation is high in summer and lower in winter.

2.3 Specification of PV panel

Several Solar panels are typically associated with various terms and ratings. It is also essential for solar modules to meet specific mechanical requirements to endure weather conditions such as wind and rain. Table *1* shows the mechanical specification of thepanel we used.

Table 1

Mechanical specifications

Cell orientation	144(6x24)
Junction box	IP68, three diodes
Output cable	4mm2, +400, -200mm/±1400mm length can be customized
glass	Dull glass, 2+2mm heat-strengthened
Frame	Anodized aluminum alloy frame
weight	32.3kg
Dimension	2256x1133x35mm
packaging	31 pcs per pallet /155 pcs per20 GP/620 pcs per 40HC

Table 2

Electric specification

Module type	LR5-72HBD-530M	
Testing condition	STC	NOCT
Maximum power (pmax/w)	530	396.2
Open circuit voltage (VOC / v)	49.20	46.26
Open circuit current (Isc/A)	13.71	11.07
Voltage maximum power (Vmp/V)	41.35	38.58
Current maximum power (Vmp/V)	12.82	1027
Module efficiency (%)	20.7	

Standard Test Conditions (STC), Normal Operating Cell Temperature (NOCT)

Table 3

Operation parameters

Operational temperature	-40C +85C
Power output tolerance	0----3%
VOC and ISC tolerance	± 3%
Maximum system voltage	DC1500V(IEC/UL)
Maximum series fuse rating	30A
Nominal operating cell temperature	45±2C
Protection class	Class II
Bifaiality	70±5%
Fire rating	UL type 29 IEC class C

Table 4

Temperature Rating (STC)

Temperature coefficient of Isc	+0.05%/C
Temperature coefficient of Voc	-0.265%/C
Temperature coefficient of Pmax	-0.34%/C

3. Methodology

This study proposes a new idea for the effective use of roadways as well as an opportunity to identify the industry's major challenge, notably, land availability for grid-interactive solar power plants. Although this study indicates numerous benefits, proper implementation requires a few additional measures [15]. For example, one must confirm that the solar panels are safely secured to the structure's base. Establishing up the solar panels in an elevated position say, 9 to 10 meters above the ground, is exposed to strong winds on stormy or rainy days. It might make them less stable than solar panels that are close to the ground. The panels might be able to resolve this issue with particular care in their installation. The movement of vehicles on highways can result in the accumulation of dust and smoke particles on solar panels, which can impact their efficiency [16]. Cleaning these panels regularly is necessary to ensure optimal performance, especially since highways tend to be wider and more exposed to pollutants. This is in contrast to ground-mounted panels in remote locations that may only require cleaning every week or every ten days. Proper arrangements must be made to clean the panels daily if they are located near highways, village roads, or narrow city roads. Reducing the emissions of smoke from vehicles to meet Euro standards can help minimize pollution caused by traffic on the panels. Therefore, while some challenges should be considered when implementing the ideas from our study, they can be resolved by adequate planning, such as ensuring secure panel fixation and routine cleaning of solar panels [17].

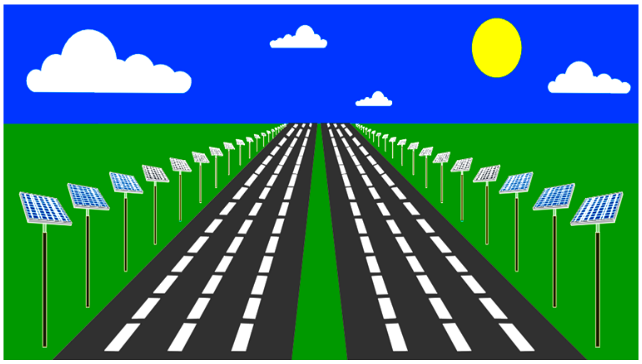

Fig. 1 PV panel between the highways

3.1 Electric energy storage batteries

The energy produced is used for 3 recharging stations for electric vehicles, installed on the highway at approximately 50 km between them, which have the role of charging electric vehicles during the day. In an average of about 6 hours/day, the charging stations work directly from the photovoltaic panels. Outside of this range of hours, we propose the installation of electric energy storage battery modules with an installed power of 200kW.

To have a continuity of operation both during the day and at night, the charging stations must have energy storage batteries as an alternative source of power. During the day, during the operating range of the photovoltaic panels, both the charging stations and the batteries must be powered by these panels. The modules with the storage batteries will be charged during the day with the energy produced by the photovoltaic panels[18].

