Journal of Physics: Conference Series

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To cite this article: G Romano *et al* 2023 *J. Phys.: Conf. Ser.* **2648** 012037

ATI-2023 IOP Publishing
Journal of Physics: Conference Series **2648** (2023) 012037 doi:10.1088/1742-6596/2648/1/012037

Building a Renewable Energy Community for the Tor Sapienza district in Rome

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Abstract. The transition away from fossil fuels towards a carbon-neutral, clean and circular economy is one of the greatest challenges of our time. Energy communities are one of the tools to re-structure our energy systems by harnessing the energy and allowing citizens to participate actively in the energy transition and thereby enjoy greater benefits.

The definition of Renewable Energy Communities (RECs) given by the European Commission, places the REC as an association that produces and shares renewable energy, generating and managing cost-effective green energy autonomously, reducing CO_2 emissions and energy waste. Observing this definition, the new Italian regulations concerning RECs boost distributed generation, encouraging the development of 'zero-mile' local energy production and smart grids. This research aims to evaluate the conditions to propose a REC in the Tor Sapienza district, as an Italian prototype, assessing the possibilities and advantages of transforming it into a large-scale sustainable infrastructure by means of a deep energy transition and the active role of local citizens, public administrations and small and medium-sized enterprises. Thanks to an in-depth technological, environmental and demographic survey of the neighbourhood, the study focuses on the retrofitting of a social housing complex in Tor Sapienza, as the main prosumer of the REC.

1. Introduction

Over the next three decades, almost 85% of European population is expected to live in cities and globally, urban areas are expected to rise to nearly 7 billion people, which will be more than two-thirds of all humanity [1]. Yet in this period cities will be less liveable due to climate change, unstable weather conditions and extreme weather events and, partially, they already are [2].

Human activities, mainly through greenhouse gas emissions, are blamed for climate change and global warming, with global surface temperatures reaching 1.1°C above 1850-1900 in 2011-2020 [3]. Human-caused climate change is already affecting many regions of the world with extreme weather and climate conditions. Energy production and use currently account for more than 75% of the EU's greenhouse gas emissions. Not surprisingly, if in previous times the attention of the construction sector from an energy point of view was mainly focused on consumption, today the efforts of this sector are increasingly focused and oriented towards the reduction of emissions deriving from the energy sector and therefore on the consequent, necessary and essential transition of the source of energy production from fossil fuel to renewable. The decarbonisation of the European Union's energy system therefore constitutes one of the fundamental strategies for achieving the climate objectives for 2030 [4] and implementing the EU's long-term strategy which aims to achieve neutrality in terms of emissions of carbon by 2050. In line with the European Green Deal, renewable energy is a pillar of the clean energy

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transition. It comes at a very low cost and is home-grown, which reduces our dependency on external suppliers.

In July 2021, the Commission proposed another revision of the directive, raising the target to 40% (up from 32%), as part of the 'Fit for 55' package [5] to deliver on the European Green Deal [6].

Energy communities organise collective and citizen-driven energy actions that help pave the way for a clean energy transition while moving citizens to the fore [7-8]. They contribute to increasing public acceptance of renewable energy projects and make it easier to attract private investments in the clean energy transition. At the same time, they have the potential to provide direct benefits to citizens by increasing energy efficiency, lowering their electricity bills [9-10] and creating local job opportunities. By supporting citizen participation, energy communities can help provide flexibility to the electricity system through demand response and storage [11]. Energy communities offer a means to re-structure our energy systems by harnessing the energy and allowing citizens to participate actively in the energy transition and thereby enjoy greater benefits [12]. This, in turn, helps contribute to a more decarbonised and flexible energy system, as the energy communities can act as one entity and access all suitable energy markets, on a level-playing field with other market actors. Through the collected data, the Energy Communities Repository identifies enabling and supporting frameworks for renewable energy communities and citizen energy communities as defined in the Energy Efficiency Directives [13-14], in the Renewable Energy Directives [15-16] and in the Internal Electricity Market Directive [17].

It is therefore urgent to find a way to make not only buildings, but entire urban areas, through the aggregation [18] and creation of communities [19], more efficient in terms of energy, exploitation and careful circular management of natural and material resources, less carbon intensive throughout their life-cycle and more sustainable.

