Università degli studi di Milano-Bicocca

Data Science Lab for Smart Cities

Final Essay

From Olympic Venue to Green Landmark: The St. Giulia Arena

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Contents

Abstract

The project analyzes the energy profile of the new Santa Giulia Arena, which is considered as a key point for the 2026 Milan-Cortina Olympic Games. The study focuses on the integration of photovoltaic technology on the arena's roof and evaluates its effectiveness in promoting green energy production and reducing CO_2 emissions.

1 Problem Description and Indicators

1.1 Energy transition and Green Infrastructure

The term energy transition refers to a shift from an energy model based on fossil resources, such as oil, gas and coal to one that relies instead on renewable sources, such as energy generated by photovoltaic panels,wind turbines and hydroelectric power to increase the sustainability of human activities. One of the main objectives of this challenge is to achieve the decarbonization of CO_2 emissions by 2050. It is a shift that requires the use of many new technologies to increase system efficiency and to integrate renewable sources. Today, around 50% of investments in the energy sector go to renewable sources. Cities are on average responsible for about 70% of total CO_2 emissions and to facilitate the energy transition, several targets have been set in European Union cities to bring an energy production towards a sustainable transition. Cities have always been the core of innovation, the fulcrum of economic growth and modernization; in fact, today more than 72% of the population lives in cities and the phenomenon of urbanization continues to grow. While ensuring a high standard of living for citizens, cities play a crucial role towards a sustainable low-carbon economy, seeking to become more and more energy efficient. Therefore, in order to meet this need, city administrators have increasingly seen their planning choices changed to integrate new technologies geared toward urban sustainability. The Smart Energy City (SEC), is the synthesis of these latest strategies and the urban planning development adopted by modern cities. SEC promotes continuous energy transition projects based on zero carbon emissions and the optimization of renewable energy resources. A SEC project can be defined as "a project aiming at the sustainability of energy systems and services through the optimized integration of increased energy conservation, energy efficiency, and the use of local renewable energy sources"[1]. As more and more people move to cities, new problems for both the Earth and the city inhabitants arise. It is expected that by 2050, 6.3 billion people will be living in cities: double the size of today's urban population. Although the city is the place where much economic activity takes place, it is also responsible for 75% of natural resource consumption and 70% of greenhouse gas emissions. It's also estimated that 8.8 million people die each year from air pollution. However, the problems are not only technical, but also social, as cities become more expensive and increasing inequalities, housing problems, security and human mobility.

The smart city is a new concept of city that aims to improve the city functioning using modern information technologies. It is defined as a system of systems to optimally manage the use of resources, improve and monitor the management, develop new business models and most importantly help citizens to make informed decisions of the responsible use of resources. There is then an integration between physical, digital, and human systems for developing and maintaining a sustainable, inclusive and a high quality of life in the city. The new technologies aim to improve the quality and performance of urban services and, at the same time, reduce cost and improve the efficient use of resources. The pillars of the smart city encompass different aspects: living, environment, economy, and governance. In this case the environmental aspect is the most relevant: a smart city, which is also called sustainable city, tries to maximize the efficiency of energy and material use, tries to achieve a zero-waste system, the main sources of electricity production are renewable and carbon-free sources, but also tries to improve the physical well-being of humans by encouraging walking and cycling. The smart city uses a smart grid to deliver electricity to inhabitants by integrating multiple power sources like photovoltaic panels on rooftops and small wind turbines. The grid is also capable of working bidirectionally, so as to enable producers to consume the electricity they produce. The production of electricity is now becoming 'local' and this creates energy communities where the electricity is produced 'locally' and this is kind of what happens with the private photovoltaic and battery systems. With the latest technologies and batteries, it is also possible to share some of the stored capacity with the neighbourhood in case of demand peak during the day. There are also new devices called 'smart meters' that are installed in each house and collect data on energy demand and consumption to extract a usage profile[2]; the data is sent to a central organization, which could be a smart city platform (municipality), to better understand total energy demand, but also to customize tariffs and encourage electricity use during peak demand.

The development of the smart city relies mostly on the so called "green infrastructures". These infrastructures are designed to provide ecosystem services and functions, such as water purification or improving air quality. All these functions have the common objective of improving the human life, support the green economy, the biodiversity and better environment conditions[3]. The main benefit of the green infrastructures lies in the planning, development and meeting of the different needs of the inhabitants, from the children to the elderly, by providing access to nature, reduce the effects of climate changes and reduce the risk of floods, like the new containment lake of the Seveso River[4]. While these new infrastructures change the paradigm of their financing, it is important to notice how the green investments are initially more expensive than conventional investments[5]. There are also costs for the maintenance and for operations like irrigation, weeding but also inspections and repairs to keep the infrastructure as good as possible. Although these investments will pay back in the following years, like in reduced healthcare costs.

1.2 Olympic Games as a catalyst for the Energy Transition

The Milan-Cortina 2026 Olympic Games are not only a sporting event but a large-scale urban operation that intends to act as a leverage for sustainability and innovation. This intention is strongly reflected in the institutional documents that accompany the Olympic planning, in particular the 'Sintesi non Tecnica del Rapporto Ambientale (Strategic Environmental Assessment - VAS)' and the 'Programma Parti Specifiche'. These documents provide a framework that explicitly frames the Games within the broader agenda of environmental transition.

According to the VAS, one of the guiding principles is to minimize energy consumption and promote renewable sources throughout the Olympic infrastructure network. The interventions are classified into four major sustainability goals:

- Improving energy efficiency in buildings, through insulation, smart control systems, and high-performance materials;
- Reducing CO_2 emissions, aiming for climate neutrality of Olympic-related operations;
- Minimizing soil consumption and land transformation, favoring the reuse of existing areas and the integration of greenery into the urban fabric;
- Promoting soft mobility and intermodality, with improved pedestrian, cycling, and public transport connections to reduce the impact of private vehicles.

The Main Operation Center (MOC) also plays a fundamental role, a centralized platform that will allow real-time monitoring of energy, water, waste, and mobility flows during the Games. This system not only ensures operational efficiency, but also represents an innovative example of how digitalization can support energy transition at the city level.

From a planning perspective, the 'Programma Parti Specifiche' [6] articulates several action lines to implement the VAS goals. These include:

- Green building certification systems (LEED, BREEAM, NZEB) as mandatory for new constructions;
- Integration of photovoltaic panels, solar thermal systems, and smart metering systems in Olympic venues;
- Use of climate-resilient materials and adaptation solutions to cope with increased climate variability;
- A requirement for Life Cycle Assessments (LCA) of materials and operations to monitor environmental performance throughout the infrastructure's life;
- Circular economy criteria for procurement, promoting reuse and recycling of construction materials.

The documents recognize that these interventions must leave a legacy for Milan beyond the short Olympic timeframe. The aim is to turn temporary infrastructures and services into permanent assets of a sustainable urban model.

1.2.1 The previous edition of the Winter Olympic Games

The Beijing 2022 Winter Games are a significant example of how major sporting events act as a catalysts for energy transition, as they have shown how to promote innovation and environmental sustainability. Thanks to the construction of Ultra-Low-Energy Buildings (ULEBs) such as the Wukesong Ice Sports Center, which reduced energy needs by 77%, compared to traditional fossil-fueled arenas, through advanced dehumidification technologies and insulated facades, there were significant energy savings. Furthermore, the integration of photovoltaic systems of around 600 kW has made it possible to generate around 700,000 kWh per year, equivalent to savings of 252 tonnes of coal and almost 700 tonnes of CO_2 annually [7]. A distinctive element was the complete power supply of the Olympic sites from renewable sources, solar and wind, made possible thanks to Zhangbei's DC grid: a flexible system capable of transferring over 1 billion kWh of green energy per year and meeting approximately 10% of Beijing's energy needs. The use of transcritical CO_2 for refrigeration systems in four ice sports venues for the first time was also important, reducing energy consumption, compared to traditional systems, by more than 40% and recovering 75% of the heat produced, with environmental benefits comparable to the reduction of emissions of 3,900 cars [8]. The approach to urban regeneration favored the reuse and renovation of five preexisting Olympic venues since 2008, limiting land consumption and waste. Meanwhile, while the Yanqing Olympic Village introduced prefabricated steel solutions, advanced thermal insulation systems, green roofs, and solar panels, all accompanied by careful energy monitoring and low environmental impact materials. Finally, ecological and landscape protection took the form of minimal and reversible interventions in mountain areas, the creation of ecological corridors for fauna, and autonomous water recycling in environments such as the Olympic Forest Park, creating a lasting positive impact on biodiversity and sustainable use of water resources. One year after the Games, a significant social and economic impact,including access to new sports facilities, comprising 654 ice rinks and 803 indoor and outdoor ski slopes,increased winter tourism with over 520 million visitors expected and revenues of CNY 720 billion in the season, and growing participation in ice sports involving 346 million Chinese since 2015 [9]. This philosophy of innovation and environmental sustainability implemented in Beijing constitutes a common thread that should ideally link all editions of the Olympic Games, promoting continuity in the values and practices of ecological transition across various Olympic events.

1.3 The Arena and the Olympic Games

Figure 1: Rendering of the Arena

The Milan-Cortina 2026 Winter Olympic Games represent a great opportunity for urban renewal and the renovation of sports facilities, as well as a strong boost to the construction of new works for both public and private use, a new opportunity to take action in urban areas that have long been marked by degradation and unfinished projects. The plan drawn up by S.I.M.I.C.O. (Società Infrastrutture Milano Cortina 2020-2026) provides for 94 urban interventions, 44 of which are functional to the construction or renovation of sports facilities and 50 related to transport infrastructure, distributed between Lombardy, Veneto, and Trentino-Alto Adige. In the south-east of Milan, specifically in the area between Santa Giulia Nord, Taliedo, and Rogoredo, a valuable piece of Olympic infrastructure will be built: the Santa Giulia Arena (also known as Pala Italia), a new arena destined to become a multifunctional hub for sporting and cultural events even after the Games. The project involves transforming the former industrial area into a LEED (Leadership in Energy and Environmental Design) district [6] through the construction of new offices, residences, university campuses, and rail links. LEED is an environmental standard that certifies the sustainability of a building by assessing its environmental, energy, social, and economic impact. It is a classification system that integrates the principles of smart growth, urban planning and "Green Building" into a national neighborhood certification system. The first district in the world to obtain it is Porta Nuova, right in Milan. To understand the actual scope of the planned interventions, it is necessary to look beyond the individual infrastructure and consider the lack of a unified strategic vision for the redevelopment of the entire neighborhood. Since the 1980s, plans and master plans have followed one another without concrete results, leaving some fundamental issues unresolved:

- the absence of adequate infrastructure connections, such as the extension of the Paullese road or the Forlanini-Rogoredo metro tramway;
- the lack of a coherent system of public spaces, which are often degraded or fragmented;
- the abandonment of entire areas, such as the section between Via Zama, Bonfadini, and Salomone, which has high strategic potential thanks to the accessibility of the new Zama station on the Circle Line.

