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Earth Observation as an enabling tool for Renewable Energy Communities through the identification of suitable grey surfaces for PV installation.

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Executive summary

The following thesis focuses on the realization of an Earth Observation (EO) system that could map, over a limited area, the most suitable roofs for PV installations, considering the slope, the orientation, the solar radiation, and the shadow impact of each roof. It subsequently analyses whether such a system could have an impact on the diffusion of Renewable Energy Communities (RECs) within the urban environment, where the impact of PV installation is minimized.

The research provides information about the needed technology and demonstrates that the realization of such a tool is feasible with commonly available data and equipment. The study then assesses the main barriers to RECs' diffusion, highlighting as main obstacles regulations, fundings and surface availability. The theorised tool could directly impact on the surface availability barrier, and partially on the funding one (by increasing the PV plant productivity and reducing the number of installations).

However, due to the current legislation, the impact this tool could have on RECs' diffusion within the urban environment is limited. The Italian regulation, indeed, hampers the possibility for the REC's participants to collectively invest in a PV plant and benefit from it as co-owners. In any case, the research also show that the tool could be used in other contexts, as industrial and green areas, with a significant impact.

1 Introduction

2023 was the warmest year recorded since 1850, with an average temperature 1.48°C above the 1850-1900 level (preindustrial period)[1]. The frequency of natural disaster (floods, droughts, and storms) has been 2.5 times higher in the 2013-2023 period (288.8 events per year) compared to the 1980-1990 period (115.2 events per year)[2]. This trend, of which the above are non-exhaustive examples, made climate change a major issue worldwide. As a consequence, new organizations and panels were created, and goals, policies and solutions were settled both at an international and at a national level.

In this context, the EU Commission has adopted the European Green Deal, a strategic roadmap to make the European economy carbon neutral by 2050. The plan involves numerous actions, investments and reforms to transform each sector and to ensure an inclusive and just transition[3]. Renewable Energy Communities (RECs) are among the solutions identified by the EU Commission to decarbonise the economy.

1.1 RECs in the European context

"RECs are legal entities that empower citizens, small businesses and local authorities to produce, manage and consume their own energy"[4]. At the European level RECs were firstly introduced by the *Clean energy for all Europeans package,* where it is stated that citizens can group in *energy communities* to share the energy they produce and that they can benefit from

[1] "Copernicus: 2023 Is the Hottest Year on Record, with Global Temperatures Close to the 1.5°C Limit.".

[2] Data from: International Monetary Fund Climate Change Dashboard. "Climate Change Data.".

[3] European Commission - European Commission. "The European Green Deal," December 11, 2019. Accessed August 20, 2024.

[4] European Commission, "In Focus: Energy Communities to Transform the EU's Energy System.".

incentives for their renewable energy production"[5]. The document provides also forecasts related to the spread of RECs: it is expected that by 2030 the 17% of the installed wind capacity and the 21% of the installed solar capacity will be provided by RECs[6].

The RECs were then detailed in the Renewable Energy Directive (RED II), issued in 2018 and revised in 2023. The Directive establishes a binding target for the renewable energy share in the gross EU consumption in 2030. This target is set at 42.5%. As said, the EU Commission has individuated RECs as one important tool to reach its decarbonisation goals. The Directive provides the definition of RECs, that are autonomous legal entities open to voluntary participation which are effectively controlled by the shareholders or members, who, in turn, have to be located in the proximity of the REC itself. The members and shareholders can be natural persons, SMEs or local authorities. Finally, the definition states that the main aim of a REC is to create a social, environmental, or economic community benefit for its shareholders and members before creating a financial one.[7]

Article 22 of the Directive, entirely focused in RECs, states that Member States must ensure that final costumers, as long it does not represent their main commercial or professional activity, are able to participate RECs without discrimination and maintaining their rights and duties as final costumers. Member States shall also guarantee that RECs are entitled to produce, consume, store, share within its member the renewable energy produced by the production plant, and sell renewable energy. Also, Member States must provide an enabling framework that: removes administrative and regulatory barriers to RECs; ensures a facilitated energy transfer within the REC by the Distribution System Operator (DSO); provides tool to foster finance and

[5] European Commission, Clean Energy for All Europeans.

[6] Ibidem.

[7] "DIRECTIVE RED II (EU) 2018/2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the Promotion of the Use of Energy from Renewable Sources (Recast)."

information accessibility; ensures a non-discriminatory treatment for consumers that are member of a REC. The Directive allows Member States to decide whether the energy produced by the Renewable Energy Source plant (RES) has to be shared through the public distribution grid or through a private network owned by the community itself[8]. Member States are entitled to reduce the administrative requirements for the RECs, and to provide both technical and financial assistance, including direct remuneration if it is classified as a small installation [9]. The main characters of a REC are the prosumer, the member who own the RES and therefore both produce and consume renewable energy, and the consumer, a passive member of the community who consume renewable energy[10]. There might be also a producer, a member who produce but does not consume renewable energy, but it is quite rare.

1.2 RECs in the Italian context

The Italian government has adopted the European directives introducing the RECs in the Italian legal system with the "Decreto Milleproroghe 162/2019". The Decree states that the RECs' members define their relations with a private law contract; that municipalities and public administrations have to be facilitated in participating in RECs and that incentive tariffs for instantaneous self-consumption are provided[11].

The RECs are further defined with the "Decreto CER" issued by the Ministry of the Environment and Energy Security (MASE). According to this decree RECs can be based on plants with a total maximum capacity of 1 mW; and the

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[8] Aquili, Alberica, "Comunità Energetiche: L'evoluzione Del Quadro Regolatorio Europeo e Italiano."

[9] "DIRECTIVE RED II (EU) 2018/2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the Promotion of the Use of Energy from Renewable Sources (Recast).".

[10] Aquili, Alberica, "Comunità Energetiche: L'evoluzione Del Quadro Regolatorio Europeo e Italiano."

[11] "Decreto Milleproroghe 162/2019, Art 42bis."

extension of a REC is limited to the territory covered by the electrical substation (cabina primaria)[12].

The resolution 318/2020, issued by the Authority for the Regulation of Energy Grids and Environment (ARERA), identify the virtual regulation model (modello di regolazione virtuale) as the model to be adopted for the RECs' functioning. This means that the RECs can only use the public distribution grid for sharing the energy produced[13]. Adopting the virtual model means that the producer feed the surplus of energy in the grid, selling it; while the consumer takes the energy from the grid, buying it; thereafter the DSO evaluate the self-consumption and provide some incentives. The physical model, instead, provides for a private grid, therefore prosumer and consumer use the energy without paying or selling it[14]. Regarding the virtual model, self-consumption is calculated as the minimum value (in an hour) between the amount of energy fed by the producer in the grid and the amount of energy consumed by the consumers.

The incentives provided for the self-consumption are composed by two different components: the incentive tariff (tariffa incentivante) and the payment of a valorisation amount (corrispettivo di valorizzazione) and they are both calculated on the amount of energy that is virtually self-consumed by the REC[15]. They last 20 years. While the incentive tariff is calculated as a sum of a fixed part (based on the plant's power) and a variable part (based on the current energy price), as shown in Table 1. The valorisation amount instead is calculated year by year by the Authority for the Regulation of Energy Nets and Environment (ARERA); for the year 2023 the valorisation amount was 8.48€/MWh. Finally, the producer receives, for the amount of energy that is fed

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[12] Ministero dell'Ambiente e della Sicurezza Energetica, "Decreto CER n. 414 del 7.12.2023".

[13] Aquili, Alberica, Diritto e Società, "Comunità Energetiche: L'evoluzione Del Quadro Regolatorio Europeo e Italiano.", 799-828.

[14] Ibidem.

[15] GSE. "Le Comunità Energetiche Rinnovabili 'In Pillole.'".

into the grid as that is not self-consumed by the producer itself, an amount of money regulated by the "ritiro dedicato", that is a simplified procedure through which the producer can sell the energy they have shared with the net[16].

Plant's power	Incentive
Power < 200kW	80€/MWh + (0-40€/MWh)
200kW < power < 600kW	70€/MWh + (0-40€/MWh)
Power > 600kW	60€/MWh + (0-40€/MWh)

Table 1, source: GSE[17]

These incentives are available also for configuration of Collective Self-Consumption, an association similar to a REC that involves individuals operating in the same building. Moreover, a 2.2bn € investment is provided to cover up to 40% of the total cost of RESs established in municipalities with less than 5000 inhabitants that will serve a REC[18]. Thus, besides the climate benefits of producing and consuming clean energy, being part of a REC not only grants clean and free energy, but also economic incentives for the consumption of that energy and, in some cases, for the realization of the RES plant.

Nonetheless, the diffusion of RECs has proceeded thus far at a slow pace. Indeed, according to the last available data, by June 2023 there were only 74 collective self-consumptions and 35 RECs in operation, involving 825 final costumers (of whom 271 involved in RECs)[19].

[16] GSE, "Ritiro Dedicato."

[17] GSE, "Le Comunità Energetiche Rinnovabili 'In Pillole.'".

[18] Ibidem.

[19] GSE, "ENERGIA E CLIMA IN ITALIA - Rapporto Periodico - Primo semestre 2023.".

1.3 Research question

As seen, despite the huge investment provided for the implementation of new RECs, as of today this innovative solution has not taken hold. The present research will thus investigate the main barriers to the diffusion of RECs and whether a system based on earth observation (EO)[20], able to automatically recognise suitable surfaces for the installation of PV systems, would be able to remove some of these barriers and facilitate the diffusion of RECs. Specifically, it will be investigated whether such a system could foster RECs in urban environments, as it generally increases the overall sustainability. Indeed, the creation of new RECs within urban environments allows to avoid soil consumption (by using roofs as installation surfaces), increase the overall productivity (by installing the plant on the most suitable surfaces) and reducing the installation costs (one installation instead of multiple installations). The research focuses on the Italian territory.

[20] Earth Observation regards the data collection about the Earth's surface and atmosphere through sensors placed directly on the ground, on airplanes or on satellites.

2 Literature review

The present chapter analyses the available literature to verify the following aspects:

- The technology needs to realise a system based on Earth Observation (EO) that is able to automatically recognise grey surfaces presenting the suitable characteristics to be installed with PV;
- The state of the art, that is verifying whether such a system is already implemented;
- The overall impact of PV systems if installed on green or grey surfaces, to define if the installation on green surfaces has a significant impact on the sustainability of PV systems;
- The main barriers to the diffusion of RECs, to check whether, in the literature, the identification of the installation's area represent a limit to RECs.