Solar farms commonly use various types of energy storage batteries such as lead-acid batteries, flow batteries, and lithium-ion batteries. Among these, lithium-ion batteries are preferred for their longer lifespan and high energy density, despite being more expensive than other types of batteries [19]. Lead-acid batteries are less expensive but have a shorter lifespan and lower energy density. Flow batteries are a newer technology that can store large amounts of energy, but they are also more expensive than other types of batteries [20], [21]. The selection of a particular battery technology will depend on the specific requirements of the PV farm and the costs associated with each type of battery [17].

In this work, we choose lithium-ion batteries because they have a long life and the possibility of parallel connection with several units, each unit being made up of modules that are compatible with single-phase systems as well as three-phase systems.

3.2 **Analysis of the electricity sales strategy in Romania along with the development of technologies that use renewable sources**.

In the European Union's effort to assume a "world leader" in the field of energy and climate policy, renewable energy is a crucial component, with mandatory objectives in the field of renewable energy for the year 2020, established on the basis of the Directive on renewable sources adopted in 2009 In this analysis, we compare the actual progress in the development of renewable electricity with the intentions expressed in the plans for the years 2011 and 2012, assessing whether there are significant risks of not reaching the proposed targets. The policy of the European Union established in 2007 the objectives for the year 2020, which are an integral part of the EU's strategy to position itself as a world leader in climate policy. These targets include reducing carbon emissions by 20% by 2020 and increasing the share of renewables in final energy consumption to 20% by 2020. Progress towards these targets is therefore a key aspect of the study as it supports the active engagement of the EU in promoting climate and energy policies.

Next, we will analyze the evolution of renewable sources developed in Romania, regarding the production and use of energy from renewable sources. We will examine the trends and growth in wind, solar, hydro, and other forms of renewable energy generation capacity in the country [22]. We will also examine the evolution of the price of electricity sold in Romania, considering the factors that influence its fluctuations in the market, such as production costs, government regulations and market conditions. Through this analysis, we will seek to understand the connections and impact between the evolution of renewable sources and the price of electricity in Romania. This analysis will be structured over three distinct periods. The first period will cover the year 2009, representing the time when the first European directives on renewable energy were developed and implemented [23]. This initial stage marks the beginning of policy and regulation regarding the promotion and use of renewable energy sources in Europe. The second period of analysis will focus on 2019, when the COVID-19 pandemic had a significant impact on the economy and energy industry globally. We will examine how the pandemic has affected the development and use of renewable sources in Romania, including changes in investment, production, and energy consumption during this difficult period [11].

The last period of the analysis will cover the year 2022, representing the post-pandemic moment. We will explore how the renewables industry and the price of electricity sold have recovered and evolved over this period, considering factors such as economic recovery, policy and regulatory changes, and new trends in renewable energy. Through this evaluation over three periods, we will obtain a more comprehensive perspective on the evolution of renewable sources and the price of electricity in Romania [24].

Table 5

Graphical production, consumption, and balance of the National Energy System in 2009

Member State	Power consumed	Coal	Hydrocarbs	Water	Nuclear	Aeolian	Photovoltaic	Biomass
Romania	6533 MW	2245 MW	707 MW	2668 MW	1410 MW	0	0	0

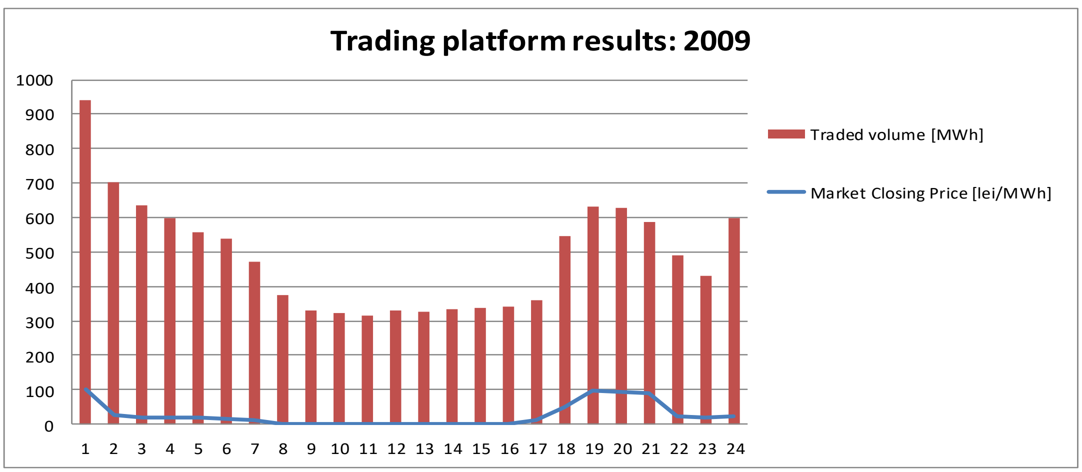

Fig. 2 Trading platform results: 2009

In Table 5, you can see the numerical values for the production and balance of the National Energy System in 2009 in Romania. We have a consumption of 6533 MW and a total production of 7030 MW.