The legacy of major events is now increasingly intangible and linked to international visibility, as was the case with Expo 2015, rather than to lasting structural interventions. After decades of indecision and fragmentation, the Olympics could be a real opportunity to address chronic issues and overturn the model that, until now, has seen the private sector influence the priorities and shape of the public city. The Arena, designed by David Chipperfield and Arup, will host the men's and women's roller hockey tournaments from February 5 to 22, 2026. The design features an elliptical shape inspired by Roman amphitheaters, with three rings interspersed with glass panels. The capacity is estimated at around 16,000 seats, with an adjacent outdoor square of approximately 10,000 m^2 designed primarily for post-Olympic social events. The completion is scheduled for December 2025, and it is estimated that approximately 400 workers will be employed for the construction. The Arena will be accessible through the nearby Rogoredo station and the East-SS415 ring road, for which the Municipality of Milan has allocated approximately 12 million euros to allow vehicular access. The Arena will subsequently be directly connected to the Rogoredo railway and metro station via a new tram line 13, scheduled to open in June 2027, thus attempting to improve public transport. In addition to the Santa Giulia Arena, numerous other smart and sustainable projects will be carried out throughout Milan. The Olympic Village, which will be built at the Porta Romana railway yard, will consist of six NZEB (Nearly Zero Energy Building) buildings, equipped with solar thermal and photovoltaic panels, rainwater collection and reuse systems, and sensors for monitoring flows, temperatures, and air quality. At the end of the Games, the village will be converted into a university campus for students in Milan. Another interesting new feature will be the "Milano Green Door," the first MaaS (Mobility as a Service) project in Italy. This involves the urban redevelopment of an area on the A7 motorway, at the southern entrance to Milan, a key hub for numerous destinations. An information and tourist center will be built to serve the city, the region, and the Olympics, alongside a new "Courtesy Point" for tolls and related services. Parking will be available, and thanks to the new "Courtesy Point," tolls and related services will be available. An information and tourist center will be built to serve the city, the region, and the Olympics, alongside a new "Courtesy Point" for tolls and related services. Parking will be available, and thanks to a collaboration with the FNM group, it will be possible to rent e-bikes or electric cars. The project also includes the construction of a cycle path connected to the existing one along the Naviglio Pavese canal, a co-working and relaxation area with state-of-the-art digital connections and healthy food distributors. The site will be self-powered by a photovoltaic system, creating one of Milan's first energy communities. There will also be innovation in the CityLife district: CityWave, a skyscraper that will stand out for its undulating shape, developed horizontally rather than vertically. It will be covered by 11,000m^2 of photovoltaic panels, capable of producing 1.3 MWh of energy per year. These features will allow CityWave to consume 45% less energy than a building of the same size, avoiding the emission of 500 tons of CO_2 per year. All these examples show how the Olympics represent not only an opportunity for Milan to create infrastructure, but above all to focus increasingly on the green energy transition, where the role of public infrastructure in cities is crucial. The construction of the Santa Giulia Arena, with its photovoltaic panels, also aims to contribute significantly to the energy transition, producing electricity both for self-consumption and for feeding into the city's electricity grid [10]. Renewable energy systems are ideal for managing peaks in electricity demand when the base load cannot meet the entire demand.

1.4 Comparison between the Pala Alpitour and the Pala Italia

An historical example of another public sports facility, useful for reflecting on the economic and social impact of structures linked to major international events, is the Pala Alpitour in Turin, built for the 2006 Winter Olympics. According to the I.O.C. (International Olympic Committee), the legacy of the Olympics must be based on economic sustainability, social inclusion, and the enhancement of the local area. From an economic point of view, the Pala Alpitour required an initial investment of approximately $87 million. Designed by Japanese architect Arata Isozaki, its capacity is almost equal to that of the Santa Giulia Arena and it is located in the Santa Rita district, in the Piazza d'Armi park near the Grande Torino Olympic Stadium. At the end of the Olympic Games, the Region, CONI, the Municipality, and the Province established the Fondazione 20 marzo 2006, which in turn created a special purpose company called Parcolimpico for the management and maintenance of the Olympic sites, keeping the ownership separate. Just like the Santa Giulia Arena, the facility was originally built to host ice hockey tournaments, a sport that has never been very popular in Italy. The Pala Alpitour suffered from a management vacuum after the Olympics due to a lack of post-event strategy, finding itself immediately without a real reason for reuse, also due to the fact that the clubs participating in potentially hosted sports championships such as volleyball and basketball preferred to use the smaller Pala Ruffini due to the high management costs. In the early years, there were very few events and the revenue generated from them failed to cover the excessive operating costs, which also included those relating to the Cesana bobsleigh track and the Pregelato ski jump stadium, which had a negative impact on the post-Olympic annual budgets.

It was only after 2010, thanks to its conversion into a multi-purpose arena and the arrival of a new company that acquired 70% of the operating company through a tender process, that the Pala Alpitour began to generate profits, becoming one of the main venues for sporting and musical events in Italy, hosting sporting events such as the ATP Finals tennis tournament and the Italbasket pre-Olympic tournament in 2016. In comparison, the PalaItalia in Milan is expected to be built with a more market-oriented approach: financed largely by private investors (CTS Eventim), it involves an initial investment of over 180 million euros and is expected to be managed sustainably and continuously over time, with a business model already in place to host concerts, international events, and indoor sports starting in 2026.

From a social point of view, the two infrastructures have important similarities. The Pala Alpitour played a key role in the redevelopment of the Lingotto district in Turin, a former industrial hub that was in a state of decay and abandonment. However, its integration into the social fabric took place gradually: in the first few years after the Games, the structure risked becoming a ‘cathedral in the desert’, i.e. an infrastructure of great value and impact, but poorly used and poorly connected to the daily life of the city. Only with time, thanks to its conversion into a multifunctional arena and more dynamic management, has the Pala Alpitour managed to carve out a stable role for itself as a hub for sporting and musical events, also contributing to the transformation of Turin’s image in terms of tourism and international appeal. The Pala Italia is also intended to be built with the idea of urban regeneration for the Santa Giulia district. However, the Arena is not conceived here as an isolated element, but as part of a completely renovated district that includes public spaces, green areas, and new transport lines. The aim is therefore to avoid the risk of an isolated building like the Pala Alpitour. Based on the CIO criteria initially provided in this paragraph: while the Pala Alpitour is an example of success achieved over time after a critical phase, the PalaItalia is proposed as a ‘legacy-ready’ infrastructure, designed to function from the outset as a multifunctional facility in the city life of Milan.

1.4.1 Governance Model

The governance model of the Santa Giulia Arena is governed by two main agreements: the General Urban Planning Agreement [11]- signed on August 4, 2022 between Milano Santa Giulia S.p.A.(MSG), the Municipality of Milan, the Lombardy Region, and Sport e Salute S.p.A.) – and the Urban Planning Agreement[12] signed on May 8, 2023, which details the implementation aspects of the project, management obligations, and economic enhancement of the structure. The public-private partnership for the construction of the infrastructure is based on a model in which MSG builds the arena at its own expense but with compensation and agreement obligations in favor of the Municipality. From an economic point of view, the initial investment for its construction is estimated at:

- 180 million euros, entirely covered by MSG;
- an indirect public contribution of 40 million euros, not as non-repayable loan but tied to public urbanization works in the area surrounding the arena;
- guarantee obligations to ensure that the project is completed on time (delivery of the work by December 2025).

MSG will also create a new separate legal entity to manage the arena, with a business plan subject to periodic review by the municipality and the region, under penalty of breach of contract. In addition, a monitoring committee made up of one representative of each of the entities that signed the agreement will constantly monitor the status of the work, post-Olympic management, and compliance with the social and environmental clauses of the facility.

The core of the management agreement is based on the management of the agreement between the Municipality of Milan and MSG. The agreement introduces a restriction on functional destination for at least 20 years: the arena must maintain a sporting, cultural, and entertainment destination, except in the case of extraordinary authorizations from the public bodies involved. The daily usage fee is set at €100,000, and sponsored events allow the Municipality to benefit from savings of €20,000 for each year. The 'Positive Calendar' indicates the Arena's programming calendar containing events organized by MSG, while the 'Negative Calendar' indicates the Municipality's programming calendar for Arena use based on the agreement days. MSG therefore undertakes to:

- a positive calendar of 115 events per year, of which at least 2 are sponsored by the Municipality of Milan (with a 10% discount on the fee);
- 25 free tickets for each of these events, with a value of €70 each (for a total of €201,250/year);
- indicate two days per year made available free of charge for institutional events (economic value of €200,000/year, corresponding to the ordinary daily fee multiplied by two days)

In addition, €40,000/year in revenue from particularly significant events is estimated. In general, the economic value of the agreement is €461,250/year, to which urbanization costs must be added. The agreement aims to limit the risk of a 'cathedral in the desert' by binding MSG to intensive use of the arena for the public benefit. The municipality retains powers of control over the effective implementation of the agreement obligations and compliance with the positive calendar.

1.5 Economic and social implications of hosting Big Events

'Big events' like Olympic Games has many economic implications such as substantial financial investments while simultaneously exerting a profound influence on a vast number of individuals. These events have a limited duration, but their influence and importance for the host city are not limited to the event itself but extends beyond it. The preparation phase, the event itself, and its future legacy influence numerous urban, economic, social, and environmental factors that represent a real revolution for the host city. The choice of a city to host events of this kind is influenced by the potential benefits it can bring, with particular attention to the economic growth of the city and urban regeneration through the large number of infrastructures required for the organization of this event. Governments hosting big events often justify their bids and budgets by emphasizing the increase in tourism and the resulting economic benefits, as well as improvements to the urban environment. However, this argument is based on the assumption that all local residents consistently benefit from the city's economic growth and improvements in urban infrastructure. This theory has met with growing opposition in recent times, as some experts say that assessments of big events need to include a fair view of how the benefits and drawbacks of such events are spread across the population. In theory, different socioeconomic groups are expected to derive distinct economic benefits. Extensive research has shown that the middle and upper classes tend to benefit to varying degrees from big events. However, existing studies offer limited evidence to support the idea that these events confer benefits on economically disadvantaged groups. This could suggest that major events may increase inequalities among city dwellers. It is important to distinguish between the three phases of preparation, the event itself, and the future legacy [13, 14, 15].

In the context of urban redevelopment, big events are used to justify the demolition of existing buildings and the forced displacement of communities in low-income neighborhoods. This is an example of how, in these processes, the voice of disadvantaged communities carries little weight in the face of state interests, which are focused on promoting their own economic interests. These interventions often cause mass evictions, rent increases, a reduction in public housing, and an increase in housing costs, making it more difficult for evicted people to find accommodation. One example was the 1992 Olympics in Atlanta, which resulted in the eviction of 15,000 people and the loss of 9,500 low-cost housing units [16]. With the projects related to the 2016 Olympics in Rio, we have seen how many evicted people were then relocated to the suburbs, where public services are scarce, thus increasing social segregation[17, 18]. Therefore, the greatest risk is that many people will be left homeless if the government fails to provide affordable housing solutions, while wealthier communities benefit from new infrastructure.

Besides the consequences for local communities, major events can also create unexpected effects on the city's sporting scene, with direct impacts on the budgets of clubs and organizations, as in the edition of Milan Cortina Olympics 2026. A fascinating return to the past, but also a noticeable economic loss: forced to move due to the Olympics, for three months the basketball team Olimpia Milano will be forced to play (from mid-December to March) its home matches at the Palalido and not in the usual Assago Forum. The difference in capacity between the two structures is notable: there is a gap of more than seven thousand seats, without considering that the usual capacity percentage is 74% on average.This represents a considerable economic loss for the basketball club which will "lose" the Forum because the figure skating and short track competitions scheduled in the Milan

Cortina 2026 program will be hosted there. An indirect implication which has direct consequences for the club's budget.

