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Harnessing Stadium Roofs for Community Electrical Power: A Case Study of Rome's Olympic Stadium Title

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Abstract: Within a city, there is a lack of space for the installation of photovoltaic panels, especially in cities with significant artistic heritage. Hence, there is a need to identify new spaces for the installation of renewable energy systems capable of supplying part of the city's energy demand. Large infrastructures for public use such as stadiums, because of their characteristics, can become an essential resource for surrounding communities by installing photovoltaic panels on their roofs. This innovative approach can supply renewable electricity to the local community, aligning with the concept of renewable energy communities (RECs). This study focuses on the Olympic Stadium in Rome, exploring a new way to produce and share the electricity generated. An energy simulation of the photovoltaic plant was carried out by means of a transient calculation tool System Advisor Model (SAM). Then, the energy output from photovoltaics was correlated with the stadium, streetlight, and household electrical energy demands. The results highlight the suitability of the photovoltaic plant and the energy, economic, and environmental advantages derived from its exploitation.

Keywords: photovoltaic; renewable energy community; renewable energy; climate change; sport stadium; sustainability

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1. Introduction

The global energy demand has experienced a substantial increase in recent years, with anticipated continued growth in the future. As delineated in the International Energy Agency (IEA) World Energy Outlook 2022 [1], the recovery observed in global energy consumption subsequent to the decline induced by the pandemic in 2020 was prematurely halted by Russia's invasion of Ukraine in early 2022. This geopolitical event has resulted in considerable upheaval in global energy markets, intensifying inflationary pressures and impeding economic growth [2,3]. Addressing this perpetual escalation in energy demand and concurrently mitigating carbon dioxide emissions represent pivotal global challenges demanding heightened scrutiny and proactive adjustments. In the face of an impending energy crisis and the urgent need to combat climate change, the importance of transitioning towards sustainable energy solutions has never been more critical. The prevailing worldwide energy infrastructure remains heavily reliant on finite fossil fuel resources, a source that yields carbon dioxide emissions upon combustion, thereby inflicting substantial repercussions on the climate. Hence, an imperative has arisen to transition towards a sustainable energy paradigm [4]. Sustainable energy embodies a framework of sustainable development wherein society can generate and employ energy without detriment to the environment, mitigating undue resource depletion relative to the Earth's capacity for regeneration [5]. The ecological shift necessitates the phased substitution of fossil fuels, acknowledged as the principal contributors to climate change, with renewable energy sources encompassing solar, wind, hydropower, biomass, and geothermal options [6,7]. Renewable sources alone may prove insufficient to sustain energy-intensive lifestyles. Simultaneously, a comprehensive reassessment of energy utilization is imperative, emphasizing the enhancement of energy efficiency in domains such as housing, transportation, and various other activities [8]. The requisite measures for realizing the objective of sustainable energy by 2030 encompass reinforcing international collaboration, streamlining access to clean energy technologies and investments in infrastructure, and advancing energy efficiency initiatives, commencing with the optimization of electricity distribution [9].

1.1. Transition to Sustainable Energy Sources and Net-Zero Emissions

Photovoltaic solar panel (PV) electricity generation plays a key role in decarbonizing the energy system and advancing sustainable development [10]. Regarded as one of the most promising solutions for curtailing greenhouse gas emissions and addressing climate change, PV solar energy offers a compelling alternative to conventional energy sources like coal or natural gas [11,12]. Substituting these sources with PV solar energy holds significant potential for reducing CO_2 emissions, thereby fostering a cleaner and more sustainable global environment. This renewable energy source distinguishes itself by emitting no greenhouse gases during the processes of electricity production and utilization, thereby mitigating the carbon footprint and attenuating the progression of global warming. The widespread adoption of PV solar energy necessitates persistent endeavors to establish suitable infrastructure, implement supportive policies, and provide financial incentives [13]. The IEA report delineates an ambitious yet feasible trajectory for the energy sector to achieve Net-Zero Emissions by 2050, obviating the reliance on emissions reduction within non-energy sectors [14]. According to the Net-Zero Emissions scenario, the installed capacity of renewable energy is projected to increase ninefold compared to the 2020 capacity. Moreover, by 2050, electricity is anticipated to emerge as the predominant energy carrier, with 88% of the electricity generated originating from renewable sources, 8% from nuclear power, and 2% from hydrogen [15]. Wind and PV solar energy are projected to collectively contribute two-thirds of the total renewable energy output [16].