Starting from a first analysis of the current energy consumption of the "Giorgio Morandi" social housing complex, the first part of the work supposes a retrofitting of the complex, which entails the upgrade of the thermal performances of the building envelope, the total electrification and its on-site energy production from the PV system. In this phase the attention given to the search for recycled and recyclable materials and the proposal of the integration of the nature based solutions in the urban district are among the main strategies to reduce the impact of the building and of the whole intervention on the urban area. Thanks to a second post-intervention energetic simulation, the work also provides an overall estimate of the annual PV production of the entire community, underlining also the environmental and economical payback of the investment and the several benefits of this conversion into a zero-energy building. The analysis continues by identifying, other possible prosumers of the REC and, starting from the results obtained by the retrofitting of the Morandi complex, evaluating the annual production of electricity obtainable through the installation of other PV systems in the urban area.

The main goal of this research is to demonstrate that the RECs are opportunities valid to decrease CO_2 emissions in atmosphere and remove them locally by reaching a joint environmental, social and economic smart management.

2. Building features and status quo

2.1 "Giorgio Morandi" social housing complex

The "Giorgio Morandi" social housing complex (Figure 1), born from the 1972 "Tor Sapienza" area plan n° 19, one of the 70 area plans envisaged by the PEEP drawn up between 1962 and 1964. Designed by the Arch. Alberto Gatti, it is located between the "Barone Rampante" public park and two other public residential building nuclei envisaged by Pdz n° 19. The building nucleus, which covers a total area of approximately 97,200 sqm, consists of 4 buildings in line delimiting a large rectangular courtyard within there is a central spine of services.

Below ground level, each building has parking spaces and cellars which can be accessed via flights of stairs created outside the overall dimensions of the buildings. Each building has 7 floors of accommodation, a free pilot floor and a usable terrace, for a total of 506 apartments connected by 36 stairways and designed for around 2,776 inhabitants.

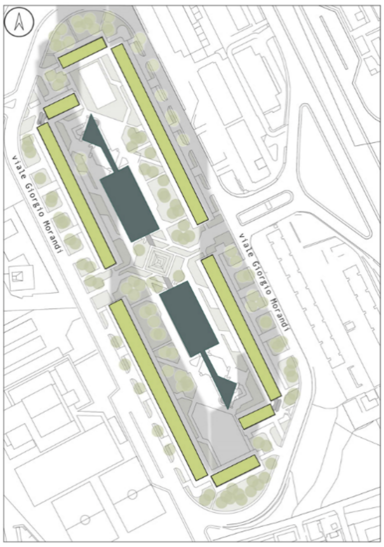


Figure 1. “Giorgio Morandi” social housing complex

From the anthropic analysis conducted it has been possible to verify that there is no correspondence between the composition of households (1-2 people) of the current resident population in the area and that for which the 6 types of housing were think yourself (4 or more people).

The bioclimatic survey instead has shown that:

- the complex has a longitudinal development of about – 30° with respect to the N-S axis;
- the overall height of the buildings of about 28.10 m and the location near lower buildings or open areas, make the roof of the complex affected only by shading phenomena due to the emerging stairwells.

2.2 The urban district of Tor Sapienza

The urban nucleus of the current Tor Sapienza district was founded in the 1920s by the railwayman Michele Testa from the “Cooperativa Tor Sapienza dell'Agro Romano’, as a village on a human scale with a pharmacy, a school and a medical clinic.

The building fabric is mainly residential in nature but has extensive areas intended for public activities and services at an urban level [20].

From the analysis carried out on the anthropic system it emerged that almost all the inhabitants are in the age range between 29 and 74 years, in most cases have a family of 1-2 people and are, for more than 50 %, employed or unemployed [21].

The analysis of the services has highlighted the presence of numerous schools, various sports facilities, production and commercial areas, religious buildings and an ATAC depot. However, what is absent in the area is the welfare and health system, located in the neighbourhoods at a distance of 3.5-5 km.

From a biophysical point of view, Tor Sapienza has large green areas, mainly of a public and sporting nature, which however are often not equipped and maintained.

In a third phase, an in-depth analysis has been conducted on the infrastructure system, on the accessibility of the district and on the mobility system, to outline the framework of the relationships with the surrounding realities. The study area, albeit marginal in the context of Rome, is accessible from the main high-speed ways, viale Palmiro Togliatti, via Prenestina and via Collatina; it is served by various types of long-distance public transport, both by road and by rail, and has exchange nodes between urban and extra-urban mobility.