Another crucial factor that drives governments to host major events is the creation of additional job opportunities. However, the distribution of these new jobs is often uneven, favoring those who already have employment or specialized skills. Most unemployed people were not selected for the positions available during the Olympics; very often, the focus was on workers without union representation and with poor working conditions. During the 1996 Atlanta Olympics, almost all of the jobs were filled by low-income immigrants without contracts, encouraging labor exploitation in the infrastructure sector [13].

Furthermore, the Olympics are often seen as an opportunity to attract tourists, but studies have shown that accessibility and participation in these events is often limited, and high costs often discourage tourists from visiting the city. This is particularly emphasized in cases where the host city is already an important tourist destination in its own right. The 2008 and 2012 Olympic Games in Beijing and London, respectively, saw a 30% and 6% drop in tourist arrivals. This also directly causes a decrease in revenue for retailers and restaurateurs [19]. Furthermore, wealthier visitors tend to visit the most luxurious and expensive urban areas. This generates a significant economic shift with negative effects on small local businesses: large brands and established suppliers benefit from increased revenues, overshadowing small local businesses and accentuating disparities between companies in the same sector [19].

Another opportunity generated by major events is the chance to improve urban transport. However, the benefits generated by this opportunity tend to be concentrated in areas close to event venues and do not reach the population living in the suburbs (often those with low incomes). New transport lines tend to favor those who already live in well-connected areas with medium to high incomes, amplifying social inequalities [14]. Another example of infrastructure and logistics issues is linked to our study of the Santa Giulia area. As reported by Corriere della Sera [20], Milan's Municipality 4 voted in early August on a motion asking the Sala council to take action with a mobility plan during the Olympic period, as the tram line that was supposed to connect the M3 in Rogoredo with the M4 will not be ready until June 2027, due to delays accumulated "because of the complexity of the project", as explained by former urban regeneration councilor Giancarlo Tancredi, forcing the municipality to arrange temporary solutions with shuttle buses every two minutes and increased service on tram 27. In addition, the high number of the vehicles involved and the simultaneous flow of people leaving events are likely to cause a high risk of traffic congestion. Added to this is the fact that the 2,750-space multi-storey car park will not be accessible to the public but reserved for athletes and staff. The municipality also had to allocate an additional 7 million euros to complete the pedestrian and cycle paths around the Arena in time, but these will only be temporary and will be demolished after the Games.

Public investment in infrastructure linked to big events causes gentrification. This effect occurs when the environmental conditions of the neighborhood improve and are reflected in increased rents, the opening of restaurants, shops, and services designed for a middle-to-high-end customers. However, this goes against the stated goal of providing housing to low-to middle-income groups. The increase in the value of real estate makes homes increasingly unaffordable for this segment of the population, who are then forced to leave their neighborhood, and commercial activities are closed and replaced by others. Those who originally lived in the areas affected by the event are therefore forced to move elsewhere, generating a phenomenon of indirect eviction. Redevelopment initiatives linked to mega-events do not improve the quality of life of residents, but push them out due to gentrification processes. One example is the Stratford neighborhood, which hosted the 2012 London Olympics, where many people were forced to move due to the high costs of the redeveloped neighborhood [21, 22]. Gentrification also impacts public spaces. With urban development, these spaces are often privatized and controlled by developers, becoming accessible only to privileged groups, making them increasingly exclusive, as in the case of the golf course built for the 2016 Olympics in Rio in the Marapendi nature reserve. Ownership of the facility passed from the state to the developer, who transformed the area into luxury residences, preventing low-income groups from accessing these natural areas [15].

Although big events are often presented as great opportunities for economic growth, they involve high costs that sometimes weigh heavily on citizens. While it can be argued that public funds are managed by elected governments, the burden of debt repayment falls disproportionately on the population through taxation. Very often, the costs of organizing major events exceed the initial estimates, resulting in budget overruns. In the case of the 1998 Winter Olympics in Nagano, Japan, the financing of the event resulted in an estimated debt of nearly £20,000 per family [23]. For the Milano 2026 edition, the Italian government has also used €21 million [24] in additional public spending to cover part of the extra costs associated with the construction of the PalaItalia and the Milan-Cortina 2026 Olympic Village. Although these are formally works carried out by private entities, public intervention has been justified on the grounds of 'public interest' of the Olympics. According to former councilor Tancredi, the total estimated extra costs amount to around 67 million euros, of which state funding covers only a portion. This decision raises questions about the economic sustainability of public-private partnerships, as well as the risk that host cities will have to use public resources to cover unexpected expenses, potentially diverting funds from priority sectors such as healthcare, education, and urban welfare. Finally, given the huge amount of money involved, many editions of the Olympic Games have been the scene of corruption or embezzlement, especially during the preparatory stages. To facilitate organization, temporary emergency laws are often adopted that suspend the usual rules, creating fertile ground for opaque practices. Large suppliers with substantial resources tend to create monopolies, further marginalizing small businesses, hindering fair governance, and exacerbating social inequalities [25].

1.6 Renewable Energy Communities

A renewable energy community (CER) is a legal entity in which the partners or members can be individuals, small and medium enterprises (for which participation in the CER does not constitute their main commercial and industrial activity), as well as local authorities, associations, companies, entities, or consortia that share, through their consumption, the renewable electricity produced by renewable energy plants. The main objective of a CER is to increase local energy autonomy by promoting collective self-consumption and reducing dependence on fossil fuels and the centralized system, as well as providing economic and environmental benefits at the community level. In a CER, renewable electricity is shared between the various producers and consumers connected to the same primary substation, thanks to the national electricity distribution network, which allows the sharing of this energy virtually. All withdrawal and feed-in points for plants within the perimeter of the individual configuration must be located in the area served by the same primary substation. The plants may also be made available by a third-party producer who is not a partner or member of the CER. CERs can access the financial contributions provided by applying for access to the self-consumption service from the GSE (Energy Services Manager). The financial contributions due are recognized for each production plant whose electricity is relevant to the CER configuration and are:

- The valuation fee established by ARERA (Italian Regulatory Authority for Energy, Networks and Environment) to reimburse certain tariff components, recognized on self-consumed electricity;
- The premium tariff recognized on incentivized shared energy.

Plant producers can also valorize all the energy fed into the grid by selling it on the market or requesting its withdrawal from the GSE through the dedicated withdrawal point (RID) service. Energy communities are based on flexible models that can be adapted to local needs: they can be created in residential, industrial, or mixed contexts. In Italy, according to a study by the Politecnico di Milano, the estimated potential is for more than 450,000 communities to be created by 2050, with a total economic impact estimated at around 500 billion euros. According to Greenpeace, by the same date, around 40% of European citizens could become 'energy citizens', i.e. active participants in energy production and management, and many of them will be part of energy communities. For CERs whose production plants are located in municipalities with a population of fewer than 50,000 inhabitants, an additional capital contribution of up to 40% of the investment cost is provided to be drawn from PNRR resources. To support their expansion, it is essential to have a coherent evolution of the regulatory framework, the adoption of new technologies such as smart grids and storage systems, as well as a strong push towards collective and responsible participation in the energy transition. The new PalaItalia in Santa Giulia, with its photovoltaic panels capable of producing electricity from renewable sources, is a public infrastructure that can play a crucial role in the local energy system. Its characteristics are favorable for integrating the arena into a renewable energy community. The inclusion of PalaItalia in an energy community would maximize the benefits of distributed energy generation, contributing not only to reducing energy costs for those involved but also to a sense of belonging to the entire community, an approach in line with the standards of the European Union according to which citizens should be the main actors in the ecological transition (energy citizens). Finally, the creation of a CER around such an important public infrastructure would represent a replicable model and an example of integration between large public infrastructures and citizens for future projects.

1.7 Chosen Strategy and Indicators

This section will analyze and propose the best strategy for positioning photovoltaic panels on the arena roof, starting from the thesis study [26], and present the reference indices for our work. The central idea of the project is to create an energy production system that balances the building's electricity consumption. Through a photovoltaic system located on the roof of the arena that takes advantage of the benefits of the 'cool roof' of the building, a technology which is capable of lowering the surface temperature and improving the panels efficiency. Cool roofs have a positive impact on the functioning of a photovoltaic system in general: they are roofs with a high capacity to reflect solar radiation and emit thermal energy in the infrared spectrum. Their advantages also include the thermal insulation of the building. The reflection of both short-wave and long-wave solar radiation reduces the flow of incoming energy and lowers the roof's surface temperature. Cool roofs are made with panels that have a smooth and light exterior finish, covered with a white PVC-P coating. It is the combination of these two properties that defines a cool material, which means a material with excellent reflective properties. On the arena roof, the implementation of this technology allows most of the incident radiation to be reflected, thus also reducing the heat flow entering the building and therefore its energy requirements. In addition, the use of these high solar reflection polymer membranes leads to a decrease in surface temperature with a beneficial effect on photovoltaic system operation.

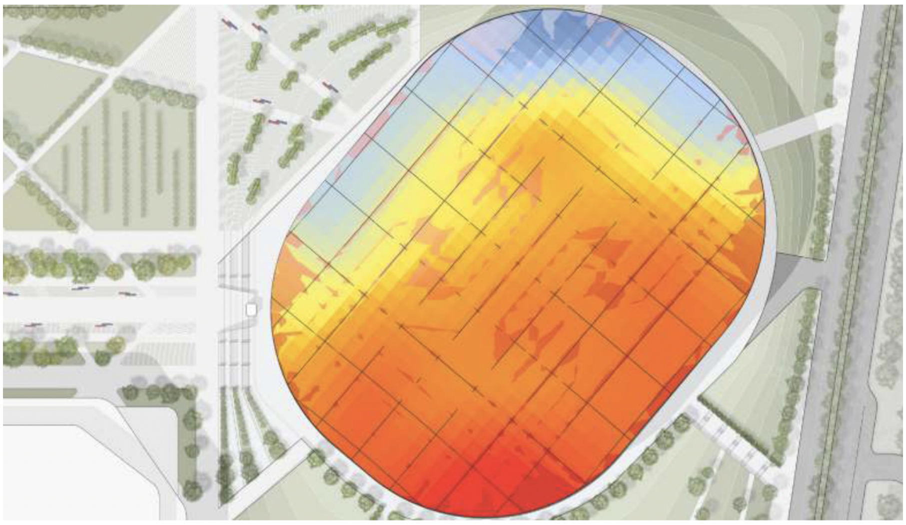

Figure 2: Radiation during Summer days

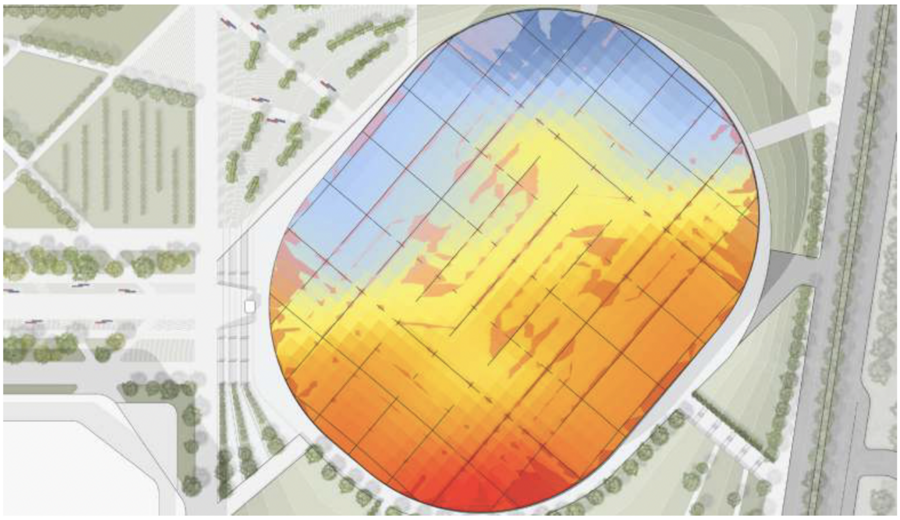

Figure 3: Radiation during Winter days

The chosen photovoltaic panels are high performance, measuring 1.9 x 1.1 m, with a power range of 370-390 kW and an average efficiency of 19% per module. Covering the entire roof with photovoltaic modules –13,827 m^2 for a total of 6,015 panels – would not be a feasible solution, as it would result in an oversized system and compromise the reflective properties of the 'cool roof', reducing its benefits in terms of outdoor comfort. Based on the analysis provided by [26], evaluating solar radiation in summer and winter and taking into account the different inclinations of the roof, an optimal positioning of the modules was identified in the areas most exposed to the sun, avoiding the less productive areas and preserving the reflective characteristics of the roof. The most productive areas are those facing southeast and southwest, whereas the areas to the north, which are less exposed, are not suitable for installing modules. The selected layout covers 2,300 m^2 (about a quarter of the total surface) with 1,100 panels.

