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Analysis of the solar potential of urban public areas for the installation of integrated photovoltaic systems.

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Abstract. The analysis of the solar potential carried out in a defined territorial context and considered as a case study, intends to estimate the potential production of electricity from solar sources starting from a survey on the availability of the present surfaces.

The use of energy from renewable sources for public purposes, obtained through the installation of integrated photovoltaic systems in public urban areas available and appropriately identified, can represent a valid energy strategy in response to the provisions of the European Directive 2009/28 / EC.

In this study we want to show how the upgrading of public areas for parking, areas of interchange, or for the shelter of pedestrians in holding areas for public transport or in parking ones for cars can become an opportunity for energy production.

In fact, all these public spaces can be transformed into places designed to characterize and redevelop the built space with the use of appropriately designed urban furnishing elements that integrate, for example, the function of shelter and energy production. This research project aimed at developing a methodology of systematic approach that can represent a further element that is part of the policies that can be drawn up in the next 30 years towards a decarbonisation in the territorial area taken into consideration.

The methodology developed concerned the following points:

- 1) Identification of the areas and spaces present in the territory taken as a case study, suitable for an upgrading project and/or for the insertion of urban furnishing elements made with integrated photovoltaic panels;
- 2) Calculation of usable areas and consequent calculation of installable photovoltaic surfaces;
- 3) Identification of the elements of urban furniture made with integrated photovoltaic panels and present in the market.

The work identifies and computes, through the use of specific softwares, the areas and spaces suitable for the insertion of integrated photovoltaic systems. Subsequently, after identifying the areas, the quantities of hypothetically installable photovoltaic surfaces and the quantities of energy that can be produced are calculated. The latter are then compared with the quantities needed to cover the energy requirements for public lighting.

1. Introduction

Among the new sustainable development objectives established in 2015 in Agenda 2030 [1] and signed by 193 countries, it has been included that able to “*Ensure access to affordable, reliable, sustainable and modern energy for all*” (Goal 7). This objective is specifically defined by the “*increase substantially the share of renewable energy in the global energy mix*” (Goal 7.2) and by “*double the global rate of improvement in energy efficiency*” (Goal 7.3). By pursuing these objectives we want to achieve the decarbonisation by favoring a low carbon emission economy.



For over twenty years the EU (European Union) has promoted the diffusion of renewable energies and, according to data provided by IRENA (International Renewable Energy Agency) [2], in the EU countries there has been a strong growth in the use of renewable energy, which rose from 9% in 2005 to 16.7% in 2015. By 2020 it is expected that the target set at 20% will be achieved.

Also the statistical report of the GSE (Gestore Servizi Energetici - Energy Services Manager) [3] related to energy from renewable sources in Italy, highlights and confirms their weight in our country. With the 18.3% of the energy consumption covered by FER (Energia da Fonti Rinnovabili - Energy from Renewable Sources), both the total data recorded in 2016 and, for the fourth consecutive year, the target of 17% assigned to Italy by the Directive 2009/28/EC for 2020.

The European Commission has proposed new and more ambitious targets for 2030, such as: a 40% reduction in greenhouse gas emissions, an increase in energy efficiency of at least 30% and a minimum renewable energy share of 27% [4]. With the ratification of the Paris agreement [5], which took place on October 5, 2016, the European Union has set the goal of limiting the increase in the global average temperature of the Earth in this century "well below the 2°C" compared to pre-industrial levels, and in practice has set at the 2060 the reduction to zero of global carbon emissions from energy consumption, maintaining this level until the end of the century.

The European Union is leading the transition to a zero-emission economy, where energy weigh heavily. The transition to an economy with this characteristic requires cooperation at different levels, particularly among Regions and Member States [6].

The electricity market is a particularly complex system [7] and regulated by ever-changing standards; recently, in fact, at the end of the legislative course of the package of proposals, presented in 2016 by the European Commission, Clean Energy for all Europeans [8] also called "Winter Package", new measures have been approved [9] [10]. In this regard, consider that the Italian legislation currently in force does not allow the creation of an energy community, i.e. aggregations of consumption and production units other than one-to-one; this legislation is superseded by the European legislative provisions that will soon enter into force and which will have to be adapted.