2.1 Needed Technology

The productivity of a PV plant is influenced by a number of different factors, including the solar radiation received, the tilt angle, the orientation of the panel and the shading that affects the panel[21]. The present section will deepen into each of these aspects and evaluate which EO technology may be used to identify the surfaces that present the most suitable characteristics.

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[21] Hammoumi et al., "Solar PV Energy: From Material to Use, and the Most Commonly Used Techniques to Maximize the Power Output of PV Systems: A Focus on Solar Trackers and Floating Solar Panels."

2.1.1 Solar radiation and tilt angle

Among the several factors that influence the productivity of a solar panel, one of the most impactful is solar radiation[22]. Solar radiation is the amount of energy received for a determined period of time by unit area[23]. Therefore, mapping the most suitable surfaces for PV installation requires an EO system able to measure the solar radiation over a surface of a few meters' dimension (as a roof).

Currently, solar radiation is mainly measured by satellites data that measure only irradiance on a horizontal plane (parallel to the earth surface)[24]. These data are used to measure solar radiation at different latitudes, but when it comes RECs that are geographically limited to the electric substation's extension, the difference in solar radiation due to latitude is irrelevant. What is fundamental, instead, is measuring the solar radiation over tilted planes, as the inclination deeply affects the solar radiation. Indeed, when the solar radiation hit the surface at an angle of or close to 90° (almost perpendicular) the radiation is concentrated on a small area, vice versa when the angle gets closer to a flat angle, the radiation hit a bigger surface, resulting in a less concentrate radiation that provides less energy per area unit[25]. Therefore, a system able to measure the slope of relatively small surfaces is needed. LIDaR (Light Detection and Ranging) is a remote sensing technology that uses a pulsed laser to measure distances; when mounted on a drone or airplane It is used to map vast areas[26]. There are different types of LIDaR with different accuracy and resolution. For example, the Copernicus Digital Elevation Model

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[22] Adeh et al., "Solar PV Power Potential Is Greatest Over Croplands."

[23] Tahir and Asim, "Surface Measured Solar Radiation Data and Solar Energy Resource Assessment of Pakistan: A Review.".

[24] EU Science Hub. "PVGIS data sources & calculation methods,"

[25] "Climate Science Investigations South Florida - Angle of Solar Radiation and Temperature.".

[26] National Oceanic and Atmospheric Administration. "What is LIDaR?" Accessed September 1, 2024. https://oceanservice.noaa.gov/facts/LIDaR.html.

(DEM) is a global map realized through LIDaR sensors mounted on satellites. The resolution of this DEM is 10m (available only for European countries), 30m or 90m[27]. Other LIDaR sensors, however, are much more precise and can generate maps with a resolution of 1 or 0.5 meters with an accuracy higher than 96%[28]. These features of high-resolution LIDaR allow to retrieve information about the slope of a roof.

In the image below (Figure 1) a LIDaR image and an aerial photograph of a building are compared. It can be noticed the accuracy and reliability of the LIDaR-generated image.

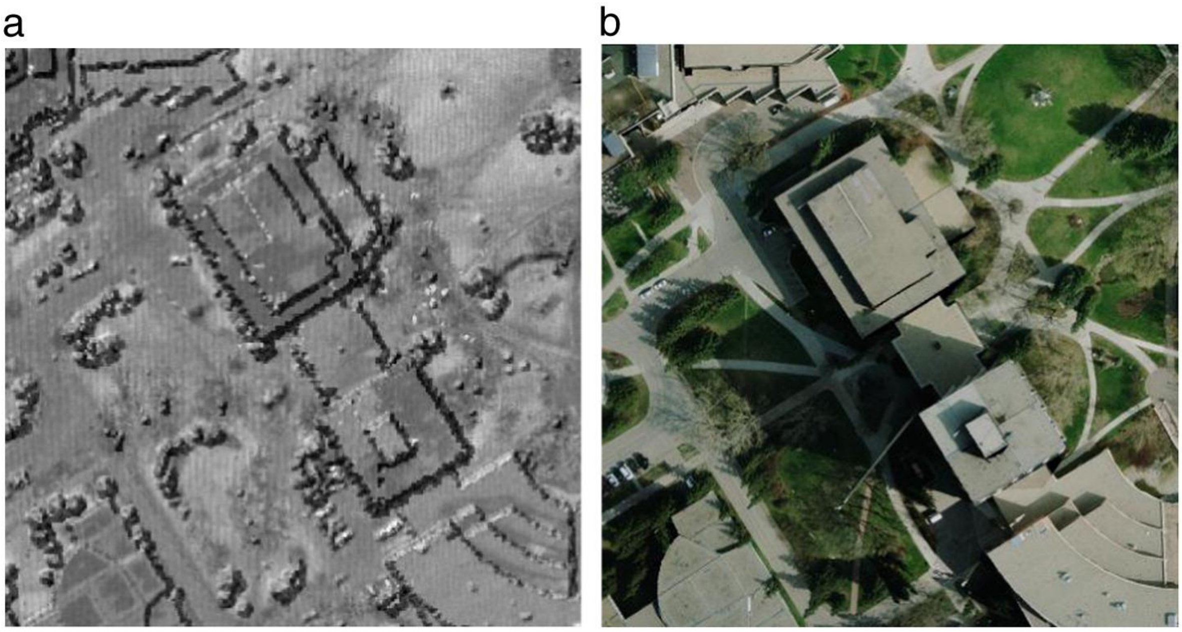

Figure 1, source: Yan, Shaker, and El-Ashmawy, "Urban Land Cover Classification Using Airborne LIDaR Data: A Review."

As of today, there is no public LIDaR data with high resolution (1m) available for the whole European territory. However, national governments are scanning part of their territory with LIDaR sensor also for other purposes, as for the hydrogeological instability's monitoring.

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[27]Ecosystem, "Copernicus DEM - Global and European Digital Elevation Model."

[28] Yan, Shaker, and El-Ashmawy, "Urban Land Cover Classification Using Airborne LIDaR Data: A Review.".

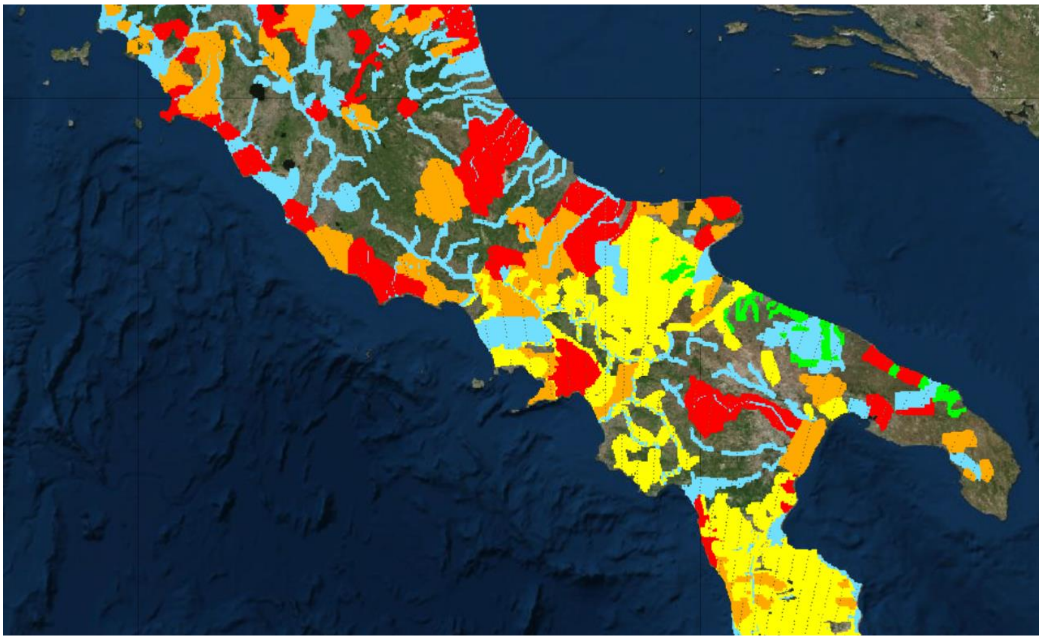

Figure 2, source: Geoportale Nazionale[29]

In the image above (Figure 2) it can be seen in different colours (different scanning missions) the areas covered by LIDaR scanning with a resolution of 1 meter; these scanning data are available at the Ministero dell'Ambiente e della Sicurezza Energetica, the Italian Environment Ministry. Moreover, LIDaR data with 1m resolution are also available for each region (a different dataset for every region) at the official portal for European data. In some cases, as for Lombardia region, 3d city models that include buildings were created[30]. Besides the publicly available data there are numerous private services for LIDaR scanning that are able to produce LIDaR images with a resolution of 0.5/1 meter. LIDaR images do not provide directly the slope of a surface, but the elevation of single points. However, through the processing of the data it is possible to retrieve a reliable approximate value, as studies have shown that the Root Mean Square Error (RMSE, an important index of reliability) is around

[29] "Geoportale Nazionale," Ministero Dell'Ambiente E Della Sicurezza Energetica,

[30] Kakoulaki, Martinez, and Florio, "Non-Commercial Light Detection and Ranging (LIDaR) Data in Europe."

5°[31]. In this context, a Geographic Information Systems (GIS) can be used to retrieve the slope from LIDaR data. GIS is a "computer systems that analyse and display geographically referenced information. It uses data that is attached to a unique location"[32]. ArcGIS, one of the most important GIS can, provide a "slope function" that, once provided the elevation data (LIDaR), is able to calculate the surface's slope[33]. GIS systems are also able to calculate directly the solar radiation over a certain surface through radiation models[34].

2.1.2 Orientation

Another fundamental characteristic of tilted surfaces to be installed with PV panels is their orientation. In fact, if a tilted surface is oriented towards south, it will receive direct sunlight during the whole day (as the research is mainly focused on the Italian territory) Even in this case the suitable EO technology is LIDaR. Indeed, as LIDaR allows to retrieve the slope of surface, and the LIDaR data can be integrated with geo-referenced data[35], taking in consideration the coordinate of the first point of a surface (the highest one) and the coordinates of the second point, it can be inferred the geographical orientation.

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[31] Yang et al., "Application and Validation of a Model for Terrain Slope Estimation Using Space-Borne LIDaR Waveform Data."