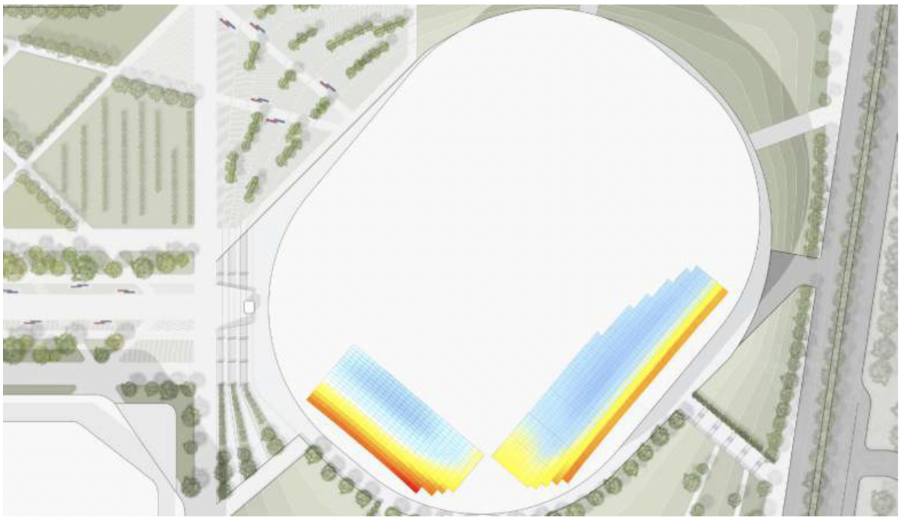

Figure 4: Chosen strategy for the positioning of the modules

Our model used to calculate the energy produced by the arena solar panels is a function of incident solar radiation and the area power of the system.

$$\text{Production} = \text{SSRD} \times \text{Area} \times \eta$$

where:

SSRD = solar irradiance in kWh/m^2

Area = installed area in m^2

η = average system performance (19%)

The first and main index chosen to measure the energy impact of the Santa Giulia Arena is the Energy Self-Sufficiency Index which is defined as the ratio between the share of locally produced energy (and thus in our case from solar panels) and the energy required by the neighborhood. It is measured on a percentage scale, where a value above 100% therefore means that the energy produced exceeds the demand; if it is 100% it means that the photovoltaic production fully covers the demand, while if it is lower, grid integration is needed.

$$\text{Self-Sufficiency Index} = \frac{\text{Production}}{\text{Requirement}}$$

Then a scenario was considered in which an intense event took place in the arena with approximately 10,000 participants, close to the full capacity of the Arena, and an energy consumption of 1.5 kWh per person during the event was estimated. This value was chosen based on the Super Bowl example, which for its duration generates a total energy consumption of approximately 50 MWh for 80,000 spectators, equivalent to about 0.7 kWh per person [27]. The 1.5 kWh per person value adopted in the model is an estimate that accounts for additional consumptions typical of arena events, such as lighting, services, operational equipment, as well as the energy required during pre- and post-event phases (entrance and exit of participants) and for security and access control systems.

The total energy demand during the event is calculated as the sum of the base system load and the additional consumption due to the event:

$$\text{event\_10000\_demand} = \text{SG\_Load\_kWh} + 10{,}000 \times 1,5$$

The energy self-sufficiency during the event is then:

$$\text{self\_suff\_event} = \frac{\text{PV\_output\_kWh}}{\text{massive\_event\_demand}}$$

Then in order to also consider the effect of humidity, which numerous studies show that a high level of it can impair panel efficiency, an empirical derating coefficient was calculated. In their study, Sohani et Astisao

Garcia [28] reported a loss of up to 46% efficiency in RH between 10% and 50%. The negative effect of humidity on PV panels is related to three main reasons, which are :

- Scattering: atmospheric moisture scatters solar radiation;
- Condensation: it can affect the modules by reducing direct irradiation;
- Refraction: the angle of incidence of light is changed

The formula used to derive PV production as a function of relative humidity (RH) is:

$$\text{PV\_derating} = 1 - \left(\frac{RH}{100} \times 0.05 \right)$$

where:

- RH = relative humidity [%]
- 0.05 = average empirical coefficient used in the literature as an estimate of maximum derating, corresponding to a loss of up to 5% with a RH of 100%.

The correct output then becomes:

$$\text{Production\_adjusted} = \text{Production} \times \text{PV\_derating}$$

- If $RH = 0\%$, then $\text{PV\_derating} = 1$, so there is no loss.
- If $RH = 100\%$, then $\text{PV\_derating} = 1 - 0.05 = 0.95$, that is, a loss of 5% of the output.

The Carbon Avoided Index (CAI) is another useful indicator for assessing the environmental impact of Arena's photovoltaic production, as it measures the tons of CO_2 avoided by energy produced from renewable sources compared to energy produced from fossil sources. This index allows a direct quantification of the contribution of the plant to the reduction of greenhouse gas emissions and thus to the mitigation of climate change. The use of CAI enables linking energy production with the decarbonization objectives set by the European Union, providing an effective metric for comparing the environmental effectiveness of the plant.

The CAI formula is:

$$\text{CAI} = \text{PV Production} \times \text{EF}$$

where:

- PV Production,it is the electrical energy produced by the photovoltaic system ;
- EF it is the average emission factor of the national electricity grid, expressed in g CO_2/kWh. For Italy, according to 2023 ISPRA data [29], this value is 256.3 g CO_2/kWh. In the analysis, this factor is converted in 0.0002563 *tons* of CO_2/kWh.

2 Data Analytics and Analysis

2.1 Data Analytics

For the purposes of analysis in the project, two distinct types of datasets were selected. The first source of data is the official website of Climate Data Store, which is part of the service provided by the Copernicus Climate Change Service (C3S). The data set chosen from this website is the ERA5 hourly data on single levels, which is the fifth generation of the EMCWF (European Centre for Medium-Range Weather Forecasts) reanalysis for the global climate and weather for the past 8 decades. It is available at the following link [30]. It is related to weather conditions in the Santa Giulia district of Milan. The meteorological data contains, in addition to the longitude and latitude of the Santa Giulia Arena and the day on which the measurements were recorded, these following variables:

- SSRD. Surface Solar Radiation is the solar radiation received by the Earth. Therefore, during the night,it is equal to 0. It measures the total amount of solar energy reaching the Earth's surface, including both direct and diffuse radiation). This variable is measured in J/m^2 (Joules per square meter). Since photovoltaic performance models typically use kWh/m^2 (kilowatt-hours per square meter) as a standard unit of solar irradiance, a conversion was applied. The transformation, carried out after the EDA phase, is obtained by dividing the SSRD values by 3,600,000, which corresponds to the number of joules in one kilowatt-hour;
- T2M measures the air temperature at 2 meters above the ground, and finally D2M represents the dew temperature at 2 meters, and p is defined as the temperature at which the air should be cooled (at constant pressure) to achieve water vapor saturation, to initiate condensation and is an indirect measure of air humidity.Both temperature variables are measured in Kelvin.

Starting from these last two variables, a direct measure of atmospheric humidity was then added the relative humidity, calculated by the following formula:

$$RH = 100 \times \left(\frac{\left(\frac{17.625 \cdot d_{2m}}{d_{2m}+243.04}\right)}{\left(\frac{17.625 \cdot t_{2m}}{t_{2m}+243.04}\right)} \right)$$

This formula, which is a simplification of the Magnus formula, measure how close air is to saturation,how much moisture it could contain at maximum at the current temperature.

The second dataset were downloaded from TERNA [31] (Electricity Transmission National Grid) and it is made up by the daily requirement data, measured each 15 minutes slot, in the area of the northern Italy between 2022 and 2025.

Since the data downloaded from Terna refers to the energy requirement of the entire northern area of Italy, the first step in the second part of the project was to proportion the data according to the needs of the Santa Giulia district using the following criterion: Lombardy accounts for about 28 percent of the overall overall energy demand, a percentage taken from regional energy balances published by Terna [32]. The city of Milan, on the other hand, accounts for about 14% of Lombardy's needs based on the ratio of the resident population (about 1.4 million) in Milan to the total population of Lombardy (about 10 million), Istat data from 2023 [33]. Finally, to define the share to be attributed to the Santa Giulia neighborhood, the population of this neighborhood (about 6,000) was considered in relation to the entire population of Milan, resulting in a percentage of 0.43 [34]. Multiplying these figures, we then obtain 0.0168% of the total electricity demand in northern Italy.