Therefore, the work does not take into consideration, for the case study proposed, in relation to the electricity grid system, those that are the possible models of physical or virtual reference configuration.

In this context, the analysis carried out in a defined territorial context and considered as a case study, finds ground precisely in order to contribute to the realization of the European strategies outlined above.

2. The methodology adopted

In the absence of active tools, such as a regional database on solar potential, useful for the identification and calculation of surfaces suitable for the installation of integrated photovoltaic systems in urbanized public areas, it was considered appropriate to develop an ad hoc methodology experiment it in the urban area of the city of Padua considering two specific locations. For this purpose, users' waiting areas were taken into consideration, along the routes of public bus and tram vehicles and areas destined for public parking or public use.

The reasons that led to the analysis and verification of these areas are as follows:

- are already public areas susceptible to transformation without impediments and complications inherent in property rights;
- these are areas already used to host urban infrastructures; they would therefore have a further use with the optimization of the use of the same, without further consumption of new soil (Regional Law Veneto No. 14 of 6.6.2017 – Provisions for the containment of land consumption and amendments to the Regional Law of 23 April 2004, No. 11 "Rules for the Government of the Territory and Landscaping" – *B.U.R. Veneto Ord. 09/06/2017, No. 56*), being this aspect relevant to sustainability.

The research work has also highlighted how these areas are quantitatively significant and therefore able to host a non-marginal share of integrated systems for the production of renewable energy and also stressed how the further proposed use of the areas can be at the same time an opportunity urban regeneration.

The **first step** of the work consisted in the identification of the areas and spaces present within the territory of the Municipality.

The **second step**, after having identified the spaces, consisted in checking the irradiation of the same as the time and the season vary, as well as the shading of the individual areas. In fact, the presence of plantings or neighboring buildings can make the site unsuitable for the purposes proposed by the research. We then proceeded to calculate the usable areas and consequently calculate the installable PV surfaces.

The **third step** consisted in identifying the elements of urban furnishing that can be achieved with integrated photovoltaic panels present in the market and their verification of use in the areas identified to achieve the expected objectives. Use must take into account both the suitability of the product in relation to the adequate production of energy and the insertion of the same in the context and according to the urban regulations that regulate the dimensional and formal characteristics of the urban furnishings of the shelters.

The **fourth step** consisted in the calculation of renewable energy produced with the installation of integrated photovoltaic systems.

3. The case study of the spaces present along the lines of public transport in the Municipality of Padua

The urban area of the city of Padua is characterized by a dense network of public transport (Figure 1) managed by Busitalia Veneto S.p.A. (www.fsbitalia.it).

