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Evaluating the Potential of Nature-Based Solutions (NBS) and Solar Energy in Urban Built Environments with Aerial Photogrammetry Dataset

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Abstract

The process of urbanisation has a significant impact on climate change, with projections indicating that over 70% of the global population will live in cities by 2050. The challenges associated with climate change impacts on urban areas include urban heat islands, unsustainable water management, floods and air pollution. This study explores the potential of Nature-Based Solutions (NBS) and renewable energy in Torino, Italy, with a particular focus on the exploitation of rooftops for solar panels and green roofs. The data from 159 buildings in San Salvario was collected using aerial photogrammetry. The solar potential was analysed with ArcGIS, taking into account both geographic and building-specific factors. Buildings that were unsuitable for solar panels were identified for green roofs. This research supports the United Nations Sustainable Development Goals 7 (Affordable and Clean Energy), 11 (Sustainable Cities and Communities), 13 (Climate Action), and 15 (Life on Land). The annual solar potential was estimated at 100,300 kWh, with 2,450 m^2 of suitable roof area for green roofs. The study demonstrates the feasibility of using rooftops to increase urban sustainability, thereby enhancing the quality of life for residents. The integration of NBS and solar energy can facilitate the creation of more sustainable and resilient urban environments. The study recommends the implementation of spatial-enabled urban planning as a means of overcoming barriers and promoting the development of green, energy-efficient communities.

1. Introduction

1.1 Literature background for the study

Urban settlements have a significant impact on climate change. The projected population growth estimates that over 70% of people will be living in cities by 2050, which will increase the relevance of anthropogenic impact on global warming and greenhouse gas emissions (World Bank, 2021). Land-use change resulting from urbanization is a major driver of biodiversity decline, as well as high energy consumption and waste management (European Environment Agency., 2021). Urban sprawl has led to the development of enormous cities, which face numerous challenges such as the rapid expansion of built environments, urban heat islands, air pollution, flooding, and a growing energy request.

To enhance urban sustainability, Nature-Based Solutions (NBS) are raised as a possible sustainable solution (Faivre et al., 2017; Frantzeskaki et al., 2019). NBS have been described as solutions, “*inspired and supported by nature, that simultaneously provide environmental, social, and economic benefits and help build resilience”*(Commission et al., 2021). European policies and initiatives recommend the use of NBS in urban planning strategies to reach, at the same time, environmental-related goals and improve the quality of life in urban areas (Zlatanova et al 2010, Dorst et al., 2019; Gonzalez-Ollauri et al., 2023). They are mentioned by the UN Sustainable Development Goals (SDGs) (United Nations, 2015, 2019; United Nations Office for Disaster Risk Reduction, 2015), and they have received support from international and European policies (Oquendo Di Cosola et al., 2021; Sharifi et al., 2024). One potential NBS is the consistent integration of vegetation for green roofs and walls to reduce the urban heat island effect, improve air quality, and improve the liveability standards in urban settlements (Joshi et al., 2020). NBS could adapt cities to the effects of climate change, with a decrease in the use of energy, but the demand is still difficult to resolve in a sustainable way, hence the need for a combined use of NBS and renewable energy sources. Among these, solar energy stands out as a promising option, offering clean and abundant energy potential, especially in the Mediterranean regions, where there is ample sunlight for days in a year.

The use of spatial mapping and scenario building is an important part of the implementation of the planning strategy (Zlatanova et al., 2020). To effectively combine NBS with solar energy solutions in urban areas, it's important to grasp an understanding of urban topography. This includes understanding the layout of buildings in the city and the natural features associated with them(Alam et al., 2012). The conventional ways of studying urban landscapes don't always give sufficient detailed data for making informed choices and decisions for urban planning processes. In this context, photogrammetry point clouds emerge as a powerful tool. By using advanced remote sensing technology such as aerial photogrammetry-based 3D point cloud datasets, a detailed representation of urban environments can be obtained (Fuentes et al., 2020; Wu and Biljecki, 2021).