However, the averagely slow traffic throughout the day and the absence of micro-mobility in the neighborhood lead to longer travel times, with waiting times of between 15 and 20 minutes, for very short journeys within the neighbourhood areas. Investigating soft mobility, Tor Sapienza is excluded from the PUMS, urban plan for the enhancement of sustainable mobility: although physically close, it is in fact outside the area circumscribed by the ring of about 50 km of the GRAB project (Grande Raccordo Anulare of the Bicycles) [22] and also from existing or planned cycle paths.

Finally, the preliminary study highlighted the almost total absence of charging stations located within the area and the complaint of poor usability, improper use or malfunction of those present.

3. Materials and Methods

Thanks to the consultation of the “Gatti Alberto and De Sanctis Diambra” Fund at the Central State Archive and of the articles dedicated to the project in a historic journal [23], it has been possible to trace the structural and constructive system of the Morandi complex.

The inspection and dialogue with the residents have proved to be fundamental for hypothesizing the actual state of the building as well as its installations components. Having access to information regarding the energy consumption of the inhabitants of the complex, in order to be able to quantify it and to evaluate its costs and impact on the environment, simulations have been conducted with a spreadsheet dedicated to these simulations.

3.1 Current condition of the building envelope

The buildings of the complex are characterized by a structure with parallel load-bearing partitions (which guarantees vertical continuity) with orthogonal stiffening elements (Figure 2), and self-supporting deck slabs cast together with the partitions with the tunnel formwork system. The vertical elements, slab planes that are the same for all the buildings, are equidistant from each other and sized on two wheelbases, one double the other (5,10m and 2,55m for the stairwell).

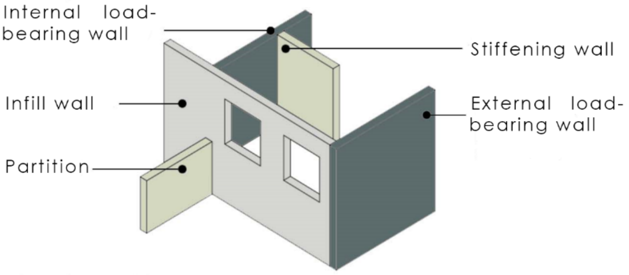


Figure 2. Structure with parallel load-bearing partitions

The load-bearing walls in reinforced concrete can be divided into two categories: load-bearing walls bordering the outside and load-bearing walls bordering the stairwells. The former, with an overall section of 255 mm, are covered, towards the internal environment, with a 4 cm insulating layer and a layer of plaster; the latter, with an overall section of 230 mm, have only a finishing layer on both sides (Figure 3).

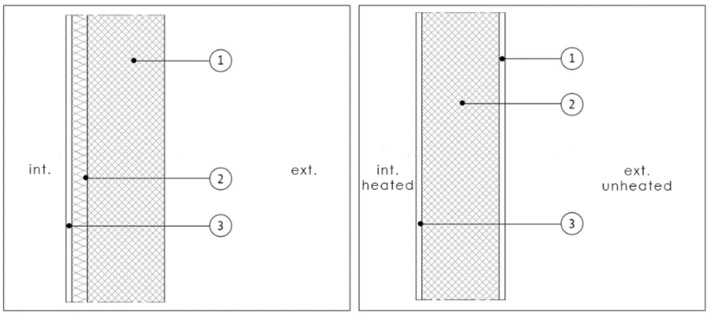


Figure 3. On the left: external load-bearing wall detail (ante operam); on the right: staircase load-bearing wall detail (ante operam)

The stratigraphy of the infill, also made starting from a layer of concrete, is stratified towards the inside with a 5 cm cavity, an 8 cm hollow brick lining and a layer of plaster (Figure 4).

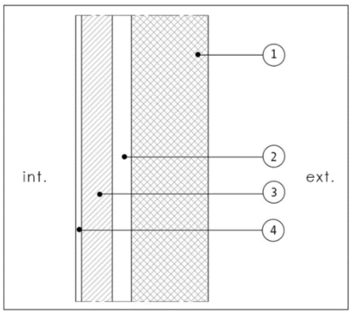


Figure 4. Infill panel detail (ante operam)

The U-values of the vertical opaque structures, which vary between 0,782 – 2,454 W/m^{2}K for the load-bearing partitions and equal to 1,363 W/m^{2}K for the façade walls, are in both cases far above the maximum established reference values updated to 2021 [24].