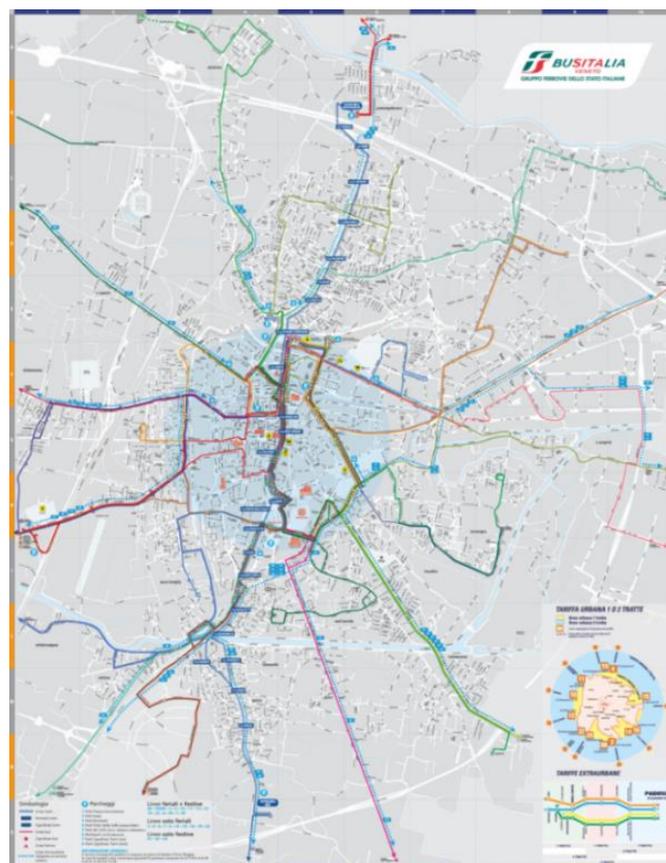


Figure 1. Network of urban lines of Padua.

According to the official website of the aforementioned company, (observation period corresponding to the year 2017), the network can count on a fleet of vehicles consisting of 640 buses and 16 trams which are divided into 70 lines between urban and extra-urban areas. However, the analysis was limited to the urban area, but also considering the sections of the urban lines that cross the municipal territory to reach the neighboring municipalities. However, for the sake of clarity, it was decided to consider also these last paths as they are present in the section where it is possible to observe strictly urban lines. The analysis carried out therefore considered 22 lines.

The urban regulations, the dimensional characteristics and the shapes of the bus stops were analyzed. The urban regulation in force for the urban furnishing and the propriety of the city foresees that the shelters can be single or modular with modules of standardized plant dimensions equal to 100 cm x 140 cm. The shelters of the tram stops (SIR1 line), on the other hand, have a longer longitudinal dimension and are almost always placed in the middle of the street (Figure 2) and therefore rarely subject to partial shadowing caused by the buildings facing. It is believed that to simplify the integration of photovoltaic systems in shelters in the territory, it is preferable to transform and replace existing ones rather than an installation from scratch.



Figure 2. SIR line 1 type of Tram stop shelter.

Once the shelters were identified, the study continued with a table in Excel showing the number of shelters present and/or installable and the relative solar exposure for each stop. In this regard, three major categories have been identified to describe the exposure of each stop: a) full sun, b) partially shaded, c) shaded. To better understand the classification in Figure 3, three images are shown for each of the described irradiation conditions.

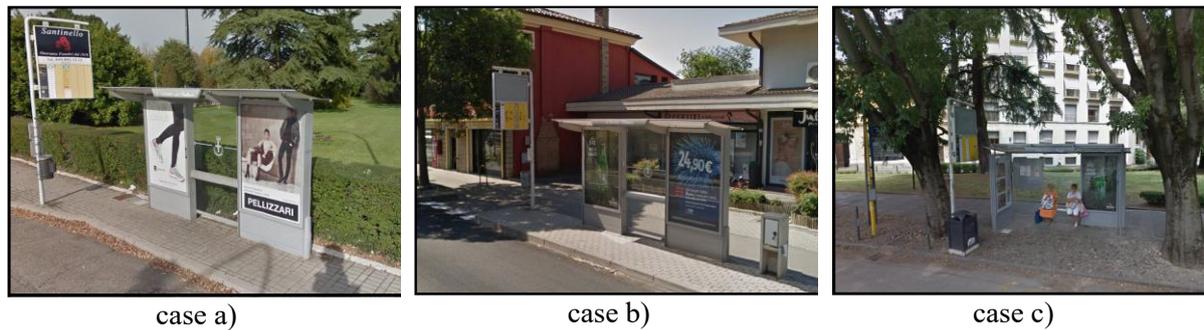


Figure 3. Examples corresponding to the categories identified.

In the case a) of full sun, the shelter receiving solar radiation was considered for most of the day with rare moments in which part of the shelter may be in the shade.

In the case b) of partially shaded, the presence of some minor plantings can obscure the shelter at times of the day no longer negligible in terms of time, but not relevant from the performance point of view. For example, when solar radiation is horizontal with respect to the photovoltaic panel and therefore with a non-optimal incidence angle.