European initiatives are promoting the creation of energy districts and communities to bring energy efficiency to the planning level. One strategy for implementing these initiatives is to install solar panels on building rooftops, connected to the energy grid, with integrated energy production management. Positive energy districts (PEDs) are urban areas that are energy-efficient and energy-flexible, which produce net-zero greenhouse gas emissions and actively manage an annual local or regional surplus production of renewable energy (Hedman et al., 2021; Marinensi et al., 2024; Volpatti et al., 2024). The development of this district must consider not only technical issues but also environmental integration, spatial planning, and economic and social factors. High stakeholder engagement is crucial, including investors, homeowners, and administrations. Therefore, local policies and barriers are of great importance (Bisello et al., 2018; Koltunov and Bisello, 2021; Moroni et al., 2019).

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Torino, the selected case study, is one of the cities that agreed to take part in the voluntary Sustainable Energy and Climate Action Plan (SECAP), which has been promoted by the Covenant of Mayors (CoM), a voluntary movement supported by the European Commission, that involves local authorities (European Commission et al., 2018; Horak et al., 2022). The plan called PAESC in the Italian version, was implemented recently in 2022, following the guidelines of the JRC (European Commission et al., 2018). The revised strategy aims to achieve two main objectives: climate change adaptation and mitigation. The adaptation strategy aims to reduce greenhouse gas (GHG) emissions, promoting virtuous energy management practices in terms of supply based on current and projected demand in the medium and long term, decreasing final energy consumption by end-users. It gives a central role to the concept of energy efficiency along with the use of renewable energy sources. Furthermore, it includes adaptation measures to mitigate the impacts of climate change, using NBS. Additionally, the PAESC aims to overcome a typically discontinuous model of actions by approving an effective multisectoral planning tool. Future planning instruments such as traffic plans, mobility plans, urban planning tools, and building regulations should align with the principles outlined in the SECAP and be part of the periodic monitoring (Cittá di Torino et al., 2022).

1.2 Aims and research novelty

This study examines the potential of NBS and solar energy to enhance urban sustainability, with a particular focus on the use of rooftops for solar panel installation or as green roofs. The research analyses a case study in Torino, Italy, using the state-of-the-art technology of aerial photogrammetry point clouds for a detailed understanding of the urban built environment. It explores the potential implementation of green roofs and solar energy in medium-sized cities from an urban planning perspective. Solar energy is one of the most common sources of renewable energy and determining how much energy urban buildings can harness is crucial for planning and developing more sustainable strategies (Zheng and Weng, 2020). This study aims to provide insights into solar energy and NBS that can assist other cities facing similar challenges of sustainable development, using a case study application.

The research aligns with the United Nations' Sustainable Development Goals (SDGs) and addresses several pertinent targets, specifically contributing to Goal 7: Affordable and Clean Energy and Goal 11: Sustainable Cities and Communities by examining NBS and solar energy to improve urban resilience and environmental quality. Furthermore, the research promotes low-carbon and climate-resilient urban development strategies, in alignment with Goal 13: Climate Action and Goal 15: Life on Land, through the promotion of urban biodiversity (United Nations, 2023).

The objective of the research is to provide valuable guidance for local urban actors, policymakers, and stakeholders on the integration of aerial photogrammetry point cloud data analysis techniques with urban planning to achieve more sustainable strategies and districts.

This paper is organised as follows. The next section presents the case study. The methodology used for the case study is outlined in section 3. In section 4 the results of the simulation are presented, and at the end, in sections 5 and 6, the discussion and conclusions for further implementations.

The study addresses two major aspects:

- The combined implementation of NBS and solar energy for sustainable urban development and planning strategies.
- The mapping of the building rooftop area using aerial photogrammetry point clouds and the quantification of its exploitable potential for solar energy production and green roofs implementation.

2. Case Study and Dataset Acquisition Systems

The locality of San Salvario in Torino, Italy, was undertaken as a study area, because it presents a mixed residential and small commerce use and because, within a small dimension, presents the most common building structure and size in the city, making it the perfect sample. A part of the district was sec comprising around 159 buildings. The location is represented in Figure 1 below. Another reason for selecting this area was the availability of existing photogrammetric takes acquired for the Torino Digital Twins project (Boccardo et al., 2024).