Even horizontal opaque closures can be divided into two categories: roofing (on a practicable terrace) and paving towards the outside. The former, despite the presence of a 4 cm insulating layer positioned between the bearing concrete layer and a 6 cm screed, have a U-value of 0,752 W/m^{2}K, higher than the reference ceilings [24]. The pavement layer is asphalt. The first floor attic on an unheated external space, unlike the roof, does not have the insulation layer with a consequent increase in the U-value equal to 2,709 W/m^{2}K (Figure 5).

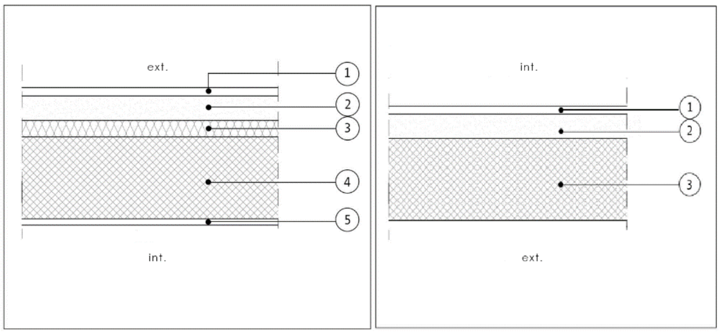


Figure 5. on the left: roofing stratigraphy detail (ante operam); on the right: close-up slab detail on external space (ante operam)

The windows, another technical element that influences the comfort conditions of the inhabitants and the energy performance of the building, are all the same with single glass and a painted metal frame.

3.2 Analysis of electricity and gas consumption in the "Morandi" complex

After collecting all the information regarding the dimensions, orientation, surfaces of the apartments in the complex, the simulations on gas and electricity consumption have been conducted:

- Analysing each of the six types of accommodation present according to its different locations within the complex (corner apartment; apartment between two heated spaces; top floor apartment, etc.);
- Assuming, for each type of accommodation, both a partial and total occupancy condition;

- Considering, for all types of accommodation, the presence of an independent boiler system with cast iron radiators as terminals;
- Conducting interviews on the usual uses of household appliances.

The data obtained have been grouped by housing type and then aggregated to evaluate the annual impact of the complex in terms of energy costs and CO_2 emission release into the atmosphere (Table 1).

Table 1. Consumption of the Morandi Complex (ante operam)

Aggregate electricity consumption [kWh/y]	Aggregate gas consumption [Sm^3/y]	CO_2 Emission [kg]	Annual electricity costs [euro]	Annual gas costs [euro]
1621893	555113	1480015	229186	452407

Referring to primary energy consumption, the simulations have shown that:

- about 50% of the primary energy is used for heating and the production of DHW with a CO_2 emission of 890818 kg*CO_2/y;
- between 10-20% of primary energy is used for consumption relating to the kitchen with CO_2 emission between 77112 – 148680 kg*CO_2/y.

4. Intervention strategies and results

The main objective of this research is the evaluation of advantages and environmental and economic possibilities coming from the creation of an Energy Community in the Tor Sapienza district [25], starting from the improvement of the energy performance of the Morandi Complex and from its total electrification up to hypothesize a local production of electricity from PV systems on the roof of the complex and on other buildings in the neighbourhood identified as prosumers of the community.

A second simulation of energy consumption of the Morandi complex has been conducted assuming:

- Insulation of the building;
- Replacement of existing systems with centralized heat pumps for heating and DHW production;
- Replacement, in each accommodation, of the old gas cookers with induction cookers;
- Replacement, in each accommodation, of the existing system with a LED lighting system.

The data collected therefore highlighted the advantages in terms of total elimination of dependence on gas. On the other hand, it is natural to find an increase in electricity consumption due to the electrification of the complex (Table 2).

In terms of costs, the overall balance is an annual saving in bills of around 306.000 euro.