[32] U.S. Geological Survey, "What Is a Geographic Information System (GIS)? U.S. Geological Survey."

[33] ArcGIS Pro, "Slope Function, Documentation."

[34] "Analysis of Solar Energy Power Generation in Urban Environments." P. 41.

[35] Di Stefano et al., "Mobile 3D Scan LIDaR: A Literature Review.", Geomatics Natural Hazards and Risk

2.1.3 Shading

One more feature to be controlled when assessing surfaces for the installation of PV panels is the presence of objects in the surroundings that may shadow the panels. Since the capacity of other objects to shadow the roof and its panels is given by their height, also in this case LIDaR data can be used. Again, LIDaR data can be used as an input for Hillshade, an ArcGIS tool. Hillshade, starting from elevation data (as the LIDaR data), is able to return a 3D map that use the sun's relative position to show the shadowing effect on the map.[36]

2.1.4 Recognizing grey surfaces

As anticipated in the introduction, this research focusses only on grey surfaces, as the main aim of the investigated system is to foster RECs within urban environments and to avoid further soil consumption and degradation. Therefore, the last technological requirement is a tool able to recognize grey form green surfaces.

In this case there are two main possibilities: the Copernicus Browser or an available georeferenced map containing information about buildings.

Copernicus Browser could be used to retrieve SAR Urban images (Figure 4), even if this tool may lead to some errors or inaccuracies as it has a resolution of 10 meters[37]. These types of images are useful to identify urban areas and single buildings. Buildings are marked in green, purple and white[38].

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[36] ArcGIS Pro "Hillshade Function | Documentation."

[37] "Copernicus Browser."

[38] Sentinel Hub, "Urban Areas Script,"

Figure 3, A neighbourhood in Rome, true colour. Source: Copernicus Browser.

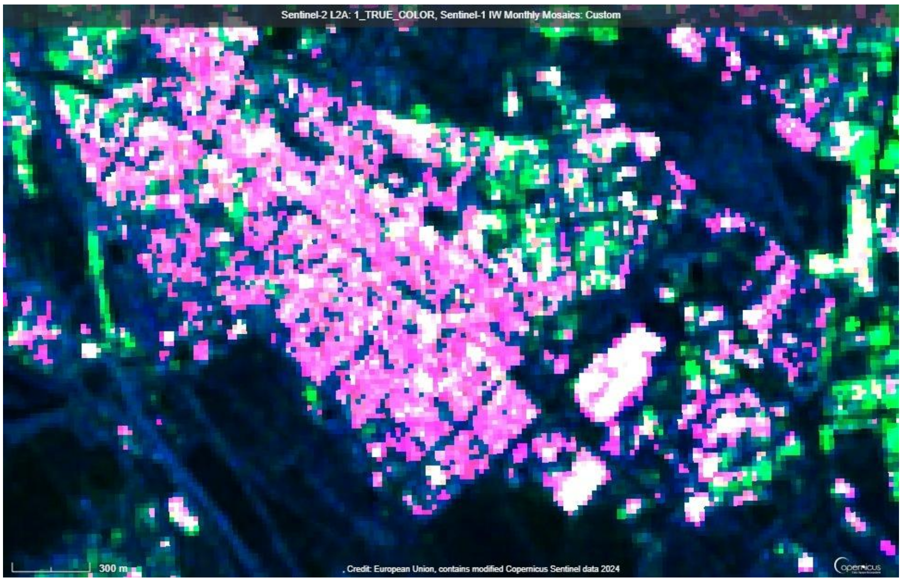

Figure 4, Same location of Figure 3, SAR Urban. Source: Copernicus Browser.

Another way to identify roofs from green surfaces is to employ available georeferenced maps that contains information about buildings and infrastructure and merge it with LIDaR data. An example, within the Italian territory is the "Carta tecnica Regionale", but every country has a similar service. As an example, Figure 5 illustrates a portion of Rome in which each building footprint is reported.

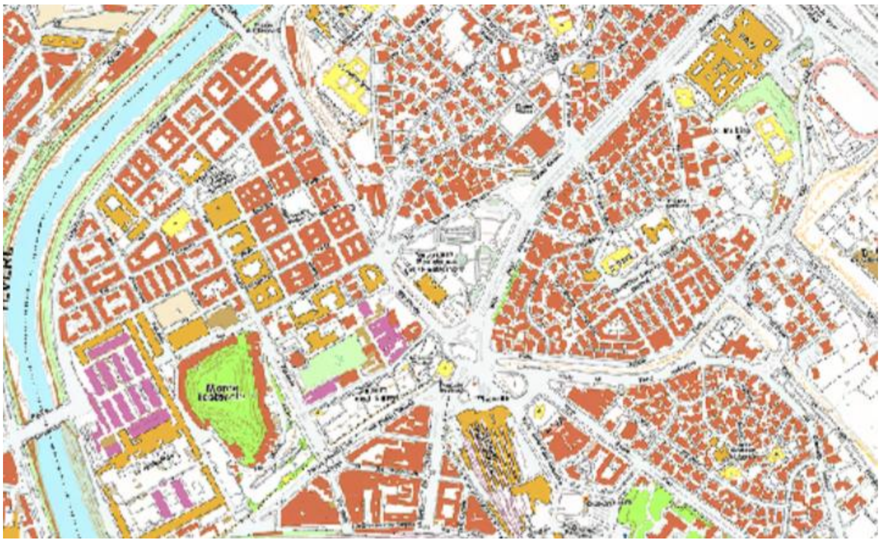

Figure 5, Carta tecnica regionale del Lazio. source: Georoma

2.2 State of the art

This section will analyse the state of the art, that is to verify whether, as of today, there are already in place systems based on EO that are able to identify roofs and to recognise which ones are suitable for PV panels installation. After thorough research the following cases were found:

- A research project conducted by Cumbria Action for Sustainability I association with Lancaster University that aimed to develop an algorithm to identify roof spaces suitable for PV installations;
- A scientific article published on *Urban Forestry & Urban Greening* that investigates, through GIS[39] data, the potential of rooftop system in Amsterdam;
- A project from Nam.R, a French software company, that aims to create a system able to predict the solar potential of a roof through aerial images and artificial intelligence;
- A Solar Potential Tool realised by the University of New South Wales (UNSW) and the Australian PV institute.

[39] Geographic Information System: computer systems that provides data and information regarding a determined position on Earth's surface.

2.2.1 Cumbria Action for Sustainability research project

Cumbria Action for Sustainability (CAFS) is a charitable organization that aims to contribute to the carbon footprint's reduction of Cumbria County, in England[40]. In association with the Lancaster University, CAFS realise a research project to realise a system able to identify the roofs suitable for PV installation through 3D satellite images in Halton-with-Aughton[41]. The project developed an algorithm that works on two different sets of data (two different maps of the same area) and that identify the roofs that present the suitable orientation and slope to PV Installation and that are not shadowed by higher objects.

The two data sets used are: Ordnance Survey open data and LIDaR data. Ordnance Survey is the Great Britain's national mapping service that provide geospatial data download products, API products, and geospatial services[42]. In this case the Ordnance Survey's data were used to outline the borders of each building in the area. LIDaR data, with a 1-metre resolution, were instead used by the algorithm to infer the roof shape, their orientation and their slope[43].

Once the data about the roof are calculated, the algorithm proceed to eliminate the non-suitable roofs for PV installations. The elimination strategy is represented in Figure 6. The algorithm eliminates the roofs smaller than 16 square meters, as only the surfaces able to host 6 solar panels of average dimensions (power capacity of 2Kw). Then it calculates the shadowing effect of chimneys and objects that may be present around the roof. The shadowing effect is calculated in 4 different times of the year, eliminating the ones that result to have a higher shadow factor. Finally, the algorithm evaluates the slope

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[40] Cafs, "Cumbria's Climate Change and Sustainability Charity."

[41] Baker and Nicholls, "Mapping Potential Roof Spaces Suitable for Solar Power Generation in Halton With Aughton."

[42] Ordnance Survey "Great Britain's National Mapping Service."

[43] Baker and Nicholls, "Mapping Potential Roof Spaces Suitable for Solar Power Generation in Halton With Aughton."

of the roofs. The roofs considered flat are kept since the panel can be installed in any direction and with any slope. The roofs with a slope between 10° and 60° are kept if they are not oriented towards from East-Northeast to West-Northwest. The algorithm eliminates also the roofs with a slope greater than 60° as they are not suitable for PV installation[44].

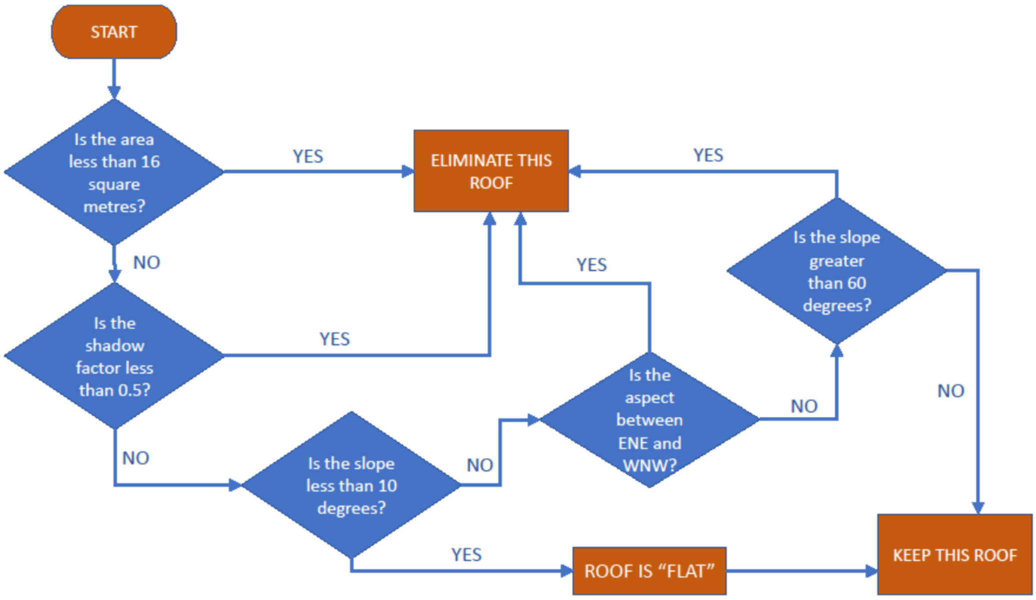

Figure 6, the roof eliminating algorithm. Source: Mapping Potential Roof Spaces Suitable for Solar Power

The algorithm uses geometry and weather data to evaluate the amount of sunlight on each remaining roof to estimate the power generation if installed with a PV system. As a result of the project, an interactive map of Halton-with-Aughton[45] containing the solar capacity's information of each roof was released (Figure 7).