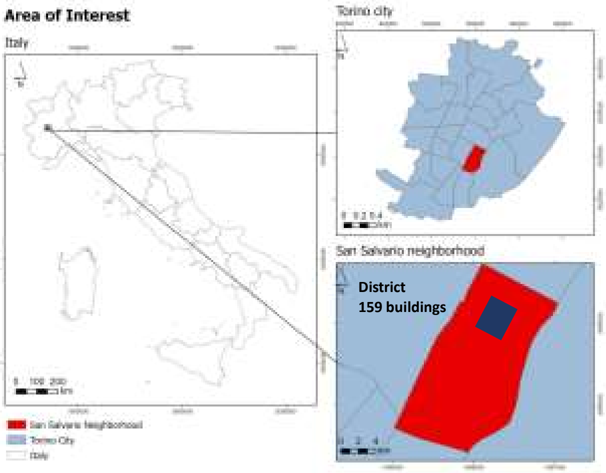

Figure 1: Case study location, Torino, Italy

The data acquisition phase involved the utilisation of optical imagery and image orientations derived from an airborne Leica CityMapper-2 system. A total of 358 aerial images were used for the selected location with a ground resolution of 5 cm for the test area. The images were processed in Agisoft Metashape software with their orientations to derive a dense point cloud and a digital surface model (DSM) for the study area. The building footprints of 159 buildings in the selected locality were obtained from the Open Street Map (OSM) Web, which were then used to mask the building rooftop surfaces for the processing phase. The datasets and software tools employed during this study are presented in Table 1.

Dataset/ Tool	*Source*	*Usage*
Photogrammetry point cloud	Aerial camera sensor	For rooftop detection
Digital Surface Model (DSM)	Photogrammetric point cloud processing	For Solar Potential estimation
Building footprints	Open Street Map (OSM)	Masking of building roofs
Agisoft MetaShape	Processing of Camera Images	Generation of photogrammetric point cloud
Cloud Compare	Cloud Compare	Data exploration and building orientation analysis
Area Solar Radiation Tool	ArcGIS Pro	Solar Potential Estimation

Table 1 Datasets and Software tools used in the research work.

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3. Methodology

In the study for the San Salvario case, the first step of the methodology was based on aerial photogrammetry data acquisition (1), which was acquired for the Torino Digital Twins Project. From there, the images were processed in Agisoft Metashape software (2) to obtain first the dense point cloud and then, from it a digital surface model (DSM). This data was then used as input for the *Area Solar Radiation* tool in ArcGIS Pro for the estimation of the solar potential for suitable buildings (3). In the subsequent step, geometrical analysis of the building rooftops (4) was carried out with a selection of three criteria for the choice of the rooftop implementation to exploit their potential either with the installation of solar panels or as greener roofs. For those suitable as solar roofs it was estimated the solar energy production (5), for those not suitable, it is proposed the conversion to green roofs, with a recommendation of vegetation for the installation (6). Figure 2 represents the methodology workflow adopted in this research work.

3.1 Data acquisition

The aerial photogrammetry dataset was chosen because of its capability to capture the 3D urban built environment with a larger number of details and texture information (Yadav et al., 2023). Aerial photogrammetry datasets offer a higher level of detail about urban features like buildings, trees, and terrain for the urban landscapes. They are useful to researchers and urban planners in assessing how nature-based solutions (NBS), such as green spaces and permeable surfaces, can be incorporated into cities to enhance sustainability and deal with problems like heat islands and climate change. These datasets assist in investigating suitable spaces for solar energy infrastructure by providing 3D inputs for the analysis of sunlight exposure and shading patterns in urban areas. They are also suitable sources for the investigation of different resolutions such as object surface resolution and blocking obstacle resolution, Higher resolutions ensure a more precise estimation of photovoltaic potential but the processing time is demanding and might require dedicated parallel processing approaches (Alam et al., 2016).

3.2 Image Processing

The datasets acquired from the airborne acquisition including the images and their orientations were processed in Agisoft Metashape software for the generation of a dense point cloud. From the dense point cloud, the DSM of the selected locality was derived for processing and analysis in the subsequent steps. A total of 358 images were used along with their interior and exterior orientations in this processing for the generation of the dense point cloud and then, a DSM.