1.2. Rise of Renewable Energy Communities and Urban Integration

Simultaneously, the renewable energy community (REC) emerges as a strategic initiative aimed at optimizing the utilization and self-consumption of locally available renewable energies, thereby empowering communities through sustainable development frameworks [17]. The proliferation of RECs, driven by the promotion of renewable installations, is poised to make significant contributions to the mitigation of carbon emissions. They are introduced by the European Union Renewable Energy Directive (RED II) [18] as legally established non-commercial entities whose primary objective is to collaboratively build new renewable power generators and share both the energy produced and the benefits derived from their operation. Thus, energy communities are emerging as a key tool to face current emergencies through energy transition [19].

Starting from this, urban space could be a candidate to produce and share energy within urban communities.

1.3. Environmental Impact of Stadiums and Potential for Sustainability

Among all building typologies, stadiums have the highest environmental impact; in particular, football stadiums consume a considerable amount of energy on the day of an event due to the need for lighting, heating, cooling, and other electrical systems. Here is why UEFA, as a guardian of the world's most popular sport, developed a Guide to Sustainable Stadiums, which gives the best practices in a wide range of areas including energy savings [20]. According to this, the installation of PV panels on stadium roofs plays a key role in achieving the green transition. A stadium, used a few times a week, can become an electrical power station working every day, without environmental or architectural impact, thanks to the installation of photovoltaic panels on the roofs [21,22]. Thus, it could provide clean electricity to the surrounding community. There are many examples around world of using PV systems in sports stadiums to save and/or export energy to a local utility grid [23].

The first stadium in the world where PV panels, with a capacity of 259 kWp, were installed is Schwarzwald-Stadion in Freiburg in Germany. This pioneering installation on the stadium roof took place in 1995.

The JC ArenA is already one of the world's most sustainable and multi-functional stadiums, and it continues to implement innovative smart energy solutions for the venue, its visitors, and the surrounding neighborhood. With a 1 MWp solar installation on its roof, the stadium currently generates approximately 8% of its electricity needs [24,25].

The biggest rooftop PV power plant, with an installed capacity of 1.42 MWp and an area of 11,530 m^2, is mounted at Mineirão Football Stadium in Brazil [26].

In 2018, Manni et al. [27] proposed a cluster of actions to reduce the energy use of Dacia Arena: two hypothetical system PV system layouts were proposed and evaluated for providing electricity. The PV system can annually generate up to 815,000 kWh. If a heat pump is installed, approximately 500,000 kWh of that total becomes surplus energy, which is not directly utilized by the arena. Instead, it is fed into the energy grid and supplied to nearby neighborhoods to offset the stadium's carbon emissions.

In 2020, Devetakovic et al. [21] examined the applications of integrated and applied photovoltaic technologies on ten landmark buildings characterized by unusual geometries like stadiums, highlighting the aesthetics of their architecture and quality of PV integration based on a proposed set of seven criteria.

1.4. Bridging the Gap: From Stadiums to Urban Communities

In light of the current emphasis on sustainable practices, researchers have predominantly concentrated on assessing how photovoltaic panels on stadium roofs cater to the energy needs of these sporting arenas. While acknowledging the significance of such endeavors, there exists an intriguing yet unexplored avenue—the potential for this renewable energy to transcend the confines of stadiums and extend its benefits to the broader urban community. The energy generated by photovoltaics, often exclusively utilized by the stadiums and their attendees, presents an untapped resource that could be harnessed to meet the energy demands of the urban neighborhood in which these sporting venues are embedded.

This fundamental transition from a localized energy focus to a more expansive urban perspective is the main aim of the present study. As sustainability gains precedence globally, football stadiums, positioned as iconic symbols of sports culture, find themselves at the forefront of this renewable evolution. This study aims to unravel the possibilities of integrating the energy produced by photovoltaics within stadiums into the broader urban fabric. This shift in perspective aligns with the overarching commitment to sustainable development and environmental stewardship.

In essence, the present study seeks to bridge the existing gap between stadium-centric energy solutions and the comprehensive energy requirements of urban communities. By investigating avenues for the effective utilization of photovoltaic energy on a broader scale, the paper aims to contribute valuable insights to the discourse on sustainable urban development. As the world increasingly prioritizes environmental responsibility, football stadiums emerge not just as venues for sporting spectacles but as potential catalysts for a greener and more sustainable urban future.