2.2 EDA of Energy Requirment data

Starting from an exploratory analysis and calculating the average daily energy load values, it is clear that the days with the highest peaks occur during the summer season, one hypothesis for the increase in demand during this period is due to the cooling of rooms using air conditioners. Looking at the ten days with the highest energy demand, it is easy to notice that they all fall in July, particularly in the second half of the month, when most people are still at home working and not on vacation. This means that the risk of blackouts is higher during the summer season and therefore the Santa Giulia Arena, equipped with photovoltaic systems, can probably contribute to greater energy efficiency. The top ten days for energy requirements are contained in the following table:

Data	Load Energy MW
2023-07-19	4.53
2024-07-17	4.51
2024-07-18	4.51
2022-07-22	4.51
2024-07-19	4.50
2023-07-18	4.49
2022-07-21	4.45
2022-07-20	4.44
2022-07-26	4.41
2024-07-16	4.40

Table 1: Top 10 days for Load Energy

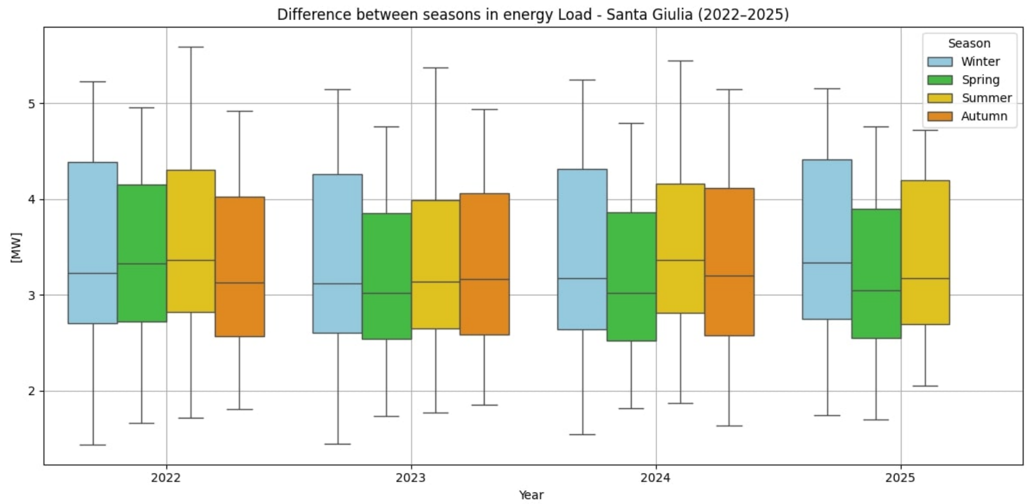

Figure 5: Seasonal Boxplot

To highlight the difference in energy demand during different periods of the year, seasonal box plots were created for each year. Winter covers the period from December to February, spring from March to May, summer from June to August, and autumn from September, October to November. It is clear that the summer season has a higher average demand than other periods; in fact, the summer median is higher than that of all other seasons, with the exception of 2025 (incomplete data for the summer period that does not include data for the hottest days). In addition, summer seasons have more outliers on the right side of the distribution, which could correspond to possible energy peaks and,therefore, potential blackouts.

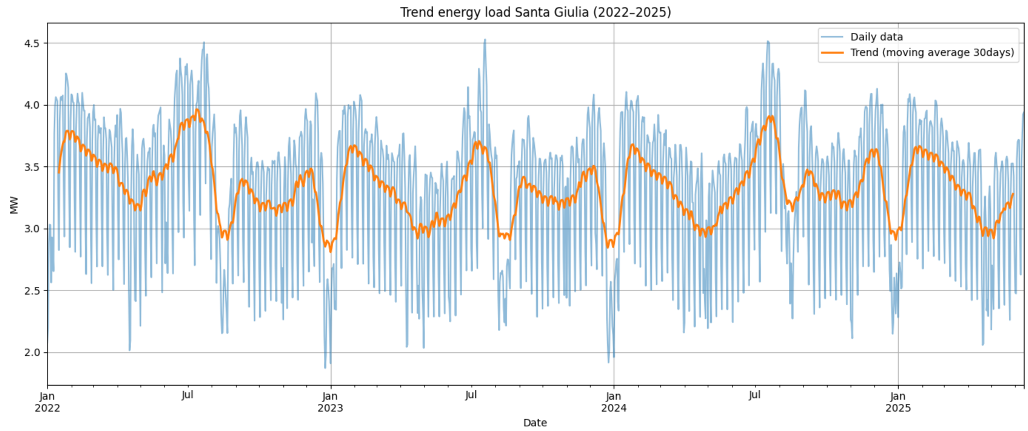

Figure 6: Seasonal Trend

The 30-day moving average chart shows a regular alternation between summer peaks and winter lows, while the overall annual trend appears to be slightly upward; the decline in 2025 is related to the lack of current data. Demand therefore shows a clear seasonality and this information can be useful in adopting different policies for each season.

2.3 EDA of Weather data

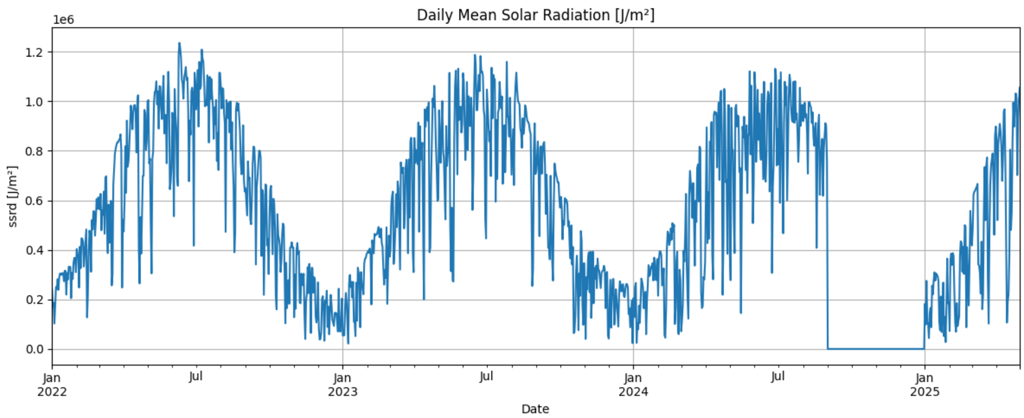

Figure 7: Daily Mean Solar Radiation

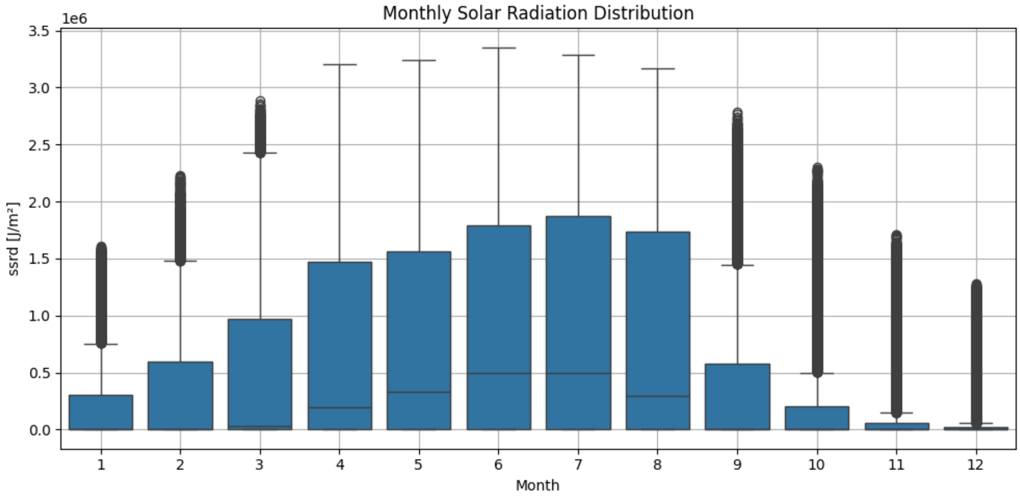

Figure 8: Seasonal Trend

Solar irradiance is the amount of solar energy that reaches the Earth's surface and is characterized by many factors, such as cloudiness, season, and time of day. It is the primary energy source that photovoltaic panels convert into electricity. The two variables are directly proportional. During the nighttime, it is equal to zero, where some anomalies in the measurement can be caused by persistent cloudiness over a long period of time. Looking at the distribution of the time series for solar irradiance data, a seasonal cyclical component characterized by peaks during the summer season and lows during the winter season is strongly visible. Seasonal box plots show that the months with the highest radiation are those in summer, from May to August. It is important to note that the variation in these months is also greater, perhaps due to the alternation of sunny and cloudy days; the variation in the distribution of winter months is lower due to the lack of light during most of the day.

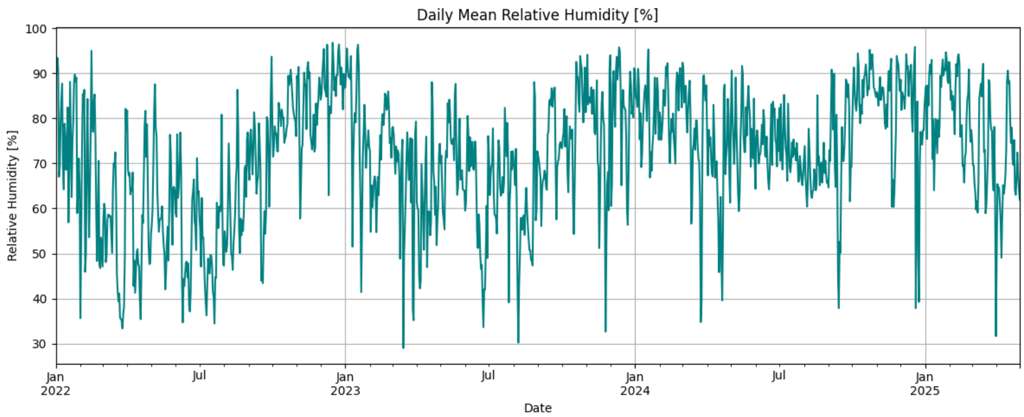

Figure 9: Daily Mean Relative Humidity Trend

Now we will analyze the data concerning relative humidity. Relative humidity is the amount of water vapor present in the air compared to the maximum amount it can hold at a given temperature. The efficiency of photovoltaic panels can be greatly affected by the level of humidity present; water absorbs and disperses sunlight, reducing the amount of radiation that reaches the panels and can also lead to the degradation of the materials used to make the panels.

On average, the relative humidity calculated from 2022 to the first half of June 2025 in the Santa Giulia district is 72%, with a fairly high variability of 18%. The central mass of the data is between 59% and 87.2%, with only a quarter of the data exceeding this percentage. The lowest recorded value is 7%, the highest is 100%.

The correlation coefficient between solar radiation and relative humidity is negative and equal to approximately -0.6. This is explained by the fact that an increase in solar radiation causes an increase in temperature, which reduces relative humidity. On days with warmer air, the relative humidity decreases, whereas on cloudy days with less radiation, the air becomes more saturated. In fact, as the trend graph also shows, it is higher in autumn and winter and lower in summer.

2.4 Analysis

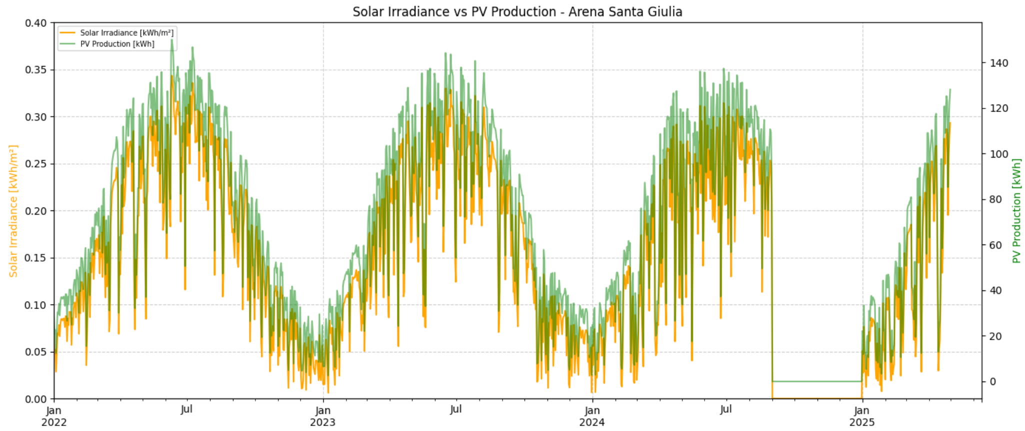

Figure 10: Solar Irradiance vs Production

The graph shows the strong correlation between average daily solar irradiance (left axis, orange) and estimated photovoltaic production (right axis, green). A clear seasonality is observed: the maximum values are recorded in the summer months, while in winter production drops drastically. The trend proves that the PV production estimation model is consistent when based on meteorological solar radiation data.