In the case c) of shaded condition, there is the presence of large plantings and/or buildings in the immediate vicinity (having 3 or more floors), as for example in the narrow streets of the old town. In this case the shelter is darkened for most of the day with consequent poor performance of the photovoltaic system.

The analysis carried out has thus made it possible to consider each product in a different way depending on the category it belongs to in relation to the conditions of irradiation present and to the hypothetical performance of the connected photovoltaic systems. In order to attribute the correct category of membership it was considered appropriate to verify the correspondence between the images obtained from Google Maps and the state of affairs with verification directly in situ.

The study showed that within the territory, there are 250 shelters of various types. Of all these shelters, 141 fall in the case a) equal to 55% of the total, 60 fall in the case b) equal to 24% of the total and the remaining 52 equal to 21% of the total fall in the case c). Taking into account the shading and the orientation, the total surface of the existing shelters fully exposed to the sun is equal to 630 sqm. while that of the existing partially shaded shelters is equal to 270 sqm.. The shelters along the tram line in full sun are 19 and the partially shaded ones 17.

On the basis of urban regulations, for which the shelters are made up of modules of 100x140 cm, considering on average the shelters formed by three modules, namely those having a length of 3 mt. and an approximate width of 1.5 mt, it is possible to easily calculate the total area of the existing shelters: the surface in full sun is equal to 1930 sqm, while the one with partial shading 940 sqm..

After having carried out the analysis on the existing one, any new spaces suitable for hosting new shelters have been identified. The research identified 437 new shelters that could potentially be installed along the bus routes, of which 288 in full sun and 149 partially shaded.

The shelters serving the Tram line in full sun are 19 with a surface area of 340 sqm, the ones partially shaded 17. Excluding the surface in the shade, the total usable area for the installation of integrated photovoltaic panels is therefore equal to 3515 sqm. The data are shown in table 1.

Table 1. Total usable area.

Shelters						
Type of shelters	Irradiation degree	No. Present shelters	Present Area	Additional installable	Corresponding Areas	Total Area
Bus (3x1,5)	Full sun	141	630 sqm	288	1300 sqm	1930 sqm
	Partially shaded	60	270 sqm	149	670 sqm	940 m ²
	Shaded	52	230 sqm			230 sqm
Tram (13x1,4)	Full sun	19	340 m ²			340 m ²
	Partially shaded	17	305 sqm			305 sqm
	Shaded	10	180 sqm			180 sqm
Total area						3925 sqm
Total area (Excluding the shaded ones)						3515 sqm

Once the area suitable for hosting the photovoltaic panels has been established, the annual production has been estimated for the Padua area.

The calculation of the renewable energy production of photovoltaic panels able to cover this surface for the climate zone of Padua is equal to **980.960** kWh/year, as summarized in Table 2.

Table 2. Estimated annual production for photovoltaic installations on shelters.

Shelters performance				
Type of shelters	Irradiation degree	Number	KWh/year per shelter	Total performance (kWh/year)
Bus	Full sun	428	1480	630.000
	Partially shaded	209	860	180.000
Produzione Totale Pensiline Bus (KWh/anno)				810.000
Tram	Full sun	19	5920	112.480
	Partially shaded	17	3440	58.480
Total Production of Shelters (KWh/year)				980.960

4. The case study of public and public use for parking areas in the Municipality of Padua

Also in this case the first step was to identify, by means of a support cartography, the parking areas. The territory has been divided into concentric areas starting from the center of Padua. We started by analyzing the spaces inside an area circumscribed by a perimeter with a radius of 1.5 km from the city center, called area 1 (see Figure 4). We continued with the analysis of the spaces outside the perimeter previously defined.