2. Materials and Methods

2.1. Methodology

The aim of the present study is to focus on the potential photovoltaic system, integrated on a stadium suspended roof, from a local community point of view. The work starts by analyzing the solar radiation throughout the whole year for the specific site. Therefore, the stadium electric loads and site availability for PV installation were estimated. A monthly energy PV performance analysis was conducted to prove the concept. The PV system is integrated with energy storage. We developed a numerical model to evaluate the energy output from the PV system and how much of this is delivered to the public grid and stored in the static battery. PV system dynamic simulations were conducted through an open-source software tool known as the System Advisor Model 2023.12.17 (SAM) [28]. The SAM was developed by the National Renewable Energy Laboratory (NREL) in collaboration with Sandia National Laboratories and the U.S. Department of Energy (U.S. DOE) Solar Energy Technologies Program. The SAM provides a robust platform for analyzing and modeling the performance of renewable energy projects. It supports a wide range of technologies, including solar, wind, and geothermal systems. The simulation is carried out in hourly steps since this is also the given resolution of the generation and load profiles. It was estimated the equivalent energy generated by the PV system and fed into the public grid able to supply enough energy for local household utilities and public lighting. The flowchart of the methodological approach is shown in Figure 1.

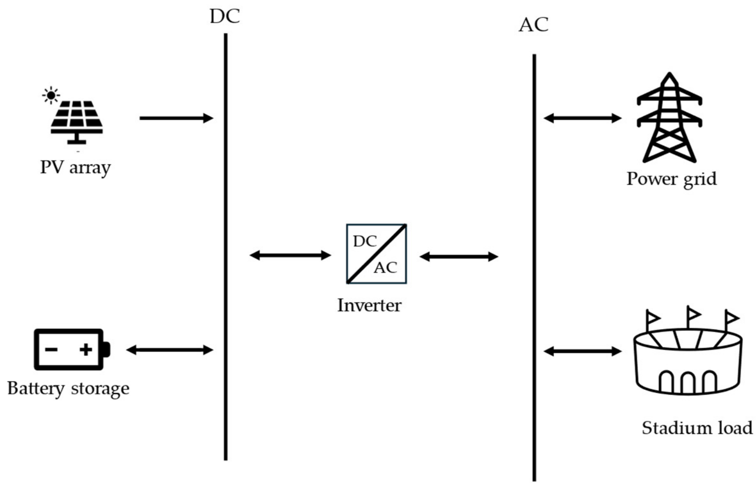


Figure 1. Flowchart of the methodological approach.

The economic performance of the solar PV system is assessed using key economic parameters, including payback period (PP), net present value (NPV), and internal rate of return (IRR). The initial investment cost is calculated from kW cost of the PV system. According to the renewable energy market analysis, reported in 2021 by the International Renewable Energy Agency (IRENA) [29], the rooftop PV and the battery energy storage systems were implemented in 2021 at 724.5 EUR/kW and 1020.7 EUR/kWh, respectively. The initial cost refers to the cost of the system components and implementation. The operation and maintenance costs amount to 9.2 EUR/kWh. The initial investment and operating costs are regarded as the cost outflows of the designed system. Cash inflows are determined by the cost of energy that satisfies the load demand and the revenue generated from energy exported to the utility grid. The cost of electricity is taken according to ARERA the Regulatory Authority for Energy, Networks and the Environment [30]. It publishes an update on the economic conditions of protection services quarterly for electricity. This price ranged from 0.44 EUR/kWhe (if the electricity is acquired from the national grid) to 0.11 EUR/kWhe (in case the electricity is sold and delivered to the national grid). The project lifetime is 25 years, which is the same as the replacement time for the PV panel [31].

Finally, the CO_2 emission reductions were investigated considering the value (258.3 gCO_2-eq/kWhe) as the CO_2 emission factor for electricity energy reported by the ISPRA Report 2021 [29].

2.2. The Case Study: Olympic Stadium in Rome

Located in the northern part of Rome, the Olympic Stadium stands as the preeminent sports facility in the city and ranks among the largest in Europe. Serving as the home venue for two prominent football clubs, S.S. Lazio and A.S. Roma, both competing in

Serie A, this stadium holds a distinguished status as a UEFA category four facility. Its infrastructure enables it to host the pinnacle clashes of the UEFA Champions League and the UEFA Europa League, in addition to matches of the European football championship. Since its inauguration in 1953, the Olympic Stadium has also been a versatile host for various sports, with a particular emphasis on athletics competitions and events such as the renowned Golden Gala. Furthermore, it has become the epicenter for oval ball enthusiasts since 2012, attracting fans during the Six Nations Rugby Championship, a paramount European competition. Beyond its sporting significance, the Olympic Stadium transforms into a vibrant cultural hub, regularly playing host to concerts and dance parties, which seamlessly augment its diverse calendar of events. Boasting an impressive seating capacity of 100,000 and a substantial total building size of approximately 33,500 m^2, the Olympic Stadium symbolizes a monumental presence in the cityscape. Figure 2 provides an aerial perspective, offering a comprehensive view of this iconic venue.