Average Self-Sufficiency[%]	**Value**
Baseline	7.23
Large scale event	0.40

Table 2: Comparison of average self-sufficiency under different scenarios

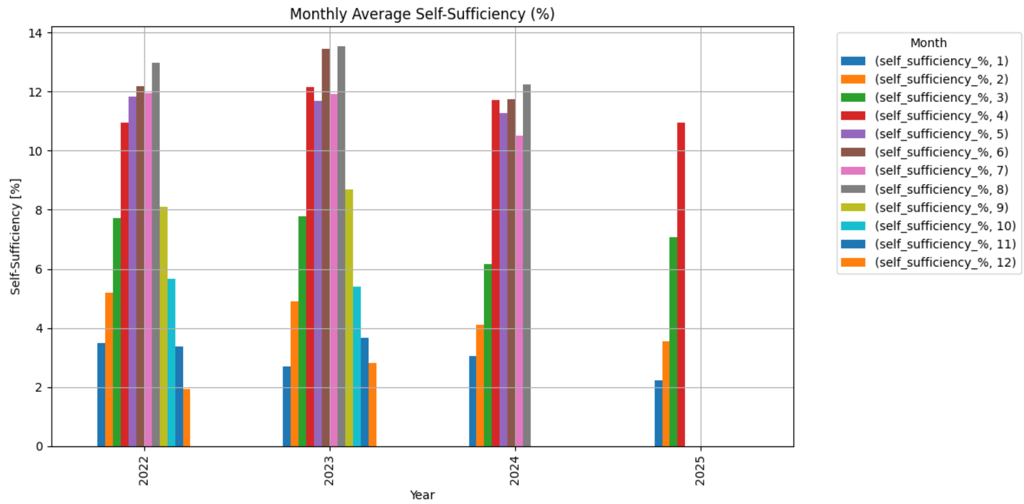

Figure 11: Monthly Average Self Sufficiency

The calculated energy self-sufficiency index provides a retrospective assessment based on the average values of the data available for the neighborhood, thus representing what the energy balance would have been if the arena had been present in the observed period. During the analysis period, the system achieves an average self-sufficiency of 7.2%, indicating that the local production produced by photovoltaic panels would cover only a small part of the total energy demand. It is interesting to observe that, despite having the highest energy demand in summer, it is in this period that the highest self-sufficiency index is recorded, thanks to the higher solar production due to more favorable irradiation conditions. This phenomenon highlights the importance of seasonality in energy management and the potential of photovoltaics to cover a significant share of demand in the summer months. Many of the monthly values show that only a fraction of energy needs are met by photovoltaic production, reflecting limited capacity relative to demand, especially outside summer peaks, as evidenced in monthly trends and seasonal. In the summer months, the share covered by photovoltaics increases, but overall self-sufficiency remains quite low throughout the year. The introduction of a large-scale event, as defined in Section 1.7, significantly reduces the self-sufficiency index, bringing it to approximately 0.4%. This net decline highlights how events can drastically affect the overall energy balance, increasing dependence on the external grid. The effect will be particularly evident if such events take place outside daylight hours or in less favorable seasons such as winter.

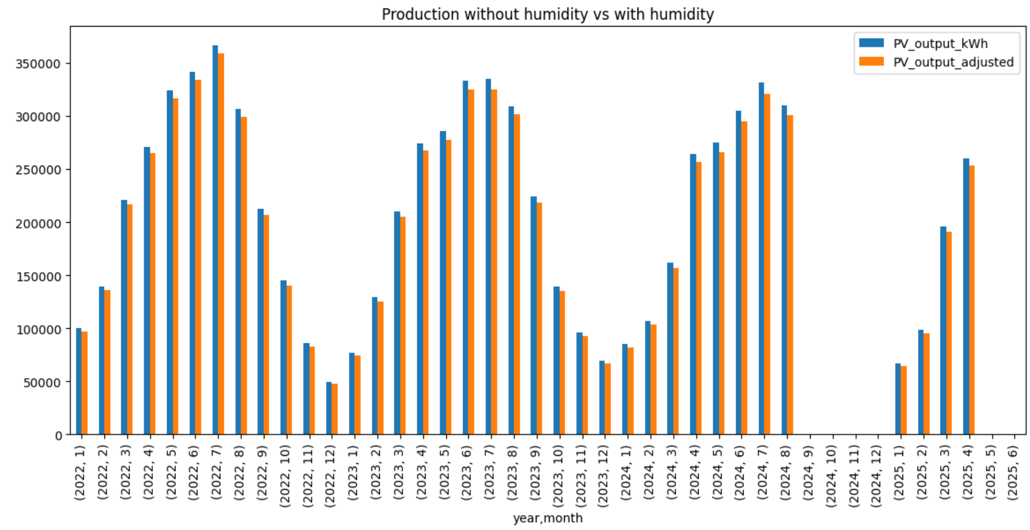

Figure 12: Production without humidity vs with humidity

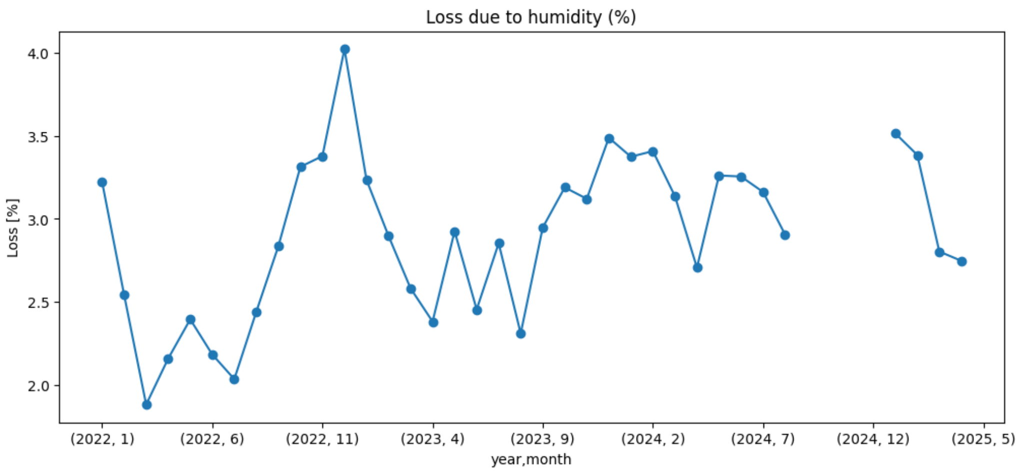

Figure 13: Loss due to humidity

The comparison between real panel output and moisture-adjusted output, together with energy loss due to humidity, highlights the influence of atmospheric conditions and seasonality on PV performance. Energy losses due to humidity can reach 4% in the wettest months, further increasing the gap between production and demand.

Table 3: Carbon Avoided Index (CAI) Annual - Tons of CO_2 Avoided

Years	**CAI (Tons of CO_2)**
2022	657.01
2023	636.25
2024	471.26
2025	159.32
Total 2022–2025	**1923.82**

Carbon Avoided Index (CAI) values indicate that, thanks to the photovoltaic production of the arena, a total of approximately 1924 tons of CO_2 were avoided in the period 2022–2025. There was a substantial amount of avoided emissions every year, with a peak of 657 tons of CO_2 in 2022.

2.5 Economic analysis

An economic analysis is proposed between the estimated photovoltaic production and the energy cost of the events, considering two different energy scenarios:

- The ARERA scenario, which takes into account the average price of electricity at 0.18 €/kWh. Due to the lack of a single price for users in the free market, given the numerous operators present on the market, the value of spending on energy materials in the ARERA greater protection market was chosen, which is published quarterly. For the third quarter of 2025 (July - September) the values are 0.173 €/kWh (F1) and 0.159 €/kWh (F2-3)[35].These data refer exclusively to the energy component and do not include network charges and a fixed portion present annually on the bill. To cover these additional costs, the value was rounded to 0.18 €/kWh ;
- The CER scenario taking into consideration a recognized incentive to Energy Communities of 0.10 €/kWh. According to CACER Decree 414/2023 [36], the premium rate (TIP) for shared electricity in the context of Renewable Energy Communities varies depending on the power of the plant:
  - Installations $\leq$ 200 kW: $\mathrm{TIP} = 80 + \max\big(0,\, 180 - P_z\big)$ €/MWh, up to 120 €/MWh;
  - Installations $>$ 200 kW and $\leq$ 600 kW: $\mathrm{TIP} = 70 + \max\big(0,\, 180 - P_z\big)$ €/MWh, up to 110 €/MWh;
  - Installations $>$ 600 kW: $\mathrm{TIP} = 60 + \max\big(0,\, 180 - P_z\big)$ €/MWh, up to 100 €/MWh.

  Where Pz represents the hourly zonal electricity price. For photovoltaic systems in the Northern Regions (including Lombardy), the decree include an increase of +10 €/MWh applies. The GSE (Energy Services Manager) manages the distribution of these incentives to the members of the Energy Communities, periodically verifying the Pz values to be applied. The Santa Giulia Arena photovoltaic system, with installed power of approximately 418 kWp (1,100 panels $\times$ 380 Wp peak), falls within the $>$ 200 kW and $\leq$ 600 kW range. Thus, the maximum premium rate is 110 €/MWh (0.11 €/kWh). For a conservative estimate, the value used was rounded to 0.10 €/kWh.

The economic analysis is based on a combination of available data, estimates and scenario assumptions, as already introduced in paragraph 1.7. In particular:

- Data available
  - Photovoltaic production (kWh): previously calculated, starting from solar irradiance (SSRD) and converted into electrical energy produced using the effective area of the panels (2,300 m^2) and the average efficiency (19%);
  - Prices of energy: defined in this paragraph before.
- Scenario assumptions
  - Energy consumption per person during an event: estimated in 1.5 kWh(para. 1.7);
  - Participants per event: set at 10,000 (para. 1.7);
  - Number of annual events: 115, as defined by the governance model (para. 1.4.1).

The following values result from these assumptions:

Event consumption (kWh) = 1.5 kWh/person × 10,000 people × 115 events = 1,725,000 kWh/year
Average cost of an event (€) = 15,000 kWh × Price €/kWh

The economic indicators calculated were then:

- Annual PV value (€) = PV production × Price €/kWh;
- Annual event cost (€) = Event consumption × Price €/kWh;
- Net annual balance sheet (€) = PV value – Annual event cost;
- Equivalent events covered = PV value /Average event cost.

Year	PV Production (MWh)	PV Value [euros]	Event Cost [euros]	Net Balance [euros]	Equivalent Events Covered
2022	2 563	461 411	310 500	150 911	171
2023	2 482	446 839	310 500	136 339	166
2024	1 839	330 964	310 500	20 464	123
2025	622	111 891	310 500	−198 609	41
Total 2022–2025	7 506	1 351 105	1 242 000	109 105	

Table 4: Annual economic summary: PV vs events (ARERA Scenario)

The ARERA scenario takes as a reference the average price of electricity recorded by the Regulatory Authority for Energy,Networks, and the Environment (ARERA) for the users. This price (about 0.18 €/kWh during the chosen period) represents the average cost that a final consumer would incurred when purchasing energy from the grid. In this sense, the photovoltaic production of the Arena is valued as an avoided cost, or as economic savings for the community compared to grid supply.

Over the four-year period 2022–2025, the overall value of PV production in the ARERA scenario is approximately €1.35 million , compared to an energy cost of the events of approximately €1.24 million. The overall balance is positive (+109 thousand euros), highlighting that photovoltaic production is sufficient to fully compensate for the costs for events, even generating a surplus.