[44] Ibidem.

[45] Available at: https://codeclass.co.uk/halton/

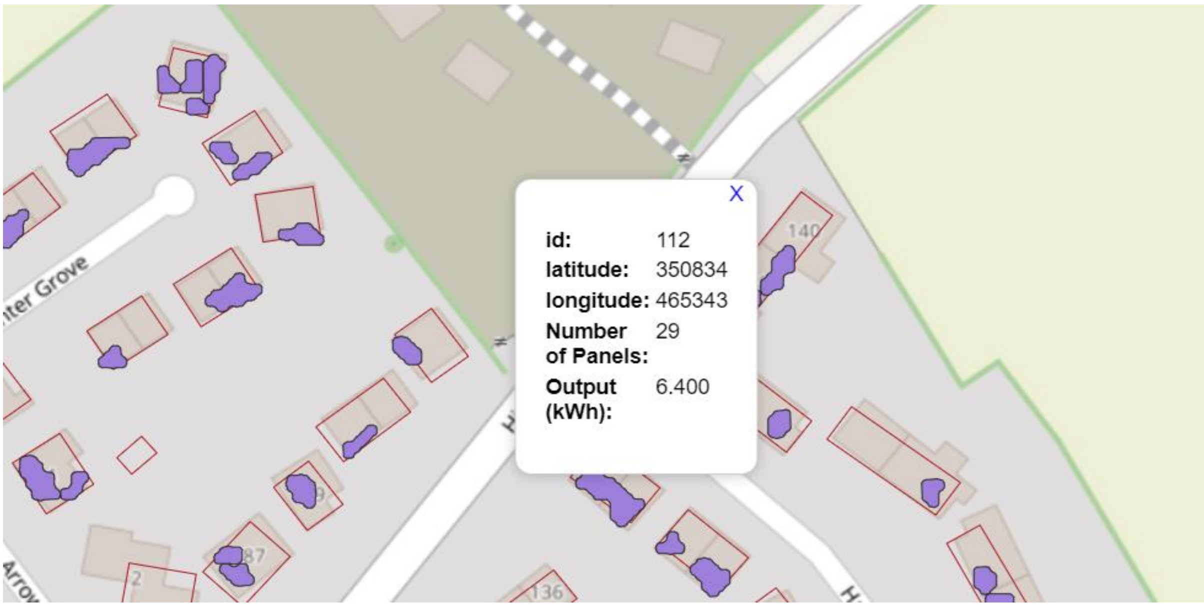

Figure 7, the CAFS interactive map. Source: Mapping Potential Roof Spaces Suitable for Solar Power

The purple areas in Figure 7 represent the roof portion considered suitable for PV installation. Pointing the mouse over a purple area will show its information, as the id, the number of panels estimated to fit the roof and the consequent energy production.

The study found that the largest 25% of the roofs could generate half of the total energy capacity estimated (3.9 Gw). This indicates that while planning to create a REC, focusing on proper roofs could cuts the total costs (less installations costs).

However, the authors state that, because of the low-resolution data (in particular the LIDaR data), the result is not completely accurate –LIDaR is quit conservative in finding roofs, but it may also overestimate the available surfaces on the detected roofs- and therefore it cannot yet replace a solar PV survey[46].

[46] Baker and Nicholls, "Mapping Potential Roof Spaces Suitable for Solar Power Generation in Halton With Aughton."

2.2.2 Nam.R project

Nam.R is a French software company that used deep learning to detect roofs from aerial images and predict their solar potential. They trained a deep learning neural network to recognise the roofs and their slopes. To train the neural network Nam.R used two sets of data, similarly to the sets used by CAFS. Indeed, the sets used by Nam.R were a 2D aerial photograph and a 3D reconstruction of a number of cities. With these two datasets and inserting manually a large number of label (that identify which image's portion represent a roof) the neural network was finally able to identify three different classes of objects: background (everything that is not a roof), roof's ridges, and roof's slopes[47]. The system recognised the 77.27% of the slopes and ridges pixels[48].

Figure 8, the identified roofs. Source: Predicting the Solar Potential of Rooftops using Image Segmentation and Structured Data

The system was then trained to recognise objects as chimneys and windows that would impede the PV's installation. Regarding the last aspects the neural network tend to overidentify objects due to the complexity of recognise them

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[47] Usoltsev, "Deep Learning for Roof Detection in Aerial Images in 3 Minutes."

[48] Andrieux, "Predicting the Solar Potential of Rooftops Using Image Segmentation and Structured Data."

from an aerial image. Since the system recognise each slope of a roof it can easily identify also its orientation (the images are georeferenced)[49].

Finally, Nam.R trained a *Random Forest*, a common machine learning algorithm, with the 3D reconstruction dataset in order to infer the inclination of each slope, but the system over infer the 20° inclination, that is the average inclination of the dataset used. At this point Nam.R calculate the number of panels that could be installed considering the roof's borders and the objects on it. To determine the solar potential, Nam.R used Global Solar Atlas using the inferred data about area, inclination, and orientation[50].

2.2.3 Urban Forestry & Urban Greening scientific paper

One more case of a system that use EO to evaluate the possibility of PV installation on roofs is a study published on Urban Forestry & Urban Greening. The study analyses the rooftop system of Amsterdam to verify whether each roof is suitable for PV installation, extensive green roof (EGR) or a combination of both[51].

The study aimed at creating a spatial analysis model able to assess roofs characteristics such as the shadowing effect, slope and orientation, and load capacity. For this purpose, a methodology was defined: the roof's characteristic needed for PV installation, EGR, and for the combination of the two were established. Regarding the PV the defined features are:

- Best case, orientation: south; slope: 0°-60°
    - Suitable cases: (1) South; 60°-90°; (2) East-west; 0°-60°; (3)North; 0°-30°.

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[49] Andrieux, "Predicting the Solar Potential of Rooftops Using Image Segmentation and Structured Data."

[50] Ibidem.

[51] Slootweg et al., "Identifying the Geographical Potential of Rooftop Systems: Space Competition and Synergy."

Once determined the methodology, the study developed a model the elaborate and evaluate the data, derived from two datasets: a LIDaR scanning of the entire Netherlands with a resolution of 0.5 meters (realized by the governments and the provinces)[52], and publicly available building stock data.

As seen in the other cases the LIDaR data were used to calculate the slope and the orientation of a roof. The shadowing effect was analysed using Hillshade, a tool that allow to calculate the shadow over a certain surface, using as input a digital elevation model[53] (that can be retrieved from LIDaR data).

2.2.4 UNSW Solar Potential Tool

The University of New South Wales (UNSW), in association with the Australian PV Institute (APVI), has conducted a research estimate the solar potential of roofs. In order to calculate the solar potential of each roof the engineers from UNSW use Property Information (data about building footprint) and different types of Digital Surface Models retrieved or from LIDaR data or from AAM, a geospatial company. The data are then elaborated by ArcGIS that assess the slope, the orientation, the shadowing effect and the solar insolation on every square meter. Then, two different methods are used to evaluate the suitability of a roof: 1) based on a minimum level of solar insolation; 2) based on shadowing effect and orientation. In both cases roofs are deemed suitable if they have at least $10m^2$ of available surface (equal to 1.5kW PV plant). In the first case, the researchers have defined a minimum level of solar radiation (set at the 80% of the expected horizontal surface's insolation). Using the second methodology only flat roofs and the ones oriented from east to west (towards north as the study was conducted in Sydney) are deemed suitable. Then, the shadowing

52 "Introduction - PDOK."

53 "Hillshade (Spatial Analyst)—ArcGIS Pro | Documentation."

effect is analysed trough ArcGIS's Hillshade. The roofs that receive a minimum of 4.9 hours/day throughout the year (sunlight hours needed to produce the 80% of an unshaded PV system) are kept in consideration[54]. On average, the second methodology is more conservative than the first and tends to assess as suitable a minor total surface.

These are the data and methodologies behind SunSPOT, an online tool managed by APVI that can be used by consumers, businesses and policymakers. This is the only case of a fully operative system that evaluate automatically roof's solar potential through EO. The tool is free-to-use for the citizens, but each Council (the third and smallest level of government) has to pay a subscription cost and to provide the LIDaR data[55].

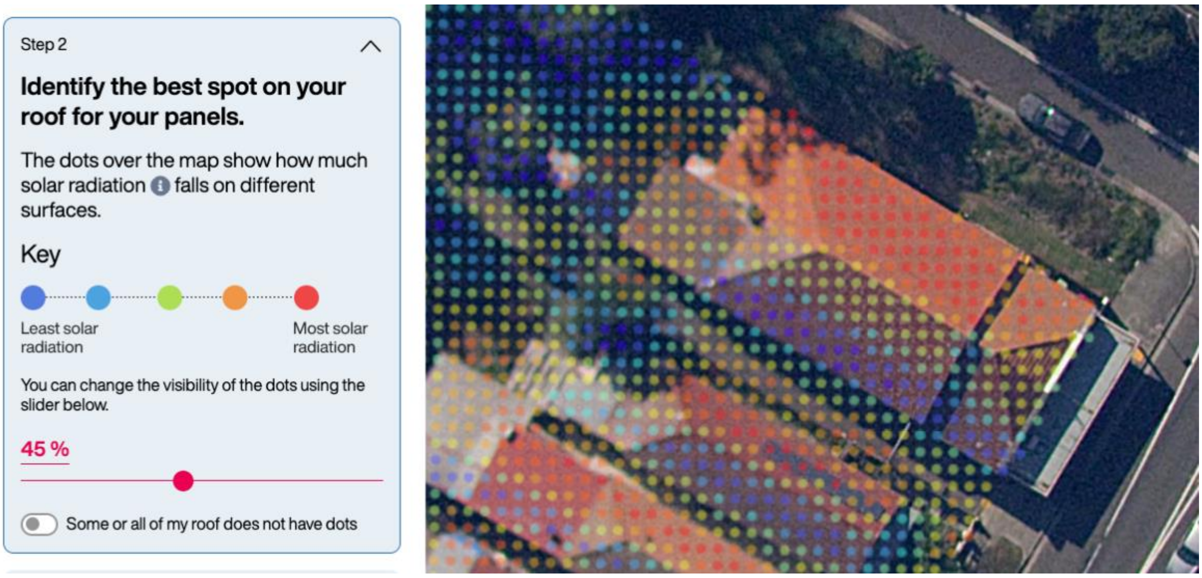

Figure 9, an example of how SunSPOT works. Source: SunSPOT website

[54] Copper, Roberts, and Bruce, "Spatial Analysis of Solar Potential in Sydney."