3.3 Solar Potential Estimation

In this processing phase, the solar potential of the residential buildings was estimated in the ArcGIS pro version 3.2.2 using the 'Area Solar Radiation' tool. The Area Solar Radiation tool in ArcGIS Pro calculates solar radiation for a given area based on various parameters. It considers factors like the position of the sun, terrain features such as slope and aspect, and atmospheric conditions. By simulating how sunlight interacts with the Earth's surface, it generates outputs like solar irradiance, which indicates the amount of solar energy received per unit area. This tool helps in analysing solar potential, identifying suitable locations for solar infrastructure, and understanding the spatial distribution of solar radiation across a landscape. The following important parameters are considered while estimating the solar potential for the building rooftops:

- Solar azimuth angle
- Geographical positioning of the area
- UTM zone of the area
- Time period for the estimation of solar potential
- Slope of the rooftop area
- Aspect of the rooftop area
- Planar area of the rooftop
- Orientation of the rooftop

One of the primary parameters in this estimation process is the position of the sun relative to the Earth's surface. This includes factors such as the time of day, day of the year, and the geographic location of the rooftop. By accurately modelling the sun's movement throughout the day and over the course of the year, the area solar radiation tool can determine the angle at which sunlight strikes the terrain at any given point and gives the estimated solar radiation received by the rooftop surface. The important parameters used in the Area Solar Radiation Tool have been summarised in Table 2.

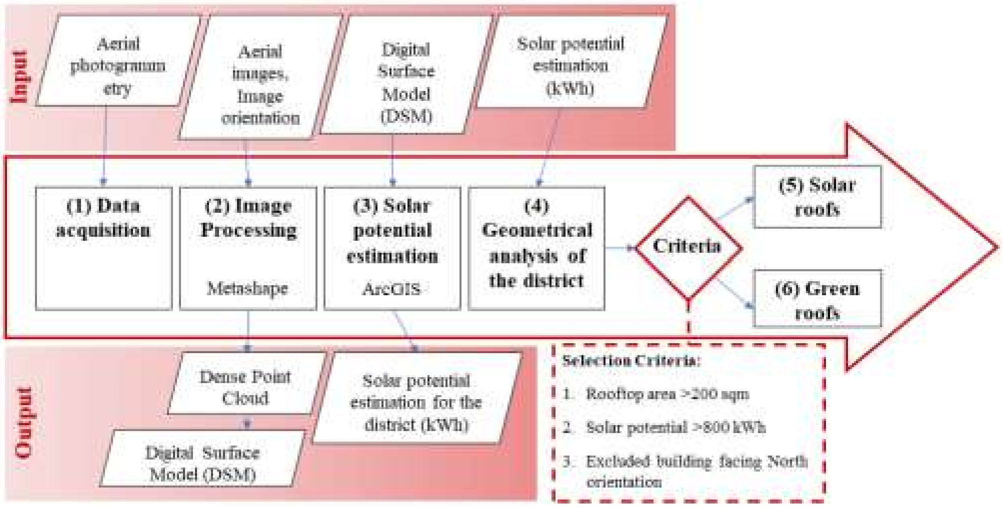

Figure 2: Methodology workflow adopted for the research work

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Parameter	*Relevance*	*Value*
Latitude	Latitude for the site area.	45.05488
Skysize/ Resolution	The resolution or sky size for the viewshed	200
Time Configuration	Time period to use for the calculations.	Entire year
Hour Interval	Time intervals through the day (units: hours) used for the calculation of sky sectors for sun maps.	0.5
Year	Calculations for an entire year using monthly intervals for calculations.	2024
Calculations directions	Number of azimuth directions	32
Transmissivity	Fraction of radiation that passes through the atmosphere	0.5

Table 2: Summary of important parameters used for the Solar potential estimation.

In the solar potential estimation, we have also considered the slope and aspect of the rooftop surface, as these factors influence the amount of sunlight received by different areas and different rooftop planes. Rooftops with slopes facing West, East and south exposition receive more direct sunlight, leading to higher levels of solar radiation, while slopes facing North may experience shading and reduced solar exposure. Figure 3 represents the geometry of the solar radiations received by the earth's surface and geometrical factors affecting the solar energy striking the earth's surface.

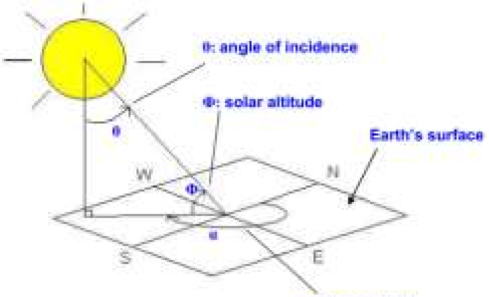

Figure 3: Geometrical representation of the solar radiations received by the building rooftop (Team Vskills, 2023)