Figure 2. Aerial view of the Olympic Stadium.

2.3. Boundary Conditions

The preliminary analysis consisted of obtaining solar irradiation and temperature, considering the factors that directly affect the output of the PV system. Monthly weather data for the Olympic Stadium were obtained from the NREL National Solar Radiation Database (NSRDB) [32]. This is a dataset with high temporal and spatial resolution consisting of the three most widely used measurements of solar radiation (global horizontal, direct normal, and diffuse horizontal irradiance) as well as other meteorological data. The annual average horizontal solar irradiation in Rome has been found to be on the order of 4.10 kWh/m^2/day. The daily average solar irradiance is shown in Figure 3.

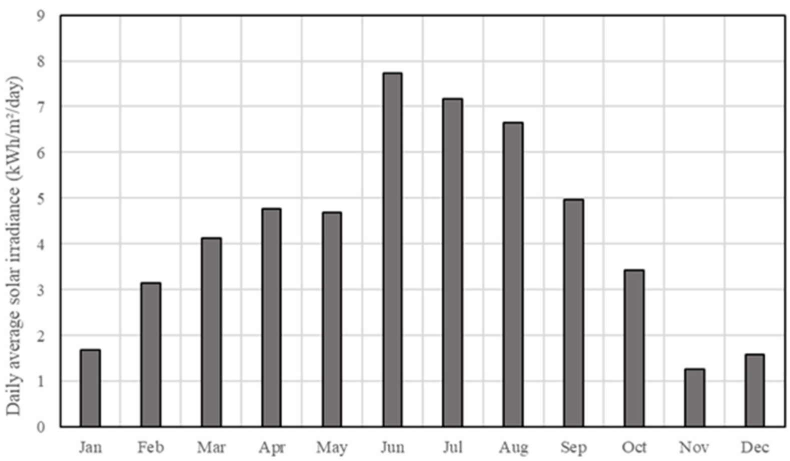


Figure 3. Daily average solar irradiance in Rome according to [32].

The electrical load demand has been considered highly irregular because it depends on the activities that take place in the stadium. A modern medium-sized stadium with a capacity of 55,000 spectators typically has an annual energy consumption of 10,000 MWh [33]. However, a significant portion of this electricity is used during a limited number of hours on match days, with energy consumption estimates ranging from 15,000 to 30,000 kWh, depending on factors such as the stadium's size, season, temperature, and number of attendees [34]. Approximately 40% of the total energy consumed during a sports event is attributed to floodlighting, scoreboards, and advertising LED boards. Additionally, over 20% is dedicated to heating food and refrigerating beverages within the stadium. The broadcasting of games to a global audience requires robust satellite transmitters, multiple HD cameras, and specialized editing suites, which together account for about 11% of the stadium's overall energy expenditure [35].

Starting from this, with detailed utility bills specific to the case study being unavailable and necessitating the estimation of electricity loads during a match or event, the electrical energy consumption was approximated at around 22,000 kWh in analogy to stadiums with similar capacity. This estimation aims to meet the peak levels of energy demand during events and ensure the storage of sufficient power from the photovoltaic system. Analysis of the official stadium calendar reveals that, on average, the venue hosts 102 events annually, translating to an average of two events per week. Leveraging these data, it becomes feasible to construct the annual curve of the stadium's electrical loads, focusing solely on the energy consumption during events.

2.4. PV Plant

The design of a PV plant is site-dependent. Numerous factors including site location, spatial constraints, grid connectivity, energy demand, and the availability of solar energy are crucial considerations. Hence, the available area for the installation of photovoltaic panels was identified on the suspended roof of the Olympic Stadium in Rome. The roof structure of the stadium was realized between 1988 and 1990 in view of the 1990 FIFA World Cup. This roof stands as a pioneering example of a spoke wheel roof structural system [36]. The cable roofing system primarily comprises a radial distribution of cable trusses, a polycentric inner tension cable ring, and an outer anchorage system consisting of a space-framed, reticular, polycentric ring [36]. The total surface area of the suspended roof is equal to 42,000 m^2, while the available horizontal area for the installation of photovoltaic modules diminishes to 23,016 m^2.