A further significant indicator is represented by the equivalent events covered: in the analyzed period, PV production energetically corresponds to approximately 500 events, a value higher than the actual number of scheduled events (460).

However, it should be noted that in 2025 there was an annual deficit (–198 thousand euros), attributable to a reduction in photovoltaic production due to meteorological factors (reduced solar radiation availability). Despite this, the overall balance over the four-year period remains positive, confirming the strategic relevance of the photovoltaic system as an instrument of economic and energy autonomy for Arena and the community.

Year	PV Production (MWh)	PV Value [euros]	Event Cost [euros]	Net Balance [euros]	Equivalent Events Covered
2022	2 563	256 340	172 500	83 840	171
2023	2 482	248 244	172 500	75 744	166
2024	1 839	183 869	172 500	11 369	123
2025	622	62 161	172 500	−110 339	41
Total 2022–2025	7 506	750 614	690 000	60 614	

Table 5: Annual economic summary: PV vs events (CER Scenario)

In the case of the CER scenario, PV production is not interpreted as a cost avoided on the bill, but rather as additional revenue from the GSE feed-in tariff for shared energy within the energy community. In this framework, the values shown in the table therefore represent the economic revenues attributable to the photovoltaic generation of the Arena, compared with the estimated energy requirements for the events.

The results show that in the first three years (2022–2024), PV production allows event consumption to be fully covered, with a positive margin between approximately +11 thousand euros and +84 thousand euros. However, in 2025, lower photovoltaic production leads to a deficit (–110 thousand euros), which however does not compromise the overall budget: over the period 2022–2025 the net balance remains positive for approximately +60 thousand euros.

A useful synthesis indicator is the equivalent events covered, that is, the number of events that could be financed with the proceeds from the CER incentive. This value stands at a total of around 500 events over four years, a quantity very close to the events actually foreseen in the calendar (460). This demonstrates that the Arena's Energy Community is able, with incentivized photovoltaic production alone, to almost fully support the energy needs linked to the scheduled events, while generating a modest economic surplus for the benefit of the community.

2.6 A review of potential future scenarios

Besides calculating the proposed retrospective indicators, it is useful to estimate how the Santa Giulia Arena's energy self-sufficiency could develop in the future decades. The following proposed models consider international climate scenarios proposed by the IPCC [37], the technological evolution of photovoltaics (IEA [38]), potential urban growth dynamics (Municipality of Milan [39]), and future energy policies (EU NZEB [40]).

The adopted international climate scenario models describe possible future trajectories according to different levels of greenhouse gas emissions and environmental policies:

- **SSP1-2.6 (Optimistic):** limited growth in emissions, more stable climate;
- **SSP2-4.5 (Intermediate):** moderate policies, average warming trend;
- **SSP5-8.5 (Pessimistic):** high emissions, maximum climate risk.

These directly impact temperature, solar irradiance and humidity data, which are used in this study to estimate photovoltaic production. For each climate scenario, three distinct urban developments are simulated.

- Conservative growth: moderate population growth and maximum energy efficiency;
- Moderate growth: intermediate population growth and continuous improvements in efficiency;
- Aggressive growth: strong increase in population and consumption, less effective efficiency.

These factors directly influence the future energy demand of the neighborhood and the share covered by FV production. The average efficiency of PV panels is assumed to rise from 19% currently to values above 25% by 2050, thanks to technological advances [38].

The global mean temperature increment predicted for a specific climate scenario is modeled as:

$$\Delta T(t) = \Delta T_{max} \times \frac{t - t_0}{t_{target} - t_0}$$

where ΔT_{max} is the maximum expected increment for the scenario (1.5 °C for SSP1-2.6, 2.5°C for SSP2-4.5 , 4.0°C for SSP5-8.5), $t_0 = 2025$ the year of departure and $t_{target} = 2050$ the last year of study.

In a similar way, the solar irradiance variation factor is calculated as:

$$F_{solar}(t) = 1 + \Delta S_{max} \times \frac{t - t_0}{t_{target} - t_0}$$

with ΔS_{max} the maximum variation relative to solar irradiance in the scenario considered. The ΔS_{max} is 0.03 for SSP1-2.6 scenario, 0.05 for SSP2-4.5 scenario, 0.10 for SSP5-8.5 scenario.

The average efficiency of photovoltaic modules grows progressively over time according to a decreasing exponential type function:

$$\eta_{PV}(t) = \eta_{base} + (\eta_{max} - \eta_{base}) \times \left(1 - e^{-k\frac{t-t_0}{10}}\right)$$

where $\eta_{base} = 0.19$ is the initial efficiency, $\eta_{max} = 0.30$ the theoretical limit efficiency and $k = 0.08$ is a growth constant.

Future energy demand $D(t)$ takes into account the following factors population growth, improved energy efficiency, and electrification growth:

$$D(t) = D_{base} \times (1 + r_{pop})^{t-t_0} \times (1 - r_{eff})^{t-t_0} \times (1 + r_{elec})^{t-t_0}$$

where D_{base} is the energy demand in 2024, r_{pop} the annual rate of population growth, r_{eff} the annual rate of improvement in energy efficiency and r_{elec} the annual rate of electrification. The annual rate of population growth is 0.02 for the conservative scenario, 0.035 for the moderate scenario, 0.05 for the aggressive scenario. The annual rate of improvement in energy efficiency and the annual rate of electrification is estimated in 0.02.

Year	Scenario	Self-Sufficiency [%]	CO_2 Avoided [tons]
2030	SSP1-2.6 Cons	7.31	1979.30
2040	SSP1-2.6 Cons	7.01	2086.67
2050	SSP1-2.6 Cons	6.68	2189.49
2030	SSP1-2.6 Mod	6.80	1979.30
2040	SSP1-2.6 Mod	5.63	2086.67
2050	SSP1-2.6 Mod	4.64	2189.49
2030	SSP1-2.6 Agg	6.33	1979.30
2040	SSP1-2.6 Agg	4.54	2086.67
2050	SSP1-2.6 Agg	3.24	2189.49
2030	SSP2-4.5 Cons	7.34	1987.17
2040	SSP2-4.5 Cons	7.09	2111.26
2050	SSP2-4.5 Cons	6.81	2232.01
2030	SSP2-4.5 Mod	6.83	1987.17
2040	SSP2-4.5 Mod	5.70	2111.26
2050	SSP2-4.5 Mod	4.73	2232.01
2030	SSP2-4.5 Agg	6.35	1987.17
2040	SSP2-4.5 Agg	4.59	2111.26
2050	SSP2-4.5 Agg	3.30	2232.01
2030	SSP5-8.5 Cons	7.42	2006.85
2040	SSP5-8.5 Cons	7.30	2172.76
2050	SSP5-8.5 Cons	7.14	2338.29
2030	SSP5-8.5 Mod	6.89	2006.85
2040	SSP5-8.5 Mod	5.86	2172.76
2050	SSP5-8.5 Mod	4.96	2338.29
2030	SSP5-8.5 Agg	6.42	2006.85
2040	SSP5-8.5 Agg	4.72	2172.76
2050	SSP5-8.5 Agg	3.46	2338.29

Table 6: Projected PV Self-Sufficiency and CO_2 Savings for Santa Giulia Arena.

Future PV production $P_{PV}(t)$ is calculated as:

$$P_{PV}(t) = P_{base} \times \frac{\eta_{PV}(t)}{\eta_{base}} \times F_{solar}(t) \times (1 + F_{storage}(t))$$

where P_{base} is the production in kWh calculated before.

The percentage of PV self-sufficiency remains consistently low (between approximately 3% and 7.4%), confirming the marginal role of photovoltaics in meeting the entire energy needs of the neighborhood.

All climate scenarios (from optimistic to pessimistic) show a decrease in self-sufficiency over time, especially under assumptions of more aggressive growth in demand.

The tons of CO_2 avoided, considering a constant average emission factor (0.2563 kg CO_2/kWh), increase constantly over the decades: from around 2000 tons/year in 2030 to around 2300 in 2050 in the most aggressive scenario. This underlines the environmental relevance of the presence of the plant.

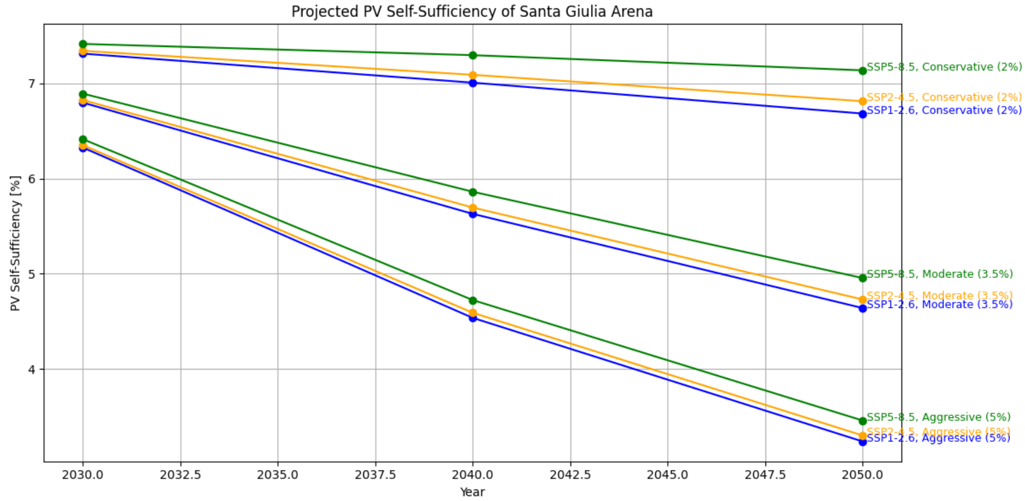

Figure 14: Future Scenario

Despite technological improvements, demand grows faster than the estimated production of photovoltaics over time, resulting in all curves decreasing and appearing lower over the years.

The green curves (SSP5-8.5, pessimistic/high-emission scenario) are always above the others, suggesting that in the presence of more solar radiation (a side effect of global warming), PV production may be slightly higher.

3 Conclusion and Policy Suggestions

This study underscores the growing need for the introduction of renewable alternative energy sources within large cities. Despite the challenges of installing photovoltaics in certain urban contexts, whose greatest difficulties may be related to both cost and geographic location, major events such as the Olympics present an opportunity to drive toward a more sustainable energy future in which public infrastructure is a crucial point. By increasing the percentage of energy derived from renewable sources, Milan can reduce its dependence on fossil fuels, reduce greenhouse gas emissions, and make strides toward its ambitious sustainability goals. Furthermore, the construction of buildings such as the Santa Giulia Arena offers the community a facility for social purposes, such as concerts, public events, and exhibitions, promoting growth in the context of Italy's lack of sports infrastructure. Economic challenges, such as the high upfront costs of photovoltaic installations, need to be balanced against the long-term benefits in terms of energy savings and environmental impact. The Policy frameworks and regulations must then be updated to facilitate the adoption of renewable technologies while respecting the safety, distribution, and eventual conservation of excess energy. To address these challenges, the following policy recommendations are proposed:

- **Strategies divided by season**: The analyses clearly show that the self-sufficiency index is strongly affected by seasonality, reaching higher values during the summer period and lower values during the winter instead. Therefore, policies should incentivize flexible strategies depending on the season by adopting, for example, local networks dedicated to energy production and distribution, contracts with different tariffs between winter and summer to compensate for seasonal fluctuations.