The atmospheric conditions such as cloud cover, haze, and atmospheric absorption have been also considered in the estimation of the solar potential. These factors significantly affect the amount of solar radiation that reaches the Earth's surface by scattering or absorbing sunlight and only a part of solar radiation is received by the Earth's surface. That's why, incorporating atmospheric data and weather conditions in the region under consideration is important for the estimation of the solar potential.
As an outcome of the processing with the above-mentioned parameters in the Area Solar Radiation tool, a solar potential layer of the building rooftops is obtained, which represents the amount of solar energy received per unit area, typically measured in kilowatts per square meter (kWh/m^2). It is worth mentioning that the solar potential estimation has been masked with building footprints (obtained from OSM) to restrict the estimation process just to building rooftops excluding any other terrain features in the analysis.

3.4 Geometrical analysis of the district

Based on the previous analysis, it was developed a selection criterion for the implementation of either green roofs or solar roofs. The choice was based on 3 main criteria:
(1) When contemplating the installation of solar panels, it is also crucial to select rooftops that do not face the North, particularly in the northern hemisphere. This is because surfaces oriented towards the North are more susceptible to receiving lower levels of solar radiation compared to those facing other directions. Conversely, in the southern hemisphere, South-facing surfaces tend to receive the least solar radiation. This geographical consideration emphasizes the importance of optimizing solar panel placement to maximise sunlight exposure and enhance energy generation efficiency.
(2) It is recommended that roofs be constructed with a slope of 45 degrees or less, as this is the optimal angle for roofing materials. It can be observed that steeper roofs receive less sunlight. To this end, the slope and aspect of the rooftops were calculated using the Surface Parameters (Spatial Analyst Tools) tool in ArcGIS Pro. Following the removal of portions of roofs with low levels of sunlight exposure, several North-facing roof surfaces remain. The North-facing slopes are those with angles less than 22.5 degrees or greater than 337.5 degrees and thus are not optimal for the installation of solar panels. Consequently, these areas have been excluded from the recommendations for solar panel installation. Nevertheless, we will also retain nearly flat slopes for solar panels, regardless of their orientation. The roofs are considered to be "flat" with slopes of 10 degrees or less.
(3) One of the most crucial considerations in the installation of solar panels on a building is the available rooftop area. This is because the size of the available area directly impacts the feasibility of the project. Torino has the majority of multi-story buildings with an average of 8-9 households per building. In this case, if the rooftop area is smaller than 200 m^2, then the solar panels won't be enough to cater to the energy requirements significantly. If the available rooftop area is insufficient to accommodate solar panels capable of satisfying the energy requirements of the building's households, the Return On Investment (ROI) is likely to be minimal. For this reason, we have considered the minimum available area of 200 m² for the installation of solar panels on the building rooftops. If the available rooftop area exceeds the capacity of the solar panels, the latter will be installed on the rooftops. Furthermore, another criterion for the recommendation of solar panel installation is the minimum solar potential of a rooftop. The annual solar potential cut-off has been taken as 800 kWh/m^2 as the minimum solar potential of the buildings suitable for installation of the solar panels (Delphine Khanna, 2023).
In other cases where the building rooftop area is less than 200 m^2 or annual solar potential is less than 800 kWh/m^2, then green rooftops are recommended for those rooftops which can help in lowering the urban heating effect and purifying the climate to some extent in the region.

3.5 Solar and Green Roofs

A study from 2020 suggests that green roofs and solar panel systems can both provide significant energy savings and should be considered as strategies to mitigate climate change (Zheng and

Weng, 2020). Therefore, the current analysis suggests the implementation of both in the study.

Green roofs are an NBS solution that can provide many benefits to a building and its users. Horizontal green roof systems can be divided into three groups according to the level of maintenance and vegetation options: extensive, intensive and semi-intensive roofs. They have very different characteristics and must be selected according to the specific conditions of the building. Extensive roofs have a thin layer (6-20 cm) and low maintenance, usually with sedum, mosses and grasses, while intensive roofs have a thicker layer (15 cm-1 m) and require permanent maintenance, using tall species such as perennials, shrubs and small trees. Semi-intensive roofs combine elements of both types, with a thickness of 12-25 cm and vegetation species such as grasses and shrubs (Croce and Vettorato, 2021). In terms of mitigation, green roofs can provide several environmental benefits, including participation in stormwater management, mitigation of the urban heat island effect, carbon sequestration, and enhancement of urban biodiversity, becoming a habitat for wildlife (Mihalakakou et al., 2023; Salman et al., 2019). Furthermore, they contribute to energy consumption, particularly in heating, ventilation, and cooling (HVAC) systems, which can result in significant energy savings. Therefore, they should be considered as strategies to mitigate climate change (Zheng and Weng, 2020). Green roof vegetation, through the process of photosynthesis, also contributes to the mitigation of air pollution, deposition of particulates, and reduction of pollutant concentrations, including $PM_{2.5}$, PM_{10}, O_3, and NO_2 (Shafique et al., 2020; Zheng and Weng, 2020). Additionally, green roofs can act as a barrier to urban noise reduction.