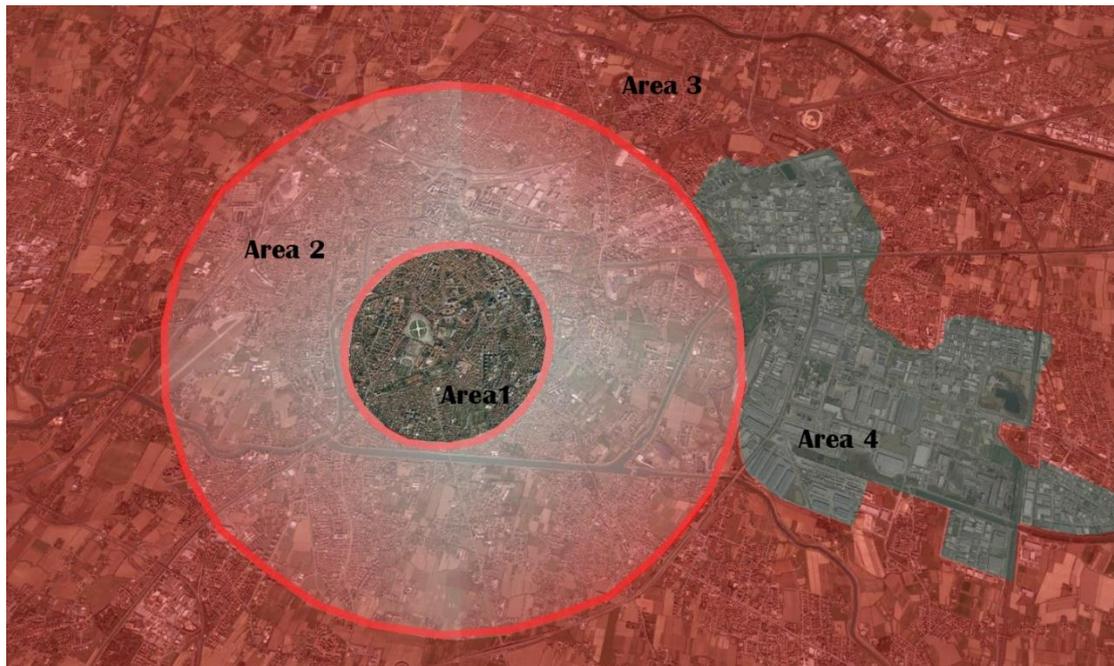


Figure 4. Identification of areas. (Fonte: Google Earth)

Once the phase described above has been completed, the analysis that has been carried out with the help of ArcGis has begun.

This second area is enclosed between the first and the second ring and is called area 2. Finally, as regards the outermost area, it has been divided into area 3 and area 4 since the latter is an exclusively industrial area and therefore with characteristics different from area 3.

With it it was possible, once imported the shape files downloaded from the GeoPortal of the Veneto Region concerning the Municipality of Padua, to mark the areas destined to public or private parking for public use as in the case of supermarkets or large companies.

To better understand the size of the hypothetical area that can be considered it is enough to think that within the urban area of Padua the regulated parking includes about 5,000 parking spaces, half of which are inside protected structures where access is limited by bars or staff member.

Many of these are managed by Aps car parks, a company that manages the road stop in the city of Padua (Figure 5).

The parking spaces in the Paduan territory are therefore of two types: the parking lots, located along the roads consisting of 2,935 parking spaces according to the data supplied by APS and the car parks located in protected areas with access regulated by bars automatic and present in different parts of the city.