Table 2. Energy consumption of the complex (post operam)

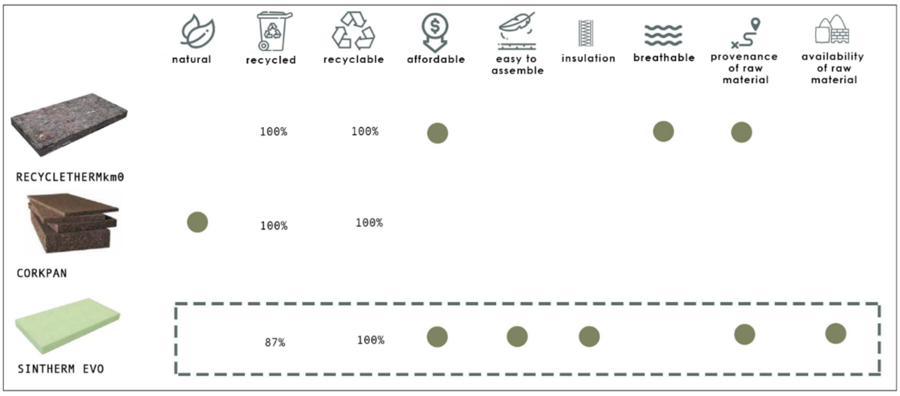
Aggregate electricity consumption [kWh/y]	Aggregate gas consumption [Sm^3/y]	Annual electricity costs [euro]	Annual gas costs [euro]
2276947	0	452407	0

4.1 Intervention strategies and technical solutions for the building envelope

For the insulation of the building, the research proposes an external insulation layer, a solution that allows the elimination of the phenomena of surface and interstitial condensation reduces thermal bridges and at the same time does not involve a movement of the residents during the works and a reduction of the internal spaces.

In this phase, particular attention has been paid to the impact of the building not only from an energy point of view but by expanding the concept to the life cycle of the materials assumed for the intervention.

The research led to the selection of three materials, produced largely from recycling and totally recyclable at the end of their life, to be compared also on the basis of their insulating capacity, cost-effectiveness, breathability, origin and availability of raw materials (Figure 6).



	natural	recycled	recyclable	affordable	easy to assemble	insulation	breathable	provenance of raw material	availability of raw material
RECYCLETHERMkm0		100%	100%	●			●	●	
CORKPAN	●	100%	100%						
SINTHERM EVO		87%	100%	●	●	●		●	●

Figure 6. Selection criteria for the insulation

The introduction of an external layer of insulation selected in recycled PET, with a thermal coefficient of 0,034 W/mK and with thicknesses ranging between 4-5-7 cm:

- on the load-bearing partition bordering the outside;
- on the façade wall;
- on the first floor slab in an unheated external space;

have made it possible to lower the U-values in a range between 0,294 – 0,299 W/m^{2}K, thus returning within the ceilings stable by the Ministerial Decree 26 June 2015.

In the case of the roof slab and the load-bearing partition separating the apartments and the stairwells, given the need to remain within limited thicknesses while still guaranteeing an optimal degree of insulation, an AEROPAN panel has been chosen.

Table 3 shows a comparison between the U-values of the components of the current envelope and those chosen for the proposed solutions.

Table 3. U-values of the building components [W/m^{2}K]

Description	Status quo	Proposed solutions
Load-bearing external wall	0,782	0,296
Load-bearing wall facing the stairwell	2,454	0,267
Façade wall	1,363	0,294
First floor slab on external space	2,272	0,299
Roof covering slab	0,752	0,215

The balance of the insulation intervention assumed, sees an overall estimate of savings in terms of primary energy for heating between 40 and 70%.

4.2. Intervention strategies and technical solutions for the systems

To convert the Morandi complex into a fully electrified building, it is proposed to replace the existing traditional system with centralized heat pumps for both heating and DHW production, the use of induction cookers and LEDs in each accommodation: this allows for a reduction in the building's energy requirements and for the local elimination of emissions of harmful substances into the atmosphere.

4.2.1 Heat-pump systems

The sizing of the heat pumps has been carried out starting from the winter thermal load resulting from the insulation of the building envelope.

For an overall volume of about 207,14 m^3 and a load of about 5,30 kW/m^3, 4 heat pumps with a total power of about 1 MW have been sized and positioned, in specific technical rooms, inside the courtyard, each serving a block of buildings.

4.2.2 Renewable energy production from PV systems

The electrification of the complex involves, as highlighted by the simulations, an increase in the electricity consumption which is drawn from the public network with consequent losses, emissions into the atmosphere and costs due to the transport of energy.

The calculation of the PV area necessary to cover the estimated electricity consumption of 2276947 kWh/year of the residential buildings has been made considering:

- average annual insolation in Rome: 1737,4 kWh/m^2y;
- standard panel efficiency η_{stc}: 14%;
- bos efficiency η_{bos}: 85%.