However, it is important to note that challenges such as high construction and maintenance costs, as well as roof leakage problems, are associated with the application of green roofs. Despite these challenges, the literature supports the adoption of green roofs as a sustainable practice to mitigate the adverse effects of urbanisation and promote climate mitigation strategies (Shafique et al., 2018).

Furthermore, some studies have indicated that green rooftops have the potential to enhance the efficiency of solar panels on rooftops by 3% to 4%. This represents a significant amount of energy, particularly when considered at a city level (Osma-Pinto and Ordóñez-Plata, 2019).

4. Results

This section of the article focuses on the outcomes of the initial processing of aerial-based camera images to get a DSM. The visual and statistics of the solar potential estimation have been also addressed in this section. The section concludes with the representation of the suitable rooftops for the solar panels and green rooftops from the selected locality after the analysis with several criteria.

4.1 Processing of the photogrammetry datasets

In the initial processing step, we employed the Agisoft Metashape software to obtain a dense point cloud and subsequently a digital surface model (DSM) model. The point cloud obtained has a point density of 55.27 points per square meter. Subsequently, the DSM was obtained for the selected area with an accuracy of approximately 3 cm. Tile size of 128 *128 pixels have been used in the further processing with DSM. Figure 4 illustrates the DSM model of the San Salvario locality obtained from the image processing in Agisoft Metashape.

Figure 4: DSM model obtained from the aerial photogrammetry datasets.

4.2 Estimation of the Solar Potential

The Solar potential was estimated for the building rooftops with the '*Area Solar Radiation*' Tool in ArcGIS pro with consideration of the important parameters as mentioned in Section 3.2. The annual solar potential of the locality with 159 buildings was found to be 20,654,014.78 kWh for the net building rooftop area of approximately 20679.42 m^2. Table 3 summarises the analysis results for the solar potential estimation.

Experiment case	*Number of buildings*	*Solar Potential (**kWh/m^2**)*	*Available rooftop area (m^2)*
All rooftops	159	998.7715	20679.42
North Facing rooftops	37	751.8312	1971.82
Rooftops with an area < 200 m^2	82	863.8721	3218.79
Rooftops with Solar Potential < 800 kWH^2	98	842.3214	4268.79
Available rooftops for Solar Potential	**67**	976.1583	**13747.90**
Available rooftops for Green Roofs	**92**	847.8795	**6931.52**

Table 3: Summary of rooftop area analysis and Solar potential estimation.

The results from the Solar Energy analysis have been represented in Figure 5 with the estimation of solar estimation of all 159 buildings from the locality with an average solar potential of 998.77 KwH/m^2. After analysis of the geometry and the orientation of the building rooftops, 37 buildings facing the North directions were excluded from the solar potential estimation with the parameters mentioned in section 3.4.

Figure 5: Solar Potential Estimation for all the buildings in the selected locality of San Salvario

In the subsequent analysis, 82 building rooftops with an area smaller than 200 m^2 were also excluded from the solar potential estimation. Figure 6 represents the different rooftop surfaces excluded from the solar potential estimation which were recommended for the installation of vegetation on the rooftops as Green Roofs. After excluding the building rooftops that are out of the cut-off criteria mentioned in section 3.4, suitable buildings were estimated for the available solar energy and the excluded building rooftop surfaces for the installation of vegetation on the rooftops. Figure 7 represents the building rooftops recommended for solar panel installations and green rooftops from the San Salvario locality after the complete analysis.

Figure 6 Buildings suitable for Solar panel installation (yellow) and Green Roofs (green) based on orientation and available rooftop area criteria.