[55] SunSPOT "Solar and Battery Calculator for Councils | Solar Savings."

2.3 PV impacts on land use and degradation

In this section the potential impact of solar energy on land use and degradation is analysed.

The renewable energy technologies have a power density -that is the power available per unit of volume- several times lower than the fossil fuels' ones[56]. As solar energy is globally expected to represent from 20% to 60% of the energy mix in 2050[57], it is fundamental to carefully assess its potential impact. Indeed, assuming a 26% of total electricity coming from solar power in 2050 in EU, the land used would be between 21 and 28 thousand square kilometres, equal to 20%-27% of the2010 urban area. Even if the new PV plants are expected to be installed mainly on cropland and commercial forest, they will end in indirectly fostering the exploitation and commercialisation of other unused arable land. Indeed, it is found that every 100ha of soil used for solar power within the EU, 31 to 43 ha of unmanaged forest could be cut globally[58].

Moreover, it is also shown that Installing PV systems over green soil affects its physical, chemical and biochemical properties. Indeed, soil analysis beneath PV plants showed an increase in pH and salinity and a reduction in soil temperature and water holding capacity[59]. These changes affect the fertility of the soil and even if PV plants are labelled reversible soil consumption, it is likely that the soil quality will remain affected also in the case of a return to an agricultural use or wild condition[60].

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[56] Van De Ven et al., "The Potential Land Requirements and Related Land Use Change Emissions of Solar Energy."

[57] Ibidem.

[58] Ibidem.

[59] Moscatelli et al., "Soil Properties Changes after Seven Years of Ground Mounted Photovoltaic Panels in Central Italy Coastal Area."

[60] Ibidem.

In the Italian context the problem of soil consumption due to PV installation on agricultural and green soil is faced in the *Decreto Agricoltura*[61]. Through this decree the Italian Government has banned the installation of new PV plants on agricultural land. The decree, however, allows the realization of new solar power plant on agricultural land if it is aimed at the creation of a REC[62]. Therefore, even if it is still allowed to use agricultural land to install a REC' PV plant, it set a clear indication that the willingness is to limit soil consumption by renewable energies.

2.4 Main barriers to the RECS' diffusion

This section analyses the current literature to investigate the main barriers to the RECs' diffusion, in order to verify whether the lack of suitable surfaces represents an obstacle for the creation of RECs. Dioba et al. have conducted research to assess the different barriers to REC's diffusion in Italy and Spain. Four main barriers' category were found and ranked from the most to the least impactful: Regulatory and Bureaucratic (1); Financial (2); Social and Cultural (3); Technical and Practical (4)[63].

The main barriers among the Regulatory and Bureaucratic category are represented by regulatory complexity and legal limitations meaning that the procedures and requirements to join a REC are excessively complex. The second most impactful barrier is the lack of support and funding that means that the national funds are not sufficient [Financial]. In order, the other main barriers are: the mistrust in community energy projects (due to lack of transparency on the overall impact) and the lack of knowledge regarding the renewable energy technologies and their reliability [Social and Cultural]; the

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61 "Decreto Agricoltura (DECRETO-LEGGE 15 maggio 2024, n. 63)," May 15, 2024.

62 Ibidem.

63 Dioba et al., "Identifying Key Barriers to Joining an Energy Community Using AHP."

low community engagement, meaning the difficulties in involving the citizens and in coordinating the members of a REC [Technical and Practical][64].

The European Commission have also realized a Report on the main barriers and action drivers for RECs' diffusion. The Report have found some cross-cutting barriers, that are general barriers that affect every RECs. Then, the Report have identified specific barriers for each of the RECs' activities, that are production, sharing, and supply[65].

Among the cross-cutting barriers, the complexity of "designing and monitoring a clear and uniform legal definition for energy communities" is considered a major obstacle. Indeed, the principles at the European level lack of the needed precision, while at the member states level a precise legislation might still miss and Citizen Energy Community -open to all type of actors- (CEC) and REC are not properly distinguished. This context hampers the private investments as the market is still waiting precise rules[66].

Another cross-cutting barrier is the lack of awareness and access to technical expertise. The lack of knowledge consists in the scarce availability of public information on what are the RECs, how to create an energy community and where it is possible to obtain technical and financial support. Moreover, even with well-defined definitions, it could be difficult for citizens to interpret correctly and comply with the regulation and may need an external aid in, for instance, establishing a legal entity and in dealing with bureaucracy[67].

The Report continues analysing activity-specific barriers. Regarding the energy supply, one major obstacle is the lack of sites for production. RECs generally start from a disadvantaged position compared to large commercial actors that, thanks to their market position, can easily obtain the necessary

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[64] Ibidem.

[65] "BARRIERS AND ACTION DRIVERS FOR THE DEVELOPMENT OF DIFFERENT ACTIVITIES BY RENEWABLE AND CITIZEN ENERGY COMMUNITIES."

[66] Ibidem.

[67] Ibidem.

land/surface (being able to offer higher amount of money). For this reason and for the competitiveness of PV systems, RECs often realize their projects using the available roofs' space[68].

The Report then analyse the barriers to sharing the energy produced, and again the main obstacle is represented by the regulation. In particular there is an insufficient distinction between RECs (as an organizational concept) and other forms of self-consumption. In general, establishing a REC is more complex than establishing an energy sharing activity. Since there is no clear distinction in rights and duties between the two, it results in a lack of incentives to create RECs[69].

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[68] Ibidem.

[69] BARRIERS AND ACTION DRIVERS FOR THE DEVELOPMENT OF DIFFERENT ACTIVITIES BY RENEWABLE AND CITIZEN ENERGY COMMUNITIES."

3 Methodology

This chapter provide the information on how each relevant phase of this thesis was conducted. These phases are:

- Literature review;
- EO system modelling;
- Quantitative research (survey);
- Qualitative research (interviews).

3.1 Literature review

A literature review was conducted in order to assess the available technology needed for the EO system realization, to verify whether similar systems were already realized and how, to assess the potential impact of PV plants on soil consumption and degradation and what are, as of today, the main barriers to RECs' diffusion.

During the literature review, different types of sources were considered: high-quality sources as article published in peer-reviewed journals; technical documents as report from different agencies and the European Commission; user guidances as the ones for Copernicus Browser and ArcGIS; European Directives and National decrees; Companies website to deepen the analysis of the case studies.

3.2 EO system modelling

Realising a realistic and feasible model of an EO system able to analyse and map, over a certain area, which are the most suitable roofs for the PV installation, required an analysis throughout almost every phase of the research. Indeed, through the literature review the available technology able to provide the required result were assessed, providing, in some cases, different alternatives. Then, examining the case studies, the most used and suitable technologies were identified. Finally, through the interview with SunSPOT team and the materials provided by Dr. Licciardi and Professor Coletta, the selected technology was confirmed.

3.3 Quantitative research (Survey)

Quantitative research was then conducted among an Italian population' sample to assess whether the final consumer may be interested in participating into a REC; whether they have or not a surface (roof) to install PV panels; whether they would be interested in using an interactive map showing the most suitable roofs; and whether they would use consultancy service that facilitate the creation of a REC and the PV plant location. To conduct the research an online survey was employed. The survey was structured as follow:

1. **Question**: Indicate the age class; **Possible Answers**: 20 or less; 21-30, 31-40, 41-50, 51-60, 61-70, 70 or more;
2. **Q:** Express the willingness to install PV panels on their own home **PA:** Yes, No, Yes but I have no available surface/no owned home, I have already installed PV panels. The respondents who answered "no" are redirected to the question at **point 3**, the ones responding "I have already installed PV panels" are redirected to the question at **point 4**, the others to the question at **point 5**;
3. **Q:** In case it was expressed no interest in installing PV systems it is asked to specify the reason. **PA:** PV systems are too expensive, the procedure to obtain the authorization and organise the installation are too time-consuming, PV is not a reliable technology/it is not a good investment, other reasons that the respondent can specify. In the case of answering "PV is not a reliable technology/it is not a good investment" the survey ends, otherwise the respondent is redirected at the question at **point 5**;
4. **Q:** In the case the respondent has answered that they have already installed PV panels on their roof, it is asked whether they would be interested, also from a forward-looking perspective, in participating in a

form of collective self-consumption, including a brief explanation of what a collective self-consumption is. **PA:** Yes (it is redirected to question at point 5), No (the survey ends);

5. **Q:** Express the willingness to participate in a REC, including a brief explanation of what a REC is and what economic incentives are provided. **PA:** Yes (question at **point 6**), No (the survey ends), Yes but they think that bureaucracy and regulations are too complicated (question at **point 6**);
6. **Q:** Express the willingness to use an interactive map (freely accessible) that shows the most suitable roofs for PV installation while creating the REC. **PA:** Yes, No. Both answers continue to question at **point 7**;
7. **Q:** If the interactive map of point 6 is not available, express the interest in using a consultancy service that helps in the bureaucracy, in finding new participants and in assessing the suitable surfaces for PV installations. **PA:** Yes, Yes only if the cost of such a service represent up to the 5% of the total cost, No.

3.4 Qualitative research (Interviews)

Qualitative research was conducted among experts of different fields in the sector to assess, from their perspective, the feasibility of the system and its potential impact.

The first interview is an open interview with an energy local aggregator and facilitator. A Local Energy Aggregator is an operator of the electricity market that group into a single virtual unit different units of production and consumption, coordinating them in an optimal way[70]. A facilitator, instead, is a figure that share information, expand the number of potential members and facilitate the balance between different interests. The interviewed aggregator/facilitator is E6 Energia, that operates in Sicily. The interview aimed

[70] Lucibello, "Aggregatore.", ENEA

at assessing the main obstacles that citizens encounter while establishing a REC and whether a EO system to map the most suitable roofs could be useful in the role of facilitator/aggregator.