The graph in Fig. 2 represents the ratio of the price of energy according to the quantity of traded energy. A maximum price of 100 lei/MWh is observed.

Table 6

Graphical production, consumption and balance of the National Energy System in 2019

Member State	Power consumed	Coal	Hydrocarbs	Water	Nuclear	Aeolian	Photovoltaic	Biomass
Romania	8033 MW	2108 MW	659 MW	2620 MW	1381 MW	1116 MW	0	50 MW

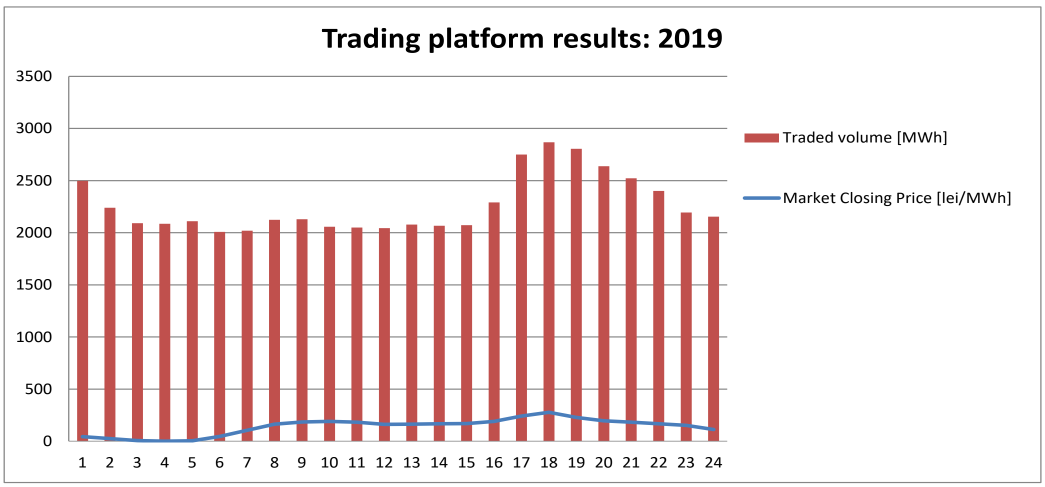

Fig. 3 Trading platform results: 2019

In Table 6, you can see the numerical values for the production and balance of the National Energy System in 2019 in Romania. We have a consumption of 8033 MW and a total production of 7934 MW. The graph in Fig. 3 represents the ratio of the price of energy depending on the amount of energy traded. A maximum price of 163.09 lei/MWh is observed.

Table 7

Graphical production, consumption and balance of the National Energy System in 2022

Member State	Power consumed	Coal	Hydrocarbs	Water	Nuclear	Aeolian	Photovoltaic	Biomass
Romania	9179 MW	1134 MW	1769 MW	2586 MW	1400 MW	2512 MW	127 MW	74 MW

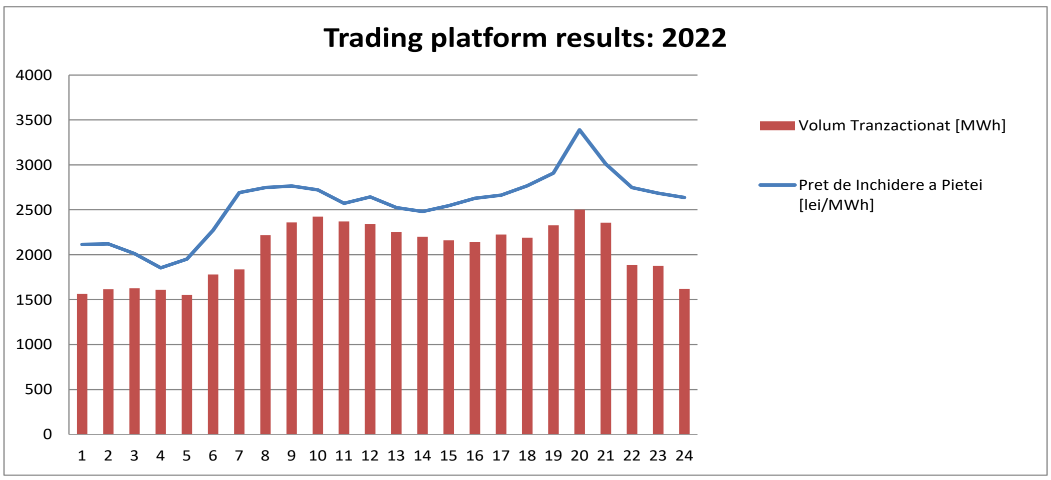

Fig. 4 Trading platform results: 2022

In Table 7, you can see the numerical values for production and balance of the National Energy System in 2022 in Romania. We have a consumption of 9179 MW and a total production of 9602 MW[1].