- **Scheduling of the events**: The number of planned events on the calendar, such as concerts or sporting events, can reduce the self-sufficiency index of the Santa Giulia Arena. In particular, from the work it is noted that events that involve the participation of more than 10,000 people are particularly influenced. So, for a correct policy and strategy aimed at saving the energy produced, it would be fair to distribute the number of events throughout the year, setting a limit on the number of monthly events and perhaps preferring more of them during the summer months, when self-sufficiency is greater than during the winter months.

- **Monitoring of weather conditions**: The analyses also show that environmental factors, including relative humidity in this case, directly affect the panel's energy production. Thus, strategies should aim to build resilient structures suitable for the local climate, equip plants with accurate sensors to monitor these factors, and constantly monitor and predict climate trends.

- **Tax and regulatory incentives for green energy users**: As a final proposal, policies should provide specific incentives for high-self-sufficiency neighborhoods that involve the use of green energy: apply rebates, facilitate access to European funds for the construction of additional facilities, and allow one to resell the amount of excess energy produced on the market to power nearby neighborhoods.

By adopting these strategies and policies, Milan through the incentives allowed by the Olympic Games can begin to transition the area increasingly toward the use of renewable energy sources. Although the Arena represents a significant investment from an economic point of view, it constitutes a strategic opportunity to increase, although to a limited extent, the share of renewable energy used on an urban level and, at the same time, to expand the offer of events and activities for the benefit of the community.

References

[1] G. W. Hunter, D. Vettorato, and G. Sagoe, "Creating smart energy cities for sustainability through project implementation: A case study of bolzano, italy," *Sustainability*, vol. 10, no. 7, p. 2167, 2018, (Available on: https://www.mdpi.com/2071-1050/10/7/2167.

[2] M. Sanduleac, M. Eremia, L. Toma, L. Alacreu, L. Pons, M. Cresta, and M. Paulucci, "Energy ecosystem in smart cities — privacy and security solutions for citizen's engagement in a multi-stream environment," in *2016 IEEE International Smart Cities Conference (ISC2)*, Sep. 2016, pp. 1–4, (Available on: https://doi.org/10.1109/ISC2.2016.7580739).

[3] Interreg, "What is green infrestructure?" 2020, (Available on: programme2014-20.interreg-central.eu/Content.Node/What-is-Green-Infrastructure-.html).

[4] C. di Milano, "La vasca di contenimento delle piene del seveso," 2024, (Available on: comune.milano.it/aree-tematiche/ambiente/acqua/vasca-contenimento-seveso).

[5] C. S. Directory, "What are the costs of implementing green infrastructure?" 2025, (Available on: climate.sustainability-directory.com/question/what-are-the-costs-of-implementing-green-infrastructure/).

[6] SIMICO, "Programma delle parti specifiche," Milano, 2023.

[7] G. Liu, S. Bian, and X. Lu, "Green technologies behind the beijing 2022 olympic and paralympic winter games," *Environmental Science and Ecotechnology*, vol. 16, 2023. [Online]. Available: https://doi.org/10.1016/j.ese.2023.100262

[8] International Olympic Committee. (2022) Beijing 2022 sustainability – all you need to know. [Online]. Available: (Available on : https://olympics.com/ioc/news/beijing-2022-sustainability-all-you-need-to-know)

[9] (2023) Beijing 2022 one year anniversary. [Online]. Available: (Available on: https://www.insidethegames.biz/articles/1133316/beijing-2022-one-year-anniversary)

[10] Fondazione Milano Cortina 2026 and SIMICO, "Sintesi non tecnica del rapporto ambientale del programma delle opere," Milano, 2023.

[11] Regione Lombardia, Comune di Milano, Città Metropolitana di Milano, and Milano Santa Giulia S.p.A., "Accordo per la realizzazione del "pala italia santa giulia" sito nel comune di milano," 2021, sottoscritto a Milano, febbraio 2021.

[12] Comune di Milano and Milano Santa Giulia S.p.A., "Linee guida per lo schema di convenzione d'uso dell'arena "pala italia"," 2021.

[13] L. Minnaert, "An olympic legacy for all? the non-infrastructural outcomes of the olympic games for socially excluded groups (atlanta 1996–beijing 2008)," *Tourism Management*, vol. 33, no. 2, pp. 361–370, 2012.

[14] R. Pereira, "Transport legacy of mega-events and the redistribution of accessibility to urban destinations," *Cities*, vol. 81, pp. 45–60, 2018.

[15] H. Zhang, "Study on the economic and social impacts of using megaevents for urban regeneration," in *Proceedings of the International Conference on Global Politics and Socio-Humanities*, 2023, pp. 163–168, (Available on: https://doi.org/10.54254/2753-7064/23/20230894).

[16] L. Porter, M. Jaconelli, J. Cheyne, D. Eby, and H. Wagenaar, "Planning displacement: The real legacy of major sporting events," *Planning Theory & Practice*, vol. 10, no. 3, pp. 395–418, 2009.

[17] M. A. Richmond and J. Garmany, "'post-third-world city'or neoliberal 'city of exception'? rio de janeiro in the olympic era," *International Journal of Urban and Regional Research*, vol. 40, no. 3, pp. 621–639, 2016.

[18] F. Sánchez and A. M. Broudehoux, "Mega-events and urban regeneration in rio de janeiro: planning in a state of emergency," *International Journal of Urban Sustainable Development*, vol. 5, no. 2, pp. 132–153, 2013.

[19] R. A. Baade and V. A. Matheson, "Going for the gold: The economics of the olympics," *Journal of Economic Perspectives*, vol. 30, no. 2, pp. 201–218, 2016.

[20] Corriere della Sera. (2025) Olimpiadi milano-cortina, i dubbi sulla viabilità attorno al palaitalia: posteggi off-limits e rischio ingorghi. [Online]. Available: (Available on: https://milano.corriere.it/notizie/cronaca/25$_a gosto_0 8/olimpiadi-milano-cortina-i-dubbi-sulla-viabilita-attorno-al-palaitalia-posteggi-off-limits-e-rischio-ingorghi-227cf410-1d0c-4e23-aaa9-2a61adaa4xlk.shtml$)

[21] J. Kennelly and P. Watt, "Seeing olympic effects through the eyes of marginally housed youth: changing places and the gentrification of east london," *Visual Studies*, vol. 27, no. 2, pp. 151–160, 2012.

[22] J. Clark, A. Kearns, and C. Cleland, "Spatial scale, time and process in mega-events: The complexity of host community perspectives on neighborhood change," *Cities*, vol. 53, pp. 87–97, 2016.

[23] B. Flyvbjerg and A. Stewart, "Olympic proportions: Cost and cost overrun at the olympics 1960-2012," 2012.

[24] Corriere della Sera. (2025) Olimpiadi milano-cortina 2026, sbloccata parte degli extra costi dal governo: 21 milioni di euro per il palaitalia. [Online]. Available: (Available on: https://milano.corriere.it/notizie/cronaca/25$_a gosto_0 7/olimpiadi-milano-cortina-2026-sbloccata-parte-degli-extra-costi-dal-governo-21-milioni-di-euro-per-il-palaitalia-6e700ce9-2f2e-41dd-9706-d0f05be0dxlk.shtml$)

[25] V. A. Matheson, D. Schwab, and P. Koval, "Corruption in the bidding, construction and organisation of mega-events: An analysis of the olympics and world cup," pp. 257–278, 2018.

[26] G. Lonardi and W. Q. Hu, "Isole di calore: mitigazione degli effetti e come limitarne l'insorgenza, applicazione al progetto di un'arena olimpica per milano e al quartiere santa giulia," Milano, Italia, 2021, relatore: Prof. Graziano Salvalai; Correlatore: Ing. Giulio Zani.

[27] M. Dilthey. (2017) How much energy will super bowl li use? the answer may surprise you. [Online]. Available: (Available on: https://www.solarpowerauthority.com/much-energy-will-super-bowl-li-use-answer-may-surprise/)

[28] A. Sohani, M. H. Shahverdian, H. Sayyaadi, and D. Astiaso Garcia, "Impact of absolute and relative humidity on the performance of mono and poly crystalline silicon photovoltaics; applying artificial neural network," *Journal of Cleaner Production*, vol. 276, p. 123016, 07 2020.

[29] A. Caputo and I. S. per la Protezione e la Ricerca Ambientale (ISPRA), "Le emissioni di co_2 nel settore elettrico nazionale e regionale," ISPRA - Istituto Superiore per la Protezione e la Ricerca Ambientale, Tech. Rep. 413/2025. [Online]. Available: (Available on :https://emissioni.sina.isprambiente.it/wp-content/uploads/2025/05/Le-emissioni-di-CO2-nel-settore-elettrico$_r 413-2025_d ef.pdf$)

[30] "ERA5 hourly data on single levels from 1940 to present," https://cds.climate.copernicus.eu/cdsapp!/dataset/reanalysis-era5-single-levels, 2023, accessed via the Copernicus Climate Change Service (C3S) Climate Data Store (Available on: https://cds.climate.copernicus.eu/cdsapp!/dataset/reanalysis-era5-single-levels).

[31] T. S.p.A., "Fabbisogno di energia elettrica in italia - dati storici," https://dati.terna.it/download-center/fabbisogno/fabbisogno-italia, 2024, (Available on: https://dati.terna.it/download-center/fabbisogno/fabbisogno-italia).

[32] Terna, "Bilanci energetici regionali 2023," https://download.terna.it/terna/0000/energia/bilanci-regionali, 2023, available at: https://download.terna.it (Available on: https://download.terna.it).

[33] ISTAT, "Popolazione residente al 1° gennaio 2023 per età, sesso e stato civile - lombardia e milano," 2023, dati demografici ISTAT (Available on: https://demo.istat.it/).

[34] Comune di Milano, "Popolazione residente nei quartieri - santa giulia (rogoredo)," 2023, dati urbanistici e anagrafici comunali (Available on: https://www.comune.milano.it/).

[35] Autorità di Regolazione per Energia Reti e Ambiente (ARERA), "Valori della materia energia per trimestre luglio–settembre 2025," 2025. [Online]. Available: (Available on : (https://www.arera.it/consumatori/valori-della-materia-energia-per-il-servizio-di-maggior-tutela)

[36] Ministero dell'Ambiente e della Sicurezza Energetica, "Decreto ministeriale cacer 414/2023, "incentivazione energia elettrica condivisa in autoconsumo"," Gazzetta Ufficiale n. 22 del 26 gennaio 2024, 2024, decreto pubblicato nella Gazzetta Ufficiale della Repubblica Italiana.

[37] IPCC, "Climate change 2023: The physical science basis," *Sixth Assessment Report*, 2023. [Online]. Available: (Available on :https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-4/)

[38] International Energy Agency, "Renewables 2024: Technology roadmap," 2024. [Online]. Available: (Available on :https://www.iea.org/reports/renewables-2024)

[39] Comune di Milano, "Piano integrato di attività e organizzazione (piao) comune di milano 2024-2026," Comune di Milano, Tech. Rep., 2024.

[40] E. Union, "Nearly zero-energy buildings (nzeb) standards in europe," *European Commission*, 2025. [Online]. Available: (Available on : https://energy.ec.europa.eu/topics/energy-efficiency/energy-performance-buildings/nearly-zero-energy-and-zero-emission-buildings$_en$)