The minimum PV area to be installed to achieve energy self-sufficiency is 11032 sqm [26] and it is higher than the total roof area of the complex.

The electricity production from RES obtainable from the roofs of the complex is therefore evaluated. The methodological approach involves the evaluation of the entire surface not affected by shading to install on the capturing area horizontal PV panels and an adequate positioning of the selected panels is assumed (chosen in the green colour with a view to reducing the visual impact and integrating the intervention into the context) with an optimal inclination of 32° [9];

The possible annual production obtainable is included in a range of 469588 – 843309 kWh/y.

In order to maximize energy consumption, creating local exchange, joint management and encouraging sustainable development, 5 other possible public and private prosumers have been identified: two schools, a sports complex, a religious building and an ATAC garage (Figure 7).

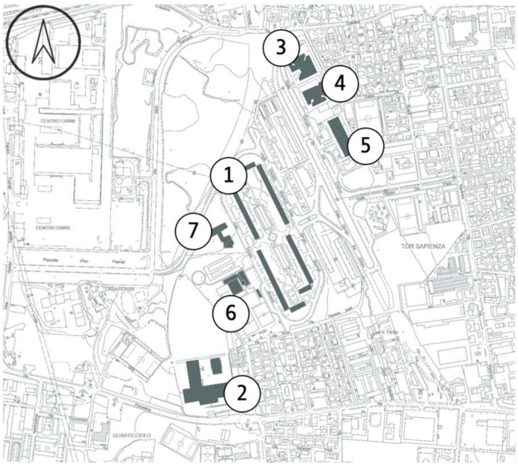


Figure 7. Possible public and private Tor Sapienza prosumers

For each of them, the annual production obtainable from the localization of PV plants on the roof is evaluated, with the same methods used for the Morandi complex and also including solutions for upgrading existing plants [27].

The research therefore returns an overall hypothesis on the internal Energy Community in terms of annual energy production, investment costs, payback times and avoided CO_2 emissions. (Table 4).

Table 4. Annual energy production, investment costs, payback times and avoided CO_2 emissions

Power [MW]	Annual PV production [kWh]	Avoided CO_2 emission [kgCo$_2$/year]	Energy valorisation tariff [euro/y]	Total cost of intervention [euro]	Payback time [years]
1,30	1810571	1176871	289186	2080000	7-10
1,98	2562108	1655370	291275	3168000	

4.3 A PV shelter for the ATAC depot

After studying solutions that do not involve further land consumption, the research focuses on one of the prosumers, the Tor Sapienza bus depot, for which it imagines a PV roofing structure for the parking area (23,342 sqm), a real own "fifth prospectus", with a dual role:

- actively contribute to the local production of electricity from RES;
- reduce the huge visual impact of the throw-in on the surrounding tissue.

So that, four scenarios have been put forward (table 5) varying the type of PV panel used and the percentage of covering area and evaluating, for each scenario, the energy production, the visual impact and the integrability of the intervention in the context.

Table 4 shows that, although the capturing area is reduced, the energy production remains very high.

Furthermore, although the range of installable power (4.2 – 1.9 MWp) is higher than the 1MW limit envisaged for installations in an energy community, the research aims to evaluate the possibilities of using the area and with a view to sharing energy and promoting renewables, imagine the transferable surplus to other CERs to be created near this one.

Table 5. Covering hypotheses for the parking area

	Capturing area [sqm]	Annual PV production [kWh]	Visual impact	Integrability
Scenario 1	23342	5224573,3	*****	
Scenario 2	19930	4566878,6	****	*
Scenario 3	19930	3552158,1	**	****
Scenario 4	13929	2482691,2	*	*****

* = minimum value *****=maximum value

For the first two hypotheses, the same panel chosen for the evaluation of the PV systems on the roofs of the buildings has been used, while in the other two hypotheses, to reduce the impact of the intervention, a BIPV photovoltaic panel with architectural integration has been selected with polycrystalline silicon cells with a power of 0,140 kWp/m^2, customizable in shape, size, transparency.

Also in this case the colour of the panel is green. (Figure 8).