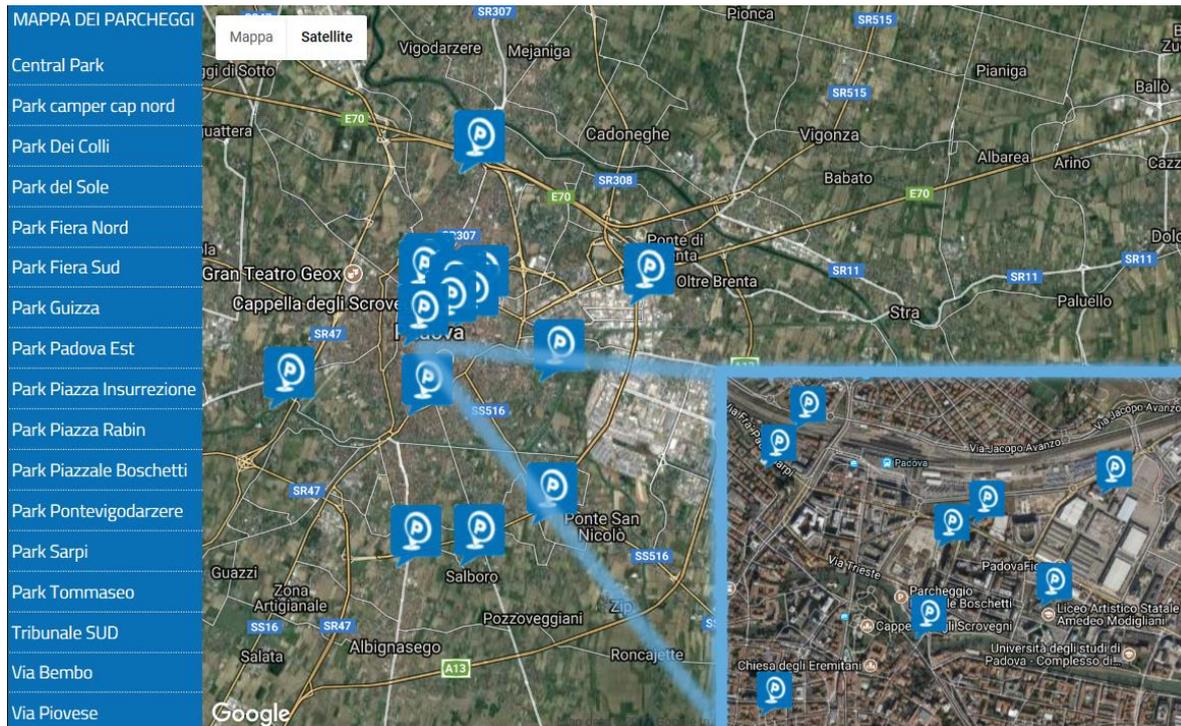


Figure 5. Map of the main car parks managed by APS.

There are also 5 large car parks managed directly by the Municipality of Padua, located in strategic points of the city. To these, there are also other 5 private parking places affiliated with the Municipality of Padua.

For greater accuracy, we have also compared from time to time the GIS map with the relative view taken from Google Earth as exemplified in Figure 6.