The simulated plant is composed of polycrystalline silicon PV modules. The tilt and azimuth parameters are constrained by the geometry and the orientation of the building. Each PV module within every physical segment is inclined at an angle of 5° to align with the suspended roof's inclination (Figure 4).

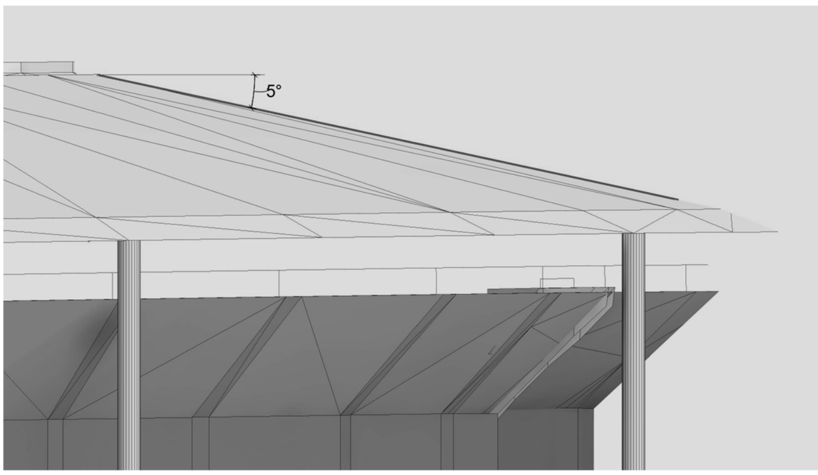


Figure 4. Design of the photovoltaic plant integrated into the roofing.

The solar panels are supported by spiraled steel girders and cover every inch of the roof. The entire roof is divided into eight zones based on different exposures to north (N), east (E), south (S), west (W), northeast (NE), southeast (SE), southwest (SW), and northwest (NW) (Figure 5).

Figure 5. Google Earth image of stadium showing proposed layout of PV plant.

Table 1 reports the estimated PV module area for the eight sectors depending on sun exposure. An average efficiency of a typical PV module of 20% is used, and the overall system loss is quantified at 14.08%. The value of the DC-to-AC ratio input is 1.1. The annual AC degradation rate is equal to 0.5%. The rated capacity of the solar energy system, expressed in kilowatts-peak (kWp), signifies the maximum power it can generate under standard test conditions [37]. This capacity has been calculated on the SAM PV Watts-Battery tool for integrated systems using the following equation:

$$\text{Rated Capacity (kWp)} = \text{Energy System Efficiency} \times \text{Solar Irradiance} \times \text{Total PV Area Installed} \quad (1)$$

Table 1. PV plant sectors surface according to the exposure.

Sector Exposure	Surface (m^2)	Power (kWp)
North	2440.408	470.21
Northeast	1956.269	376.92
East	4902.105	944.52
Southeast	2097.41	404.12
South	2791.29	537.82
Southwest	2052.466	394.46
West	5259.295	1012.35
Northeast	1517.074	292.30
Total	23,016.32	4432.67

The PV plant yields a total peak power of 4432 kW. We simulated a ground-breaking battery energy storage system (BESS) connected to the PV plant. The BESS was sized based on the criterion that its energy capacity should adequately cover the light load during a football match (Berg et al., 2021) [38]. To do that, we analyzed a battery energy storage system similar to JC ArenA in Amsterdam [24]. The BESS had a capacity of 2.8 MWh and a power of 3 MW, and it was made from 2nd-life electric car batteries. When its rated capacity falls below 80%, its performance diminishes to a level insufficient for powering a vehicle. Reuse can provide the most value in markets where there is battery demand for stationary energy storage applications, as in this case study [38]. The PV system can export surplus energy to the utility grid, thereby prompting the design of a grid-connected system.

2.5. Energy Output from Grid to Household Utilities

According to the 2022 IEA report [1], the building sector consumes about 30% of global final energy consumption and is responsible for 26% of global energy-related emissions. Electricity accounted for approximately 35% of buildings' energy use, up from 30% in 2010. The trend reflects the penetration of renewable energy sources, making electricity the energy carrier with the most preponderance in building energy use [39,40].