5. Discussions

The findings of this research highlight the significance of incorporating spatial-enabled approaches in urban planning to prioritize the sustainable integration of green solutions and renewable energy sources. The study estimated the average annual solar potential for 159 buildings was estimated to be 976.1583 kWh/m^2 and the green rooftop area was 6931.52 m^2 from the selected locality. Urban rooftops play an important role in promoting climate resilience and sustainability in cities.

Figure 7: Visual Representation of Solar Potential Estimation for the Selected Buildings and Excluded Buildings for Green Roofs.

Croce (Croce and Vettorato, 2021) presents a comprehensive range of solutions for utilizing urban surfaces, including rooftops, incorporating green solutions, water solutions, urban agriculture, cool materials, and renewable energy systems. The authors stress the importance of integrated and multidisciplinary approaches to tackle the challenges of designing and implementing surface uses in urban areas. They underline the significance of planning strategies to facilitate more efficient and environmentally friendly solutions. However, the question remains: how can these solutions be practically implemented? In this regard, the planning strategy and regulation from the side of the city assume great importance. The objective of a full integration between the energy planning and the mitigation strategy can be seen also in the strategic redefinition of the objectives of the local plans. One example of this integration is the implementation of the Sustainable Energy Action Plan (SEAP) to reduce local emissions into the Sustainable Energy and Climate Action Plan (SECAP)(European Commission et al., 2018; Horak et al., 2022). The SECAP plan reports an analysis of the energy consumption for the city, which has decreased due to the implementation of measures for energy efficiency over the past few years. The plan reports a 64% decrease in energy consumption in the residential sector between 2005 and 2019. The upcoming challenge now is going to be the shift towards green energy production and the adaptation strategy to climate change. As evidenced by the PAESC plan, the utilisation of photovoltaic energy generation is on the rise in the residential sector. However, it is still far from achieving the goal of energy communities or PEDs, thus underscoring the necessity for further implementation. The plan anticipates the implementation of solar energy generation in both private and public buildings, yet it lacks specifics regarding the quantity and manner of implementation. About the adaptation strategy, the implementation of green roofs is not considered. Instead, the plan mainly focuses on afforestation strategies. The use of visual analysis, such as that established in the paper, could be very useful to local administrations attempting to implement green roofs and solar energy production on a residential level. The integration of digital participatory processes, such as the Public Participation Geographic Information System (PPGIS) or Geodesign, could be a solution to integrating scenario analysis into the planning strategy, in direct collaboration with the involved stakeholders.

In addition to the administrative barriers, another aspect to consider when building a strategy for adopting integrated NBS and solar energy strategies is the citizens' response. The implications of these changing processes frequently elicit discontent among citizens, who are the end users and who would gain the most benefits from it. Literature recommends that social involvement is taken into account in the earlier stages of the process. If studies are based on a preliminary mapping analysis, as the one conducted, it could help overcome technical, economic, and social barriers to experimenting with energy and green communities.

The work is a preliminary analysis and it could be expanded in several ways. The shadowing effect from the buildings and trees has been not addressed in the solar potential estimation which can be an opportunity for future works. In the same way the computation of the PV potential could be addressed in further developments. From the planning point of view, future research could explore better the scalability and replicability of the methodology, to facilitate the adoption of NBS and solar energy strategies in other urban contexts, also with the use of other case studies from different geographical locations. Another topic that was not addressed is the integrated use of PV and green roofs, which so far reported a slight increase in the efficiency of the energy production of the PV, confronted with a concrete roof. This is due to the cooling effect of green roofs on air temperature, which may influence heat transfer by convection (Osma-Pinto and Ordóñez-Plata, 2019).

6. Conclusion

This paper has presented a case study from a residential locality in the city of Torino for the potential exploitation of both solar energy and green rooftops for the urban built environments. Using aerial photogrammetry-based DSM, the available rooftop area and solar potential of the building estimates were provided for green roofs and roofs suitable for solar panels. From the results, 42 % of the buildings with 66.47% of the total rooftop area in the selected locality are found suitable for the installation of solar panels which has an annual solar potential of 13,420,126.69 kWh whereas 58% of the rooftops with 33.53% of total building rooftop area have been recommended for the installation of vegetation as the green rooftops. With the suggested implementations, these green rooftop areas and solar energy will contribute to the enhancement of the liveability of the citizens in the urban settlements. Important steps still have to be taken into account in the planning sector and they could be integrated, pushing the implementation a step closer to the realization.

7. Acknowledgment

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