The second interview is a semi-structured interview conducted with the SunSPOT's Research, Data Processing, Analytics and Technical Support team. The main aim of the interview is to verify the suitability and precision of the chosen technology and to investigate its impact on PV diffusion.

Finally, Dr Giorgio Licciardi, technologist at the Italian Space Agency (ASI), and Professor Alessandro Coletta, Cosmo-SkyMed dual radar system mission director for Earth Observation at ASI, were contacted to verify the chosen technology soundness. Licciardi and Coletta provided detailed materials to assess whether the individuated technology is appropriate for the purpose.

4 Results

This section presents the results of the research. In particular, the model of the EO system, the survey and the interviews outcomes are reported.

4.1 System model

After having analysed the available scientific literature and four different case studies, the following are the technology and data employed in the theoretical realization of a system able to detect the *best* roofs for PV installation. The system focuses on the Italian territory.

The first data needed are the ones to assess the altimetry. These data are retrieved from the *Official portal for European data*, where a dataset with 1 metre resolution for each Italian region is available.

Using GIS software as ArcGIS it is possible to retrieve, from LIDaR data, the slope, the orientation and the shadowing effect, as shown in the Literature review.

After having retrieved this information, it is possible to add different layer and overlap them. In order to identify the roofs from other types of surfaces the Carta Tecnica Regionale is used. This type of maps is issued by the local governments and represent the objects in the territory with their real shape and position (therefore the building footprint is represented with no approximations). Figure 10 shows a detail of the Rome's Carta Tecnica Regionale[71]. The different colours identify different types of buildings; a potential source of additional information. For instance, the buildings coloured in red/orange are residential building while the ones coloured in ochre are buildings of public interest[72].

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71 "GeoRoma."

72 "Informazioni Geodetiche e Fotogrammetriche."

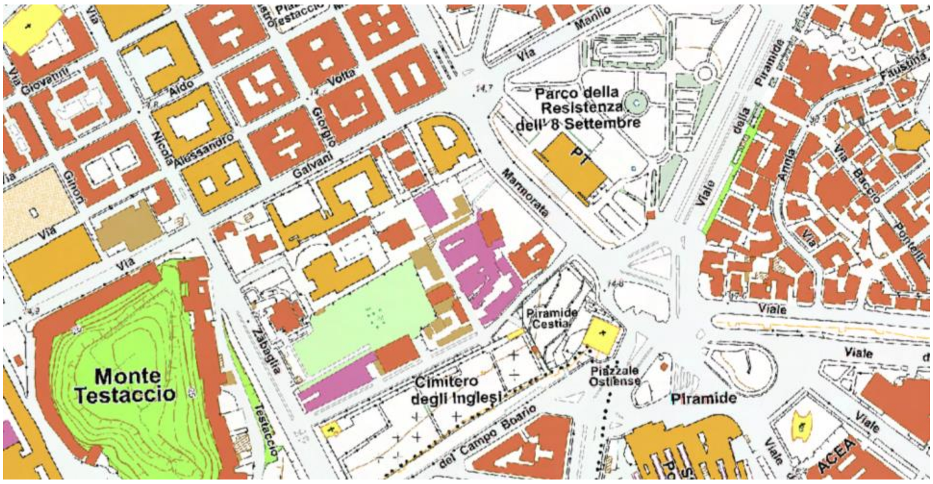

Figure 10, detail of Rome's Carta Tecnica Regionale. Source: Georoma.

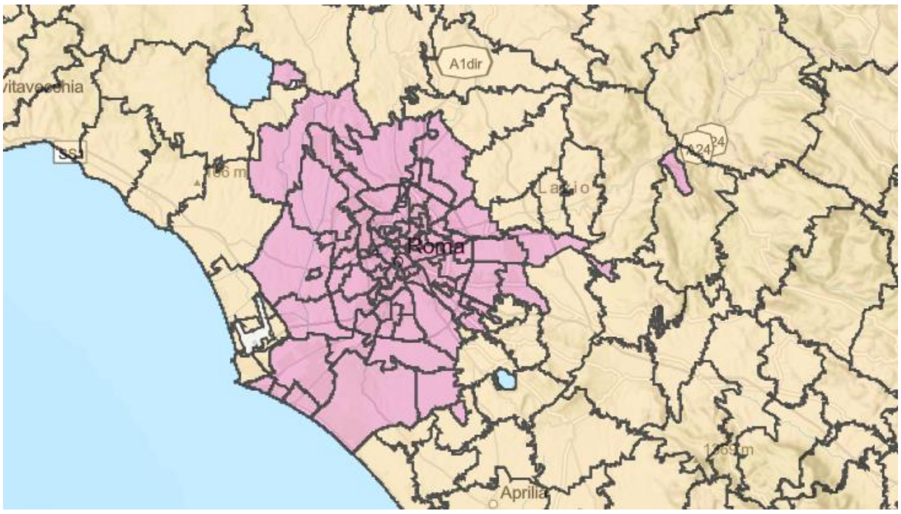

Figure 11, Map of the electrical substations of Rome and surroundings. Source: GSE.

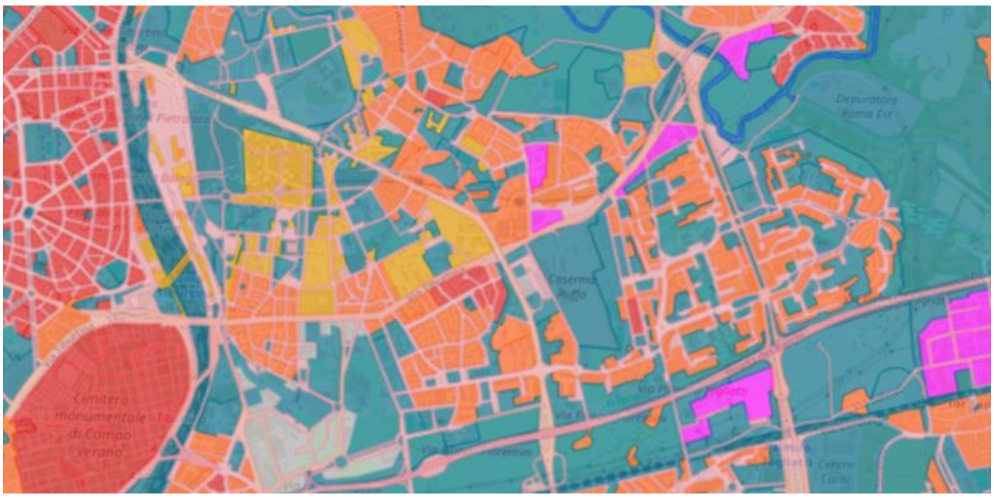

Figure 12, Detail of Rome's masterplan. Source: Geoportale Cartografico di Roma Capitale.

Another layer that can be added is the Cabine primarie's map (electrical substation's map) shown in Figure 11. As REC's can host members within the same electrical substation, it is fundamental to import this geographical limitation while assessing the roofs. In this way it will be possible to compare only the roofs that belong to the same REC.

Finally, an additional layer can be added: the city masterplan (Figure 12). Masterplans report in different colours different zones of the city. Each colour represents a specific type of area (e.g. historical centre, residential area…) with the relative regulation. Each city may have limitations to the installation of PV panels due to, inter alia, artistic restrictions. therefore, it may be useful to integrate this information to exclude from the analysis the roofs on which it is not possible to install PV panels.

All the needed information is at this point available to be analysed and processed. Based on the case studies analysis, this is the algorithm workflow:

- Firstly, it keeps only the portion of the map recognised as a roof;
- Secondly, it eliminates non-suitable roofs. Flat roofs are kept, roofs with an inclination up to 60° and an orientation towards east-southeast-south-southwest-west are kept as well. Sloped roofs faced to north or with an inclination higher than 60° are eliminated;
- Thirdly, it assesses the shadowing effect through the Hillshade tool. Hillshade allows to evaluate the shadowing effect, calculated according to the sun relative position. According to the methodology adopted by APVI and UNSW, the system keeps the roofs that receive, on average, at least 4.9hours of light per day in a year. The remaining roofs are provided with a shadowing coefficient based on the hours of light they receive;
- Fourthly, the solar radiation is measured for each roof. This analysis is conducted through radiation model based on GIS (as the ArcGIS Raster Solar Radiation). Roofs are ranked for their total solar radiation (based on kWh/m^2 and total available surface);

– Finally, the solar radiation is multiplied by the shadowing effect and shows the solar potential for each roof.

4.2 Survey

The survey was conducted among the Italian population to investigate the consumer sentiment about the PV technology, the RECs, the roof mapping tool and to the involvement of a third party that could facilitate RECS' creation.

285 people took part to the survey. Of them, 52.9% of the respondent have between 31 and 60 years old, the main target of the survey (since this is the range of ages in which a person is more likely to face decisions as whether to install PV or to take part to a REC).

Of the 285 respondents, the 64.5% declare that they are interested in installing PV panels, among these respondents, the 35.4% (101 out of 285) states that, even if they are interested in PV installation, they have no suitable surfaces for it. The 23.5% declare to have already installed PV panels on their roofs and the 12% are not interested in PV installations (Figure 13).