Starting from this, in this framework, the electrical energy produced by the PV system has been estimated in terms of the number of household utility energy demands in the city of Rome. Considering the lack of contemporaneity between the PV energy output and the public energy demand, the energy generated by the PV system is fed into the grid, and an equivalent amount will subsequently be drawn to fulfill a portion of the energy demand designated for household utilities. The data concerning the household utilities in Rome were extracted from the study by [41]. It reports both domestic and non-domestic electrical consumption in the 155 urban planning zones of Rome, regardless of the energy supplier with whom the contract is entered. The data from 2021 have been provided by the distribution company Areti [42]. Detailed average data are reported in Table 2.

Table 2. Domestic and non-domestic electrical consumption in Rome according to [41].

	Utility Number	**Average Monthly Consumption (kWh)**	**Average Monthly Consumption per Individual User (kWh)**
Domestic electrical consumption	1,321,992	233,737,722	177
Non-domestic electrical consumption	298,920	510,686,443	1708
Total	1,620,912	744,424,165	459

2.6. Energy Output from Grid to Streetlights

Public lighting able to power millions of streetlights is responsible for 19% of global electricity usage, 30–50% of a typical city's energy demand, and the already excessive levels of CO_2 emissions [43,44]. Thus, this represents a priority issue for cities in their strategy towards sustainability. In this framework, the electrical energy produced by the PV system has been estimated in terms of the number of streetlights served in the city of Rome. Considering the lack of contemporaneity between the PV energy output and the public energy demand, the energy generated by the PV system is fed into the grid, and an equivalent amount will subsequently be drawn to fulfill a portion of the energy demand designated for public lighting. The data, concerning the public lighting network of the city of Rome, are from 2021 and have been provided by the Agency for the Oversight and Quality Assurance of Local Public Services of the Capital City of Rome (ACOS) [45]. According to the ACOS 2021 report [46], the public lighting network covers approximately 6370 km of roads and over 650 illuminated monuments, powering 226,728 lamps (averaging one lamp per 12 inhabitants and one light point every 28 m of road). The installed LEDs constitute approximately 92% of the total public lighting fixtures. Detailed average data are reported in Table 3.

Table 3. Characteristics of the public lighting network in Rome according to [46].

Total Number of Lamps	Average Distance between Lamps (m)	Total Annual Energy Consumption for Lighting (MWh)
226,728	31.39	66,801

3. Results

According to the methodological approach explained before, hourly energy simulation was carried out. The annual AC energy output is equal to 4,901,879 kWh (Figure 6). Figure 7 reports the monthly energy output from the PV system. The highest energy consumption, equal to 735,662 kWh, is achieved in June, whereas the lowest one, equal to 115,823 kWh, is achieved in November. Estimating the total electrical loads during the stadium events, it was possible to estimate the energy sent to the battery. It amounts to 2,112,000 kWh (176,000 kWh per month). Thus, the annual AC energy output, exported to the public grid, is equal to 4,421,879 kWh. Figure 5 reports the monthly energy output fed into the utility grid.