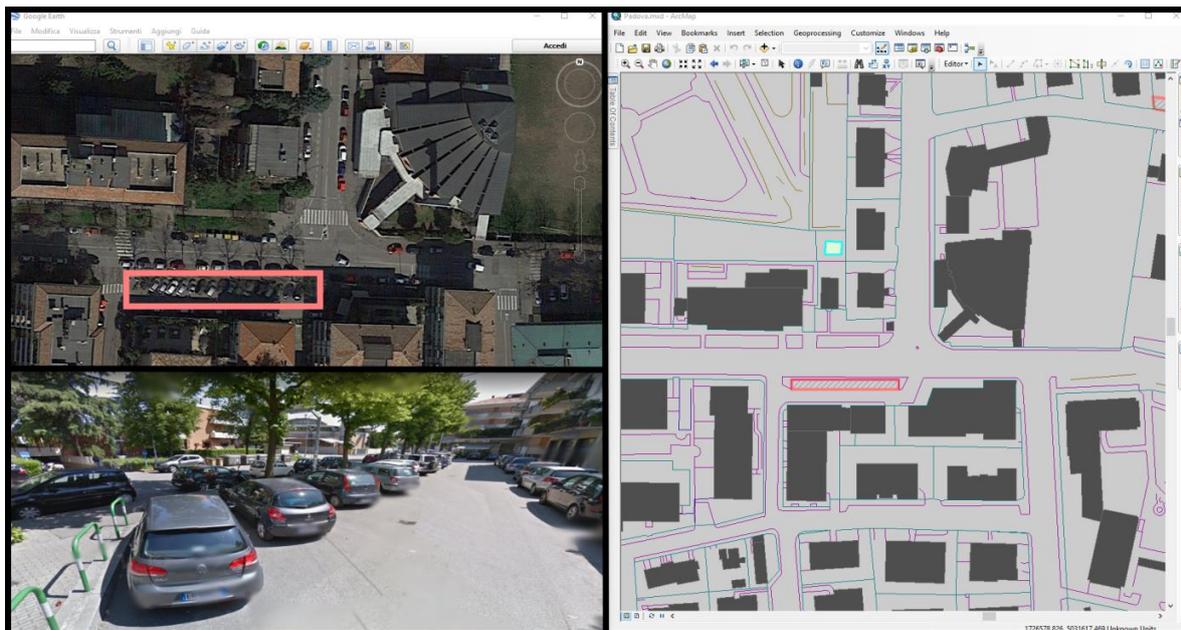


Figure 6. Example of comparison between GIS map and Google Earth view performed for each identified area.

After having identified all the suitable areas with the help of the ArcGis software, the sum of the surfaces was made, thus obtaining the total area potentially able to host the photovoltaic systems. In this way, it emerged that there is an area of 773,807 sqm for parking that can perform the additional function of energy production site.

In Table 3 you can see how the 603 parking lots identified are distributed according to the size of the occupied area. Precisely we can appreciate the number of parking spaces divided by size.

Considering the subdivision of the territory of Padua in the four main areas, it can be seen that the first, the most central one, highlighted the smaller number of parking areas, is an area of strong historical anthropization with high population density and scarce availability of space not built. In contrast, area 2 is the one with the largest number of parking spaces. It follows the more peripheral area 3 characterized by lower parking areas than the other two areas.

Table 3. Cataloging of parking areas according to their extent.

Spaces intended for parking areas		
Type of spaces	Number	Area
Total	603	773.807 sqm
< 200 sqm	94	13.367 sqm
> 200 sqm	509	760.440 sqm
> 400 sqm	381	722.488 sqm
> 1000 sqm	210	610.140 sqm
> 5000 sqm	27	230.219 sqm

The analysis showed that even the parking areas located on the roadside, have characteristics that allow the placement of photovoltaic shelters to cover cars. Also this type of parking was therefore considered in the calculations of the surfaces and turns out to be one of the most interesting parts of the analysis itself. In fact, the development of this type could in some cases guarantee a covered parking to residents without a garage. In this way, the private sector would have the advantage of compensating for the lack of a garage and the availability of renewable electric energy that can be used, for example, to recharge electric cars.

Another aspect that emerged from the research is the dislocation of the main usable areas.

We have already mentioned the differences that have been found in the different areas. Area 2 located to the east of the Padua station is an extensive area of recent construction characterized by large parking areas able to satisfy the demand not only of that area but also of the neighboring ones.

Comparing this area with that of the industrial area (area 4) some common features have emerged, such as the presence of large buildings and large open spaces. It was therefore considered appropriate to compare the capacity of the parking spaces of these two areas and compare it with that of the rest of the city. From this comparison it emerged that an important part of the useful spaces is located in area 3 and in area 4, which is therefore able to host large plants.

The data shown in Table 3 refer to the gross surface comprising the parking area and the area required for maneuvering and traffic areas. To calculate the actual surface on which to install the photovoltaic systems, design simulations were carried out as illustrated in Figure 7 and Figure 8. Figure 7 shows the status of a parking area.



Figure 7. State of fact of Paolo Sarpi street parking area.

Figure 8 shows the design simulation of the same parking lot equipped with photovoltaic shelters. As you can see the installation of the shelters involves the redesign of the car parks since for the optimal production of energy it is necessary that these are oriented to the south.



Figure 8. Design status of Paolo Sarpi street parking area.

Similarly, in Figure 9 the status of fact is shown and in Figure 10 the design simulation for the Via Canaletta parking lot.



Figure 9. State of fact of Canaletta street parking area.