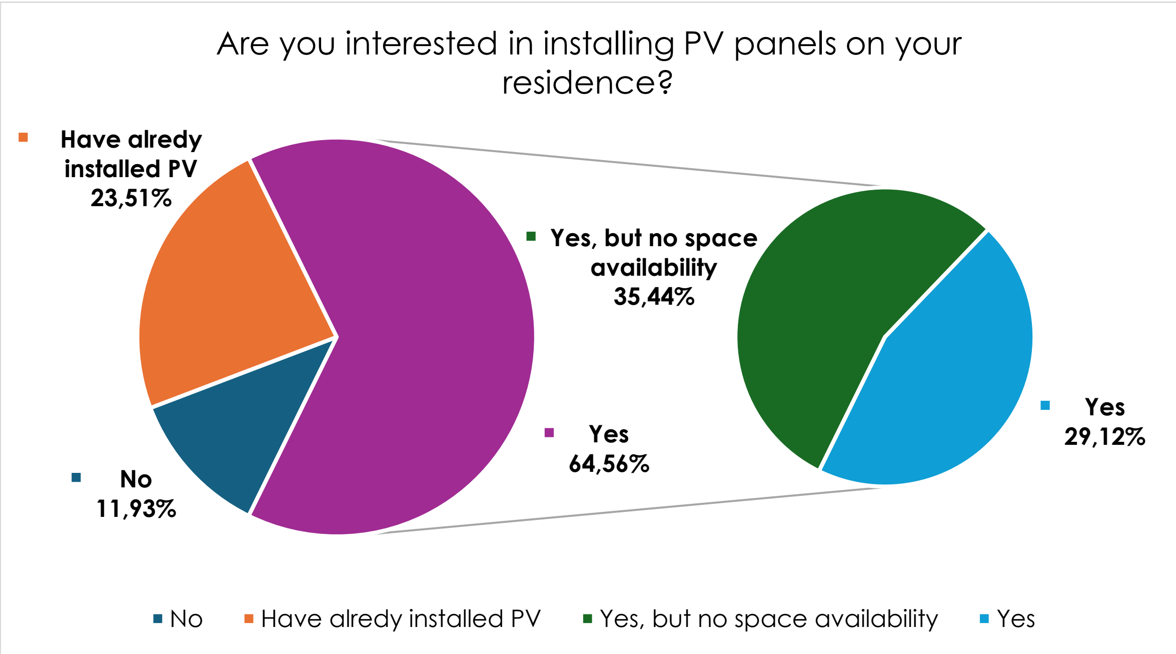

Figure 13, percentage of respondents interested in PV installation

The respondent (268) who were interested in PV installation, those who already installed PV panels and those who are not interested in PV installation for other reasons except for ", PV is not a reliable technology/it is not a good investment" were asked if they would be interested in participating in a REC. In this case, the 45.9% (123) declared that yes, they are interested, the 29.5% (79) answered that they would be interested but it seems the bureaucracy behind is too complicated and finally the 24.6% (66) answered that they are not interested in taking part into a REC.

Among those who declared to be interested (202 including also who consider bureaucracy too complicated), it was asked whether, during the creation of a REC they would use a system to detect the most suitable roof to install the PV system. The 96% (194) of the respondent answered that they would use such a system.

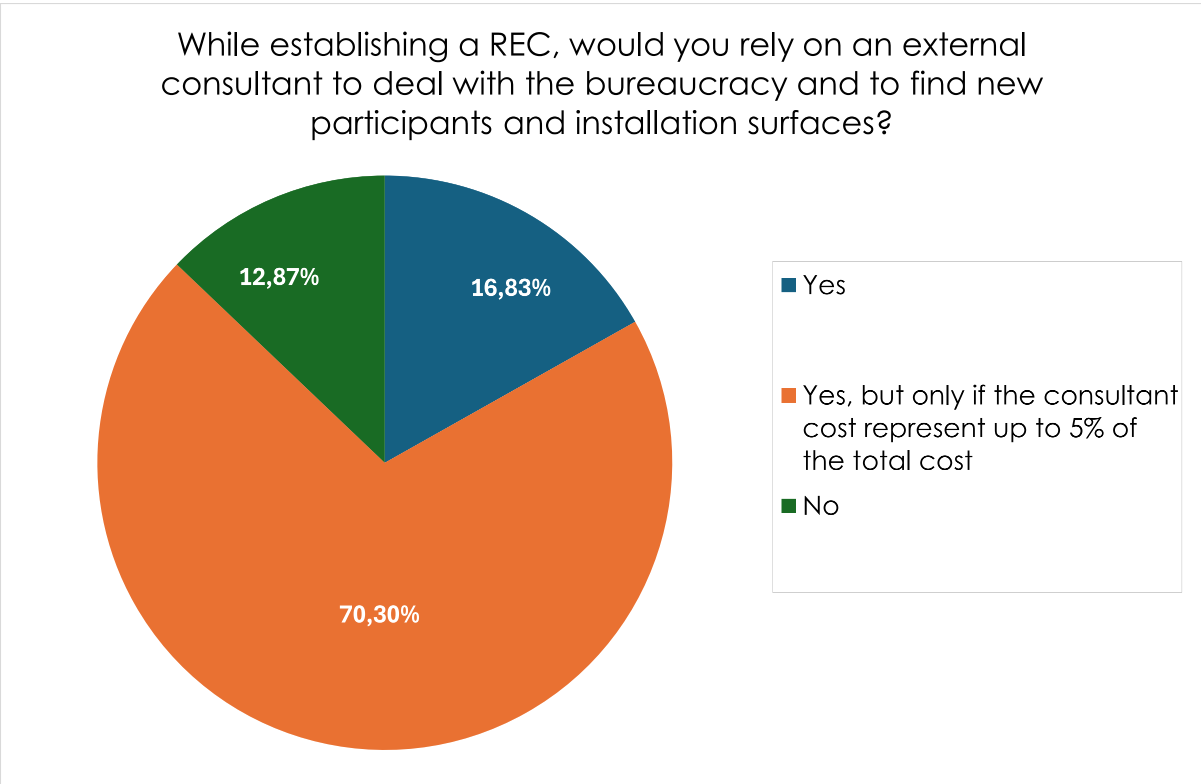

Figure 14, consumer sentiment about the involvement of an external consultant.

Finally, the respondents (202) were asked if they would rely on an external consultant in the REC's creation to deal with the bureaucracy and to find other participants and surfaces for the PV installation. 16.8% (34) answered yes, 12.9% (26) answered no, and 70.3% (142) answered that they would rely on an external consultant only if their cost is up to 5% the total cost of the REC's realization.

4.3 Interviews

4.3.1 Local energy aggregator

The interview was conducted with Dr. Gaetano Galipò, energy manager and owner of E6 Energia, an energy community developer in Sicily. E6 Energia developed "Calamita" a web platform that allows consumers and producers/prosumers to express their willingness to participate in a REC and thus to facilitate the creation of RECs.

Question: What are the main obstacles that the potential members encounter in the creation of a REC?

Answer: There are a couple of barriers. As of today, the GSE website (the Italian DSO) presents some errors that hamper the REC's registration process. Besides these technical difficulties, one major issue is the virtual regulation model that provides no instantaneous benefits to the final costumer (consumer). Indeed, since virtually consuming the energy produced by the REC means to take the energy from the public grid, a consumer will not save on their energy bill, as they have to pay also for the REC's energy they have virtually consumed. In a second time the GSE will pay back to the consumer the owed incentive. The prosumer, instead, have instant benefits as they consume directly the energy they produce and therefore they do not take it from the public grid. Prosumers also receive afterward incentives. With a physical regulation model both the consumer and the prosumer would have instant benefits as they would physically share the energy (through a private grid) and therefore also the consumer will save on the energy bill. Another barrier related to the virtual regulation model is the investment's risk. The investor that realized the RES aims to reach the break-even point as soon as possible and to have a return on the investment but, on the other hand, the consumer needs to have adequate benefits to participate to a REC. Since the virtual model reduce the consumer's benefits to the incentive provided by the GSE, this balance is not always granted.

Q: What could be, according to your experience, the impact of a system that shows the most suitable roofs for PV installation on the diffusion of RECs?

A: This type of system, in the context of small surfaces and private citizens as member of the REC, would probably have no great effects, as the role of the energy aggregator already comprehend a feasibility study that assesses also the roof's solar potential. Such a system could instead be useful in assessing larger roofs with a minimum 300m^2' surface. In this case, the tool could be used to map surfaces that may attract external investors as Energy Service Companies (E.S.Co.) that could be interested in having the concession over that surface to realize a PV plant and a consequent REC. Moreover, the tool could be used with even more results in assessing lands -and not only roofs. According to the decree "Aree idonee 21/06/2024", every Italian region, given the limitation imposed by the "Decreto Agricoltura", has to identify and report the suitable lands for RES installation. Therefore, the tool could be used to assess those areas and to guide E.S.Cos in the design of new PV projects.

4.3.2 SunSPOT

The interview was conducted with Dr. Mike Roberts, Senior Research Fellow in the School of Photovoltaic and Renewable Energy Engineering (SPREE) at UNSW, and with Dr. Ellie Kallmier, Research assistant at the School of Photovoltaic and Renewable Energy Engineering (SPREE) at UNSW; both members of the SunSPOT's Research, Data Processing, Analytics and Technical Support team. SunSPOT is a tool available both in a free and in a premium version that allows citizens to evaluate their roof' solar potential, to estimate the energy production and consequent savings. The premium version requires the subscription from the council (local government) and it is based on LIDaR data. The free version is available on the whole Australian territory and requires the user to input some data as the roof's slope (this version is not based on LIDaR data).

Q: SunSPOT uses LIDaR data to retrieve the roofs' slope and the shadowing effect from the surrounding structures. Is there any evidence about the precision in calculating the roof' solar potential?

A: There are a number of issues that can cause inaccuracies. Regarding the LIDaR data, if the dataset used is quite old the surface evaluated may have changed with new or renovated buildings and new structures. In this case the tool evaluates roofs that could no longer exist or that were modified or that present a different shading impact. Another aspect that may hamper the result is the alignment LIDaR data and aerial imagery. When the two images are not perfectly aligned the roofs, border may be not as accurate as they could, for instance including a little portion of ground in the roof perimeter. Anyway, the validation results for 2023 show that the error between the calculated annual yield (solar power) and the actual yield is between 6-10%, indicating a good level of accuracy, considering also that the forecasted results are based on typical meteorological year.

Q: SunSPOT provides also data to the subscribed councils. Which type of data does SunSPOT provides? Is there any evidence of the SunSPOT impact in PV diffusion?

A: SunSPOT provides Councils with a wide range of information. The main information are about the number of rooftop solar installations in their area, the average production of these systems and an estimation of their financial impact, about the SunSPOT usage by the costumer in the area, and the residential PV density (proportion of houses with PV). Anyway, even if there is data about PV density in each Council, there are too many factors that may influence the PV diffusion to draw any conclusion of causality between

SunSPOT usage and PV diffusion. However, there are data about SunSPOT usage among the population. For instance, in the Byron Council, that have 32.378 inhabitants, from January 2022 to September 2024, 305 solar potential analysis were mad through SunSPOT.

5 Discussion

The present chapter analyses the results obtained in the light of whether automatically mapping the suitable roofs and their solar potential over a certain area could impact the RECs diffusion.