The graph in Fig. 4 represents the ratio of the price of energy depending on the amount of energy traded. A maximum price of 3388.91 lei/MWh is observed.

After the analysis is carried out, it becomes evident that with the passage of years, there is a significant increase in the demand for energy. The development of various industries and sectors leads to an increasing demand for electricity. In this context, we propose investments in electricity production using renewable sources. This investment has outstanding advantages, such as a relatively short and potential payback period. By adopting renewable sources, we can obtain a sustainable and environmentally friendly source of electricity, which contributes to reducing dependence on traditional sources and protecting the environment. Thus, investing in renewable sources of electricity becomes a viable and beneficial solution in the current context, bringing both economic and ecological benefits.

3.3 Modeling of The National Highways (MATLAB CODE and Results)

i. Modeling of The National Highways - MATLAB CODE

$$km\_1 = \frac{1000}{W} \quad (1)$$

Where, km_1 is the distance in one kilometer, W= 1.133 is the length of the photovoltaic panel;

$$P_i\_km\_1 = \frac{P_i * km\_1}{1000} \quad (2)$$

Pi_km_1 is the installed power of the photovoltaic panels on a one-kilometer section of the highway [W], Pi=411 [W] the installed power of a photovoltaic panel;

$$P_i\_km\_200 = \frac{P_i\_km\_1 * 200}{1000} \quad (3)$$

Pi_km_200 is the installed power of photovoltaic panels on a 200km section of highway [W];

$$Cost\_pv = P_i\_km\_200 * 1\frac{€}{W} \quad (4)$$

The cost of photovoltaic panels is approximately 1 euro/W;

$$Cost\_pt = n\_pt * 200000 \quad (5)$$

The cost of the transformer substations [Euro] is 200,000 euros, n_pt=96 transformer stations needed to discharge the total power generated.;

$$Cost\_st = n\_st * 9500000 \quad (6)$$

The cost of the transformation stations [Euro] is 9,500,000 euros, n_st=4 transformation stations needed to discharge the total power generated into the network;

$$Cost\_ev\_station = n\_ev\_station * 100000 \quad (7)$$

The cost of electric vehicle charging stations [Euro] is 100,000 euros, n_ev_station=5 superfast charging stations located 50 km apart.;

$$Cost\_battery = n\_battery * 200000 \quad (8)$$

The cost of batteries for energy storage [Euro] is 200,000 euros, n_battery=5 battery assemblies for energy storage, for each electric vehicle charging station;

$$Cost\_variabil = 800000 \quad (9)$$

The variable cost represents the costs for labor and equipment [euro];

$$Cost\_tot = Cost\_pv + Cost\_pt + Cost\_st + Cost\_ev\_station + Cost\_battery + Cost\_variabil \quad (10)$$

The total cost represents the sum of all the previously mentioned costs [euro];

$$Inv\_2022 = E_t * 1000 * price\_2022 \quad (11)$$

The amortized investment related to the price of energy from the year 2022 [Euro], Et= 87GWh the total energy generated, price_2022 = 370 euros is the price of energy for 1 MWh;

$$Inv\_am1 = \frac{Cost\_tot}{Inv\_2022} \quad (12)$$

Where, Inv_am1 is the amortization of the investment compared to the price of 2019;

$$Inv\_2019 = E_t * 1000 * price\_2019 \quad (13)$$

The amortized investment related to the energy price of 2019 [Euro], Et= 87 GWh total energy generated, price_2019 = 100 euros is the energy price for 1 MWh;

$$Inv\_am2 = \frac{Cost\_tot}{Inv\_2019} \quad (14)$$

Where, Inv_am2 is the depreciation of the investment compared to the price of 2019:

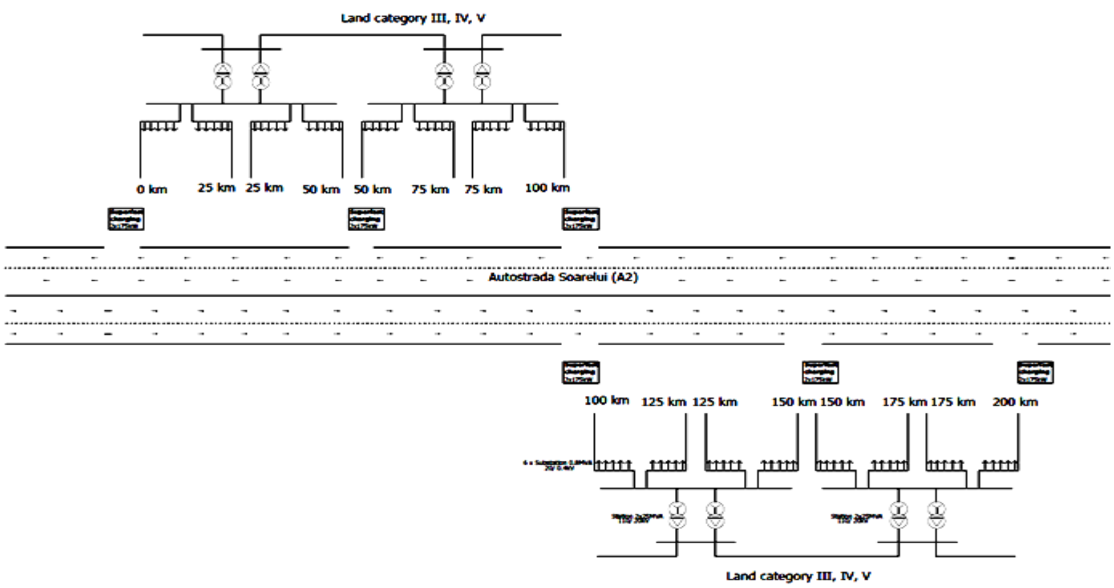

Fig. 5 single-line diagram of the electrical system

ii. The Results

Performance of grid-connected PV:
Power for each panel = 411 W.
Power for 1km = 363 kW.
Power for 200km = 72.6 MW.
Yearly PV energy production = 87 GWh.
EV Superfast charging stations 2x175kW from 50km to 50km = 5 pcs.

Energy storage batteries 200kW for each superfast charging station = 5 pcs.
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Total expenses:
Cost for PV = 72000000 € + VAT.
Cost for PT = 19200000 € + VAT.
Cost for ST = 38000000 € + VAT.
Cost for 5 superfast charging stations 2x175kW= 500000 € + VAT.
The cost of the 5 storage batteries 200kWh for each station= 1000000 € + VAT.
Variable Cost = 800000 € + VAT.
Total Cost = 131500000 € + VAT.
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Investment recovery:
Taking into account the price for the date of 06.09.2022: 370 €/MWh.
For 87 GWh injected into the network = 32190000 € + VAT.
The investment will be recovered in 4 years.
Taking into account the price for 2019: 100 €/MWh.
For 87 GWh injected into the network = 8700000 € + VAT.
The investment will be recovered in 15 years.

4. Conclusion

This study proposes a model for superfast recharging stations based on renewable energy sources. Since the power is quite high, we will divide the network into approximately 800kVA (725kW). This power is generated in a length of 2 km of photovoltaic panels, so for 100 km of installed panels, we will have approximately 48 pieces of substation transformers 20/0.4kV. The energy produced is used for 3 recharging stations for electric vehicles, mounted on the highway approximately 50km apart, and the rest of the power is discharged into the SEN with the help of station transformers 20/110kV. According to the calculations, the station transformers chosen will be 2x25MVA, there will be two of them, each being fed by 24 substation transformers. The superfast charging stations will be 2x175kW, during the day, for approximately 6 hours they will work 100% on the photovoltaic panels and at night they will work on the energy storage batteries.

This project aims to reduce the amount of carbon emitted into the atmosphere, on the one hand, from vehicles traveling on the A2 highway, and on the other hand, from power plants. In Romania, most of the charging stations for vehicles are in the big cities (Bucharest, Constanta, Brasov, Timisoara, Arad, Cluj), this represents a rather big problem. If we installed 5 charging stations 200 km from the highway, the population would be much more motivated to purchase electric cars, leaving aside the conventional cars with thermal engines. This highway is overpopulated approximately 6 months of the year, if by installing charging stations we could convince half of this population to switch to electric cars, the impact on the environment would be very high. In Romania there are quite a lot of euro 2,3,4 type cars that emit a very large number of boxes, with the transition to electric cars, they would give up their old cars through state-funded programs (such as "Rabla Auto").

On the investment recovery side, in addition to the energy injected into the network sold at that day’s market price, the beneficiary could also amortize his investment through green certificates or the sale of shares and bonds of the company.

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