Figure 10. Design status of Canaletta street parking area.

The design simulations carried out make it possible to state that the effective usable area dedicated to containing the photovoltaic panels is lower than the gross area calculated and shown in Table 3. Table 4 shows the effective useful area that is equal to 288.000 sqm. This is in fact the surface that must be taken into account to calculate the annual production possible. As for the area of Padua 3Kwp installed produces 3590 KWh/year and for this production are required 18 sqm of photovoltaic panels it follows a total annual production of 57 GWh/year as shown in Table 4.

Table 4. Estimated annual production for photovoltaic installations in parking areas.

Spaces in parking areas					
Type of spaces	Lost surface percentage	Total lost area percent	Total space	“Useful” space	Total production (GWh/year)*
Regulars	50%				
Irregulars	65%	60%	720.000	288.000	57
Publics for “private” use	-				

* The calculation considers 3Kwp (3590 KWh/year) every 18 sqm.

5. Results obtained

The results obtained in the two different case studies taken into consideration for the placement of photovoltaic systems, are the following:

- from the use of the areas near the bus and tram lines of the city of Padua equipped with photovoltaic systems, an annual production of electricity from renewable sources is estimated at **980.960** KWh/year;
- from the use of the parking areas equipped with photovoltaic systems, an annual production of electricity from renewable sources is estimated at **57.000.000** KWh/year.

The total production possible, shown in Table 5, is equal to 57.980.960 KWh/year.

If we compare this data with that relating to the consumption of electricity for public lighting of the Municipality of Padua, which for the year 2015 was equal to 15.920.359 KWh/year with a total cost of 4,000,000 euro (data supplied by APS), it is clear that the installation in the identified areas of integrated photovoltaic systems would make a significant contribution in terms of energy production from renewable sources as well as in economic terms.

Table 5. Estimate of the total production of installable energy.

Overall energy production	
Type of identified spaces	Total production (KWh/year)
Shelters	980.960
Parking spaces	57.000.000
Total energy	57.980.960

To demonstrate the validity of the study in economic terms, the following should be observed. If you wanted to equip the identified areas along the bus and tram lines of shelters with an integrated photovoltaic system having a surface area of 3515 sqm. (see table 1), the estimated cost deriving from market analysis is approximately 800.000 euros. Considering that the annual expenditure for the supply of electricity for public lighting, according to the data provided by APS is equal to € 0.25/KWh and that the total estimated production for the areas identified for shelters is equal to 980.960 (KWh/year), we note that the cost for the installation of the plant pays for itself in 3.26 years.

6. Conclusions

The European Union has adopted the strategy of transition to a zero emission economy, where the principle of the use of energy from renewable sources plays a fundamental role, and has made it one of the strengths of its program of decarbonisation. The transition to an economy with this characteristic requires cooperation at different levels; in particular, on the basis of the principle of collaboration between Regions and Member States on the territory it becomes strategic to identify every area useful for the realization of the program. The work carried out has been developed according to the methodology described and articulated in 4 steps that sequentially provides:

1) identification of areas; 2) the verification of irradiation and shading of each and the calculation of the areas by type that can be used overall, 3) the identification of urban furnishing elements that can be made with integrated photovoltaic panels, compatible with the context, 4) the quantity estimate of renewable energy obtainable with the application of integrated photovoltaics.

In this regard, it should be noted that in this paper, in order to focus on the main topic, which is the analysis of solar potential, we chose not to report on the integration aspects of photovoltaics to highlight the results of undoubted interest obtained. In conclusion, if in the identified areas the maximum quantity of photovoltaic that can reasonably be installed is applied, it is observed that the estimated quantity of energy producible and obtainable overall in the two case studies taken into consideration, fully covers energy consumption for the public lighting. On the contrary, this quantity represents about 1/4 of the entire quantity that can be produced, for which much more energy is available for many other uses, by the municipal administration. All this obviously could represent not only a contribution in terms of decarbonising the environment, but also a significant economic contribution to the municipal budget.

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