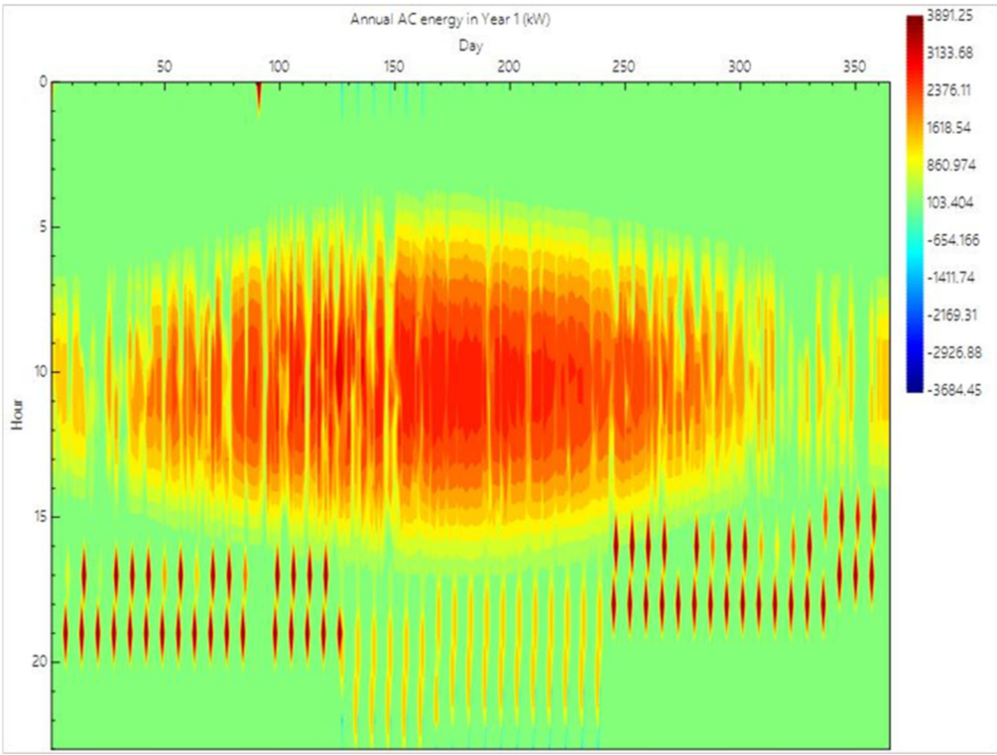
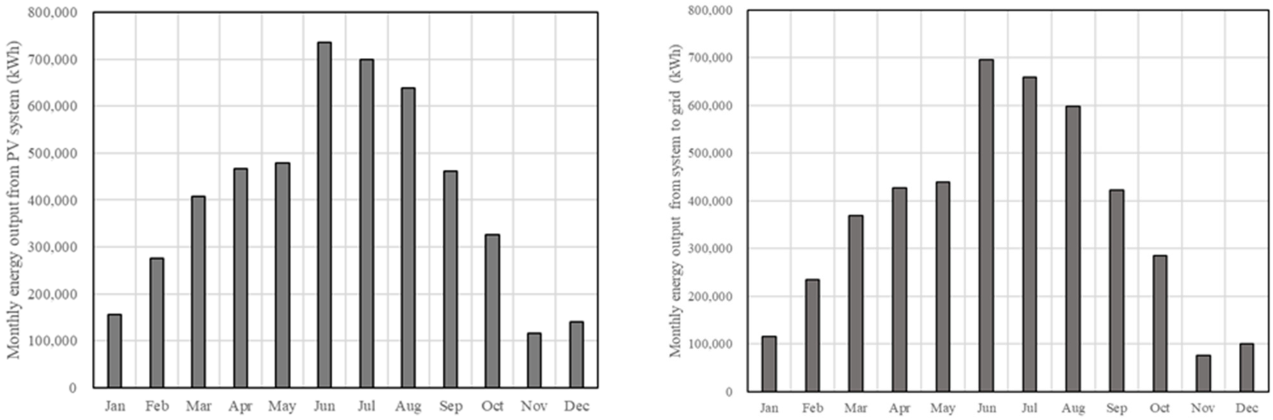


Figure 6. Annual AC energy in Year 1 (kW).

Regarding the results for energy produced by the PV system in terms of household utilities' energy demand, the electrical energy output could supply the energy demand of 634 household utilities, equal to 1325 people, or 1385 non-domestic utilities. The summary results in terms of satisfied energy demand are shown in Table 4. Similarly, regarding the results for energy produced by the PV system in terms of the number of streetlights served in the city of Rome, the electrical energy output could supply the energy demand of 15,008 lamps. The summary results in terms of satisfied energy demand are shown in Table 5.



(**a**) (**b**)

Figure 7. Monthly energy output from PV system (**a**) and from PV system to grid (**b**).

Table 4. Energy output from PV system to domestic and non-domestic utilities.

	Number of Supplied Utilities	Percentage of Coverage of the Total Energy Demand by the PV System (%)
Domestic electrical consumption	2084	0.16%
Non-domestic electrical consumption	215	0.07%

Table 5. Energy output from PV system to streetlights.

Total Length of Illuminated Roads (km)	Number of Supplied Lambs	Percentage of Coverage of the Total Energy Demand by the PV System (%)
471.1	15,008	0.07%

The initial cost is calculated as EUR 5,413,689.95. Figure 8 illustrates the cash flow performance of the solar PV system, which considers the discount rate equal to 4.64% as given in [47]. The annual cash flow is observed for 25 years, and the simple payback period is 14 years. The net present value (NPV) is calculated as EUR 2,644,605.70, which provides a profitability index (PI) of 0.49. The profitability index compares the NPV with the initial investment cost. A profitability index greater than zero signifies that the project is profitable.