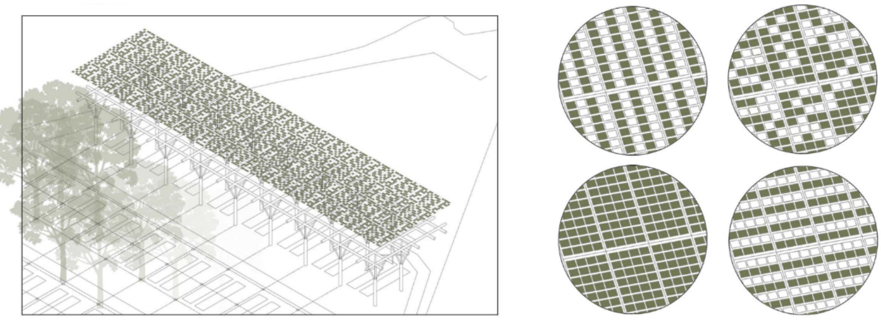


Figure 8. On the left: hypothesis 4 of the structure of the PV shelter; on the right: possible configurations of the BIPV panels

With the aim of reducing the visual impact and also the acoustic and atmospheric pollution, specifically for the school and the sports facility adjacent to the parking lot, 3 strategic actions are proposed:

- replacement of the existing pavement with draining pavements or recycled asphalt pigmented in the green colour [28];
- use of nature based solutions: protective strips of vegetation with evergreen trees and bushes with high foliage density and rapid growth, and raingardens for water drainage [29];
- integration of the shelter system with a LED lighting system powered by PV panels.

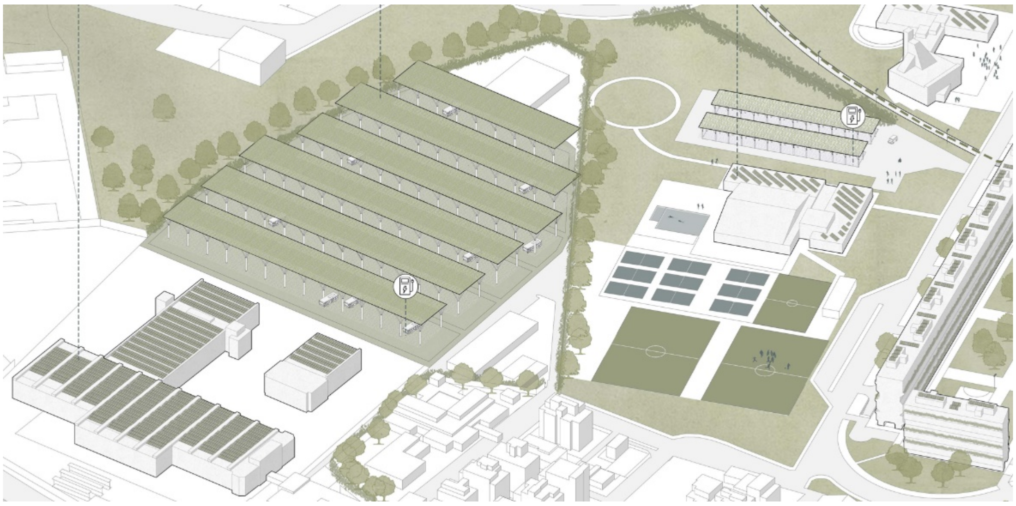


Figure 9. The new ATAC bus depot in Tor Sapienza

5. Conclusion

Following the planned and simulated interventions, and starting from the premise of the research of creating a renewable energy community on a larger scale than the Morandi complex and the ATAC depot, the research has demonstrated how to create an intervention with a relevant function of social and territorial cohesion actively involves citizens, public administrations and small and medium-sized enterprises and concretely benefits them in all aspects of sustainability: from a social point of view, thanks to the productive induced and new local employment, as well as the autonomous and local production of electricity; from an environmental point of view, thanks to on-site production, the zeroing of CO_2 emissions, the reduction of energy waste and distribution losses; and from an economic point of view given the reimbursement that each member of the Energy Community receives in the form of a reduction in the bill thanks to the sharing of the guaranteed benefits. However, the economic aspect of the research is still in the phase of analysis, data collection and study. Further future development of the work is foreseen on this.

This approach, in addition to promoting circular economy and energy efficiency, is also a huge opportunity to support and re-launch the growth of Small and Medium-sized local Enterprises, which can find a role in the development, construction, operation and maintenance of renewable plants, the advantage of the industrial and employment fabric of the territory in which they operate. For this reason, the research wants to outline a starting point to follow and replicate in different urban districts.

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