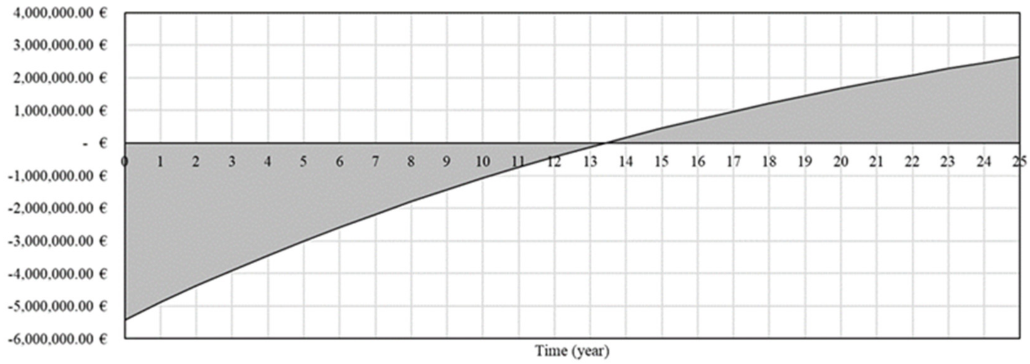


Figure 8. Cash flow performance.

According to emission factors of greenhouse gases from the electricity sector for the generation of electrical power reported by the ISPRA Report 2021 [46], the estimated annual CO_2 emission reduction is equal to 1266.15 tonCO_2.

4. Discussion

The investigated approaches have demonstrated positive influences on the sports facility from energy, economic, and environmental perspectives. This is particularly noteworthy when considering the typical spatial configuration of stadiums, which, especially in Italy, are often constructed away from other buildings. This spatial separation mitigates concerns related to shading from adjacent structures on the roof, ensuring optimal photovoltaic system performance and minimizing any potential decrease in energy production. The energy simulation of the photovoltaic system installable on the roof of large architectural complexes, as examined in this study for the Olympic Stadium in Rome, highlights its potential as a significant energy resource for the local community. The annual electrical energy production, amounting to 4.9 GWh, surpasses that of typical photovoltaic systems installed on the roofs of urban buildings.

The total amount of annual energy from the PV system was found to be 212.9 kWh/m^2. Significantly, the spatial layout of stadiums, typically free from shading concerns, enhances the efficiency of the photovoltaic panels. This efficiency translates to a considerable advantage in terms of energy production when compared to installations on the roofs of densely populated urban buildings. Moreover, the energy demand for a citizen can be supplied by 76 m^2 of PV panels. The payback period, net present value, and profitability index indicate that the designed solar PV system is economically viable, offering an excellent return within a short timeframe (14 years). The electricity production from PV panels guarantees higher earnings, underlining the financial feasibility of such installations.

The culmination of energy, economic, and environmental assessments sheds light on how the produced energy can be strategically reinvested for the local community, as explained before. These findings aim to provide a robust and pragmatic approach for football associations or local administrations, offering a model for moving towards a sustainable and economically feasible future.

5. Conclusions

This study, focusing on the energy performance of a solar PV system for the Olympic Stadium's suspended roof in Rome, investigates the transformative potential of large architectural complexes, such as stadiums, to serve as energy resources for local communities through the installation of photovoltaic systems on their roofs. The examination of the Olympic Stadium in Rome reveals that the PV plant, dynamically simulated using the System Advisor Model tool, has a peak power of 4432 kWp. The sizing performed highlighted how the system could function as a veritable energy station in an urban context. It is feasible to store part of this energy in electrochemical accumulators, such as electric vehicle batteries, with a total capacity of 2.8 MWh. The remaining portion of energy was correlated with the average energy needs for both residential and non-residential users, as well as for public lighting. The results demonstrate how this system could be a significant contributor to the energy needs of the community, fostering sustainability and resilience. The designed system can store part of the event energy demand (176 MWh/year) and export energy (4.4 GWh/year) to the utility grid.

The integration of renewable energy solutions, particularly through the designed PV system, showcases its potential contribution to the broader community's energy needs. The results demonstrate its ability to supply the energy demand of 634 household utilities or meet the lighting demand of 15,008 lamps within the framework of a renewable energy community. This underscores the pivotal role of large structures, like stadiums, in fostering sustainability and resilience within urban environments.

The findings presented here mark the initial steps in an ongoing research endeavor. Future developments will involve implementing the proposed energy system on the Olympic

Stadium and evaluating real-world energy and economic data to compare against the hypothesized scenario. This iterative approach ensures a practical understanding of the system's performance and its actual impact on the local community, aligning with broader goals of sustainable urban development and renewable energy integration.

In summary, this study not only sheds light on the energy potential of the Olympic Stadium but also serves as a model for similar urban structures, emphasizing their role as integral components of renewable energy communities and contributing significantly to the broader sustainability agenda.

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