Through the literature review the main aspects of the topic were assessed.
Firstly, the feasibility of the EO system -able to identify roofs and evaluate their solar potential and their suitability for PV installations- was evaluated. The technology needed was identified and analysed and the results were consolidated through the analysis of four case studies. The analysis shows that the EO system is feasible and that the necessary data, for instance LIDaR data with 1 metre resolution, are publicly available.
Secondly, the potential impact of PV plants diffusion over green lands was assessed to justify the choice of focusing on grey surfaces. As shown in the literature analysed the installation of PV plants over green surfaces have a relevant impact both in terms of soil degradation and of soil consumption.
Finally, the available literature was examined to identify the main barriers to the RECs' diffusion. The main findings were that the major obstacle to RECs' diffusion is the complexity and the lack of clarity of regulations. Other barriers found in the literature were: the mistrust in the technology and in RECs, the availability of fundings and the surface's availability for PV installations. Among these barriers, the system here theorised could impact mainly on the surface's availability, as it can be used to assess and find different locations.

The quantitative analysis showed some relevant data about the consumer's interest in solar power and RECs, the surface availability and about the possibility to involve an external professional figure in the realization of RECs. The survey results show that there is a significant interest in PV technology, as the 88% of the respondents declared to be interested in installing PV panels on their roofs or that they have already installed them.

Also, an important portion of the respondent (35.4%) declared that they would install PV panels but that they do not possess any suitable surface; highlighting how the lack of surface is an obstacle to solar power diffusion.
The survey shows both a significant interest in RECs as 45.9% of the respondent would take part in a REC and confirm that one major obstacle to RECs' diffusion is represented by the regulation's complexity, as the 29.5% would be take part but consider the bureaucracy too complicated. The total of potentially interested respondent is 75.4%.
Subsequently, the respondents were asked whether they would use a tool that shows on a map the solar potential of every roof, in order to carefully choose the best location for the RES' installation. In this case the vast majority of the respondent, 96%, answered that they would rely on a similar tool. This data proves that the theme of efficiency in energy production is considered a fundamental aspect among consumers.
The last question evaluated whether the respondents are willing to rely on an external professional figure to comply with the bureaucracy, to look for other participants and for the best surfaces for the RES installation. In this case, the main outcome is that the majority of consumers (70.3%) would rely on such a figure only if the costs does not weight for more than 5% of the total cost. This result confirms the perceived regulation complexity and the willingness to find an efficient location for RES installation, but with some constraints regarding the cost.

The interview with SunSPOT's Research, Data Processing, Analytics and Technical Support team confirmed that the technology chosen is adequate and that the system has a satisfying precision, however it could not prove an impact of this type of tool on the diffusion of PV plants.

The interview with the Local Energy aggregator highlighted another obstacle to RECs diffusion: the virtual regulation model chosen in Italy. With this regulation model, indeed, the consumer of a REC will receive no instant benefits, but only an ex-post incentive from the GSE, reducing the attractiveness of RECs towards potential consumers. This aspect hampers -in

the context of domestic roofs- the use of the tool analysed in this thesis. A direct consequence of the virtual regulation model is that it is not convenient for the members of a REC to invest collectively in a single PV plant to be installed over a single roof, since the benefits would not be the same for each participant (only one member would have the instant benefit of not paying the energy consumed from the RES, the others would receive the ex-post incentive).
According to the Local Energy Aggregator, the EO tool could still be useful in identifying larger surfaces and in involving E.S.Co.'s. Attract E.S.Co.'s in the realization of RECs would channel new capitals in the sector, facilitating its expansion.

However, to facilitate RECs' diffusion within the urban environment, further research is needed. Specifically, it should focus on assessing whether it is possible to realize a hybrid regulation model that would allow the participants to use the public grid (virtual model) but that would not count the self-consumed energy in the energy bill (physical model). Such a model would hence allow participants to invest collectively in the RES, and therefore to share the costs, receive equal and higher benefits, increase the RES productivity, and facie the issue of surface availability (observed both in the literature review and in the quantitative research). If this model were realised, both potential members and facilitators/aggregators could effectively use the EO system to identify the best locations to install the PV plants.

The following table (Table 2) the research's results are summarized.

Research Method	Technology	Barriers to RECs' diffusion	Consumer sentiment towards PV and RECs	EO tool Potential impact
Literature review	Identified the possible technology for the EO system	Regulation complexity, fundings, space availability	/	/
Survey	/	Space availability, (35% would install PV but do not have a suitable surface)	Large interest in PV (88%) and in RECs (75%)	Vast majority would use the EO tool (96%); 70% would rely on an external figure if the cost is limited
Interviews	SunSPOT's team and professionals from ASI confirmed the selected technology	The Local Energy Aggregator highlighted the obstacle of the virtual regulation model	/	The Local Energy Aggregator individuated larger surfaces and the involvement of E.S.Co.s as the main field in which the tool can have a positive impact as of today

Table 2, results' summary.

6 Conclusion

The present thesis aimed to investigate whether an EO tool able to automatically map the most suitable roofs for PV installation could positively impact the RECs' diffusion within the urban environment.

Initially, the relevant technology needed for the described tool were identified through the literature review. The analysis found LIDaR to be the most suitable technology for the purpose. Alongside LIDaR, other sources of information are needed, as the cities' masterplans and the Regional Technical Map. The cases study analysis and the interview with SunSPOT team confirmed this configuration.

Subsequently, the main barriers to RECs' diffusion were analysed to verify whether such a system could impact on one or more of them. Among the individuated barriers, the most relevant for this purpose were the regulation complexity and the lack of installation surfaces.

The current regulation not only is an obstacle to the RECs' diffusion itself, but it also hampers the full potential of the EO tool. Indeed, by impeding members of a REC to directly consume the energy produced by a single RES, the regulation (virtual model) indirectly makes unfeasible a collective investment for the realization of a single RES. A collective investment would allow the members willing to invest but without a suitable surface (35.4% according to the survey) to contribute to the realization of a PV plant while receiving direct benefits (no self-consumed energy in the bill). Moreover, it could decrease the cost (just one or few installation) and increase the productivity (installations on the most suitable surfaces).

With the current regulation, instead, the participants who are interested in direct (and higher) benefits are forced to install the PV plant over their own roofs, splitting the installations and indirectly preventing those who have no suitable surfaces to invest in PV technology (not enough payback with the current incentives).

However, even if as of today this type o system may not have a deep impact on RECs' creation in urban environments, it may be impactful in fostering new RECs in industrial (larger grey surfaces) and in green environments. Indeed, when it is possible to realize larger RES, also E.S.Cos. may be interested in participating in the REC as a form of investment. A tool that identifies the most suitable (large) surfaces for PV installation could be efficiently used by an intermediary/facilitator in involving large investor as E.S.Cos. and in turn in fostering RECS.

Bibliography

Adeh, Elnaz H., Stephen P. Good, M. Calaf, and Chad W. Higgins. "Solar PV Power Potential is Greatest Over Croplands." Scientific Reports 9, no. 1 (August 7, 2019). https://doi.org/10.1038/s41598-019-47803-3.

Andrieux, François , "Predicting the Solar Potential of Rooftops using Image Segmentation and Structured Data," Medium, April 14, 2020, accessed September 4, 2024, https://medium.com/nam-r/predicting-the-solar-potential-of-rooftops-using-image-segmentation-and-structured-data-61198c39d57c.

Aquili, Alberica," Diritto e Società, vol. III serie-4/2022 "Comunità energetiche: l'evoluzione del quadro regolatorio europeo e italiano, 799–828.

ArcGIS Pro "Hillshade function | Documentation," n.d., https://pro.arcgis.com/en/pro-app/latest/help/analysis/raster-functions/hillshade-function.htm#:~:text=The%20Hillshade%20function%20produces%20a,aspect%20of%20the%20elevation%20surface.

ArcGIS Pro, "Hillshade (Spatial Analyst) | Documentation," https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/hillshade.htm.

ArcGIS Pro, "Slope function, Documentation," n.d., https://pro.arcgis.com/en/pro-app/latest/help/analysis/raster-functions/slope-function.htm.

Baker, Roe and Nicholls, Tom, "Mapping Potential Roof Spaces Suitable for Solar Power Generation in Halton With Aughton," Cumbria Action for Sustainability, 2021.

Boccalatte, Alessia, Dipartimento Di Ingegneria Meccanica Energetica Gestionale E Dei Trasporti and Non Assegn, "Analysis of Solar Energy Power Generation in Urban Environments," Hdl.Handle.Net, November 14, 2023, https://doi.org/10.15167/boccalatte-alessia_phd2023-11-14.

Cafs, "Cumbria's climate change and sustainability charity," CAfS, September 3, 2024, https://cafs.org.uk/.

Castagno, Jeremy and Atkins, Ella, "Roof Shape Classification from LIDaR and Satellite Image Data Fusion Using Supervised Learning," Sensors 18, no. 11 (November 15, 2018): 3960, https://doi.org/10.3390/s18113960.

Copernicus Browser. "Copernicus Browser," n.d. https://browser.dataspace.copernicus.eu/?zoom=5&lat=50.16282&lng=20.78613&themeId=DEFAULT-THEME&visualizationUrl=U2FsdGVkX192EHV3gywPkZ%2B3py0j8aarb2UtNJ7kb4Dh74vtFQz2S0ZAjyl%2FxysUxEamzi3d8lMcDGneLOwFJFOqaTdsTdJiHkQXkyOnr%2F1MAwe4VBlai1rwezD7dtr8&datasetId=S2_L2A_CDAS&demSource3D=%22MAPZEN%22&cloudCoverage=30&dateMode=SINGLE.

Copernicus Data Space Ecosystem. "Copernicus DEM - Global and European Digital Elevation Model.", August 6, 2024. https://dataspace.copernicus.eu/explore-data/data-collections/copernicus-contributing-missions/collections-description/COP-DEM#:~:text=Digital%20Surface%20Model%20(DSM)%20provided,INSPIRE%2C%20DGED%2C%20DTED).

Copernicus, "Copernicus: 2023 is the hottest year on record, with global temperatures close to the 1.5°C limit" https://climate.copernicus.eu/copernicus-2023-hottest-year-record.

Copper, Jessie, Roberts, Mike, and Bruce, Anna, "Spatial Analysis of Solar Potential in Sydney," Australian PV Institute, 2017, https://apvi.org.au/wp-content/uploads/2017/05/CMC_SydneySolarPotential_Final_reduced.pdf.

Di Stefano, Francesco et al., "Mobile 3D scan LIDaR: a literature review," Geomatics Natural Hazards and Risk 12, no. 1 (January 1, 2021): 2387–2429, https://doi.org/10.1080/19475705.2021.1964617.

Dioba, Albina et al., "Identifying key barriers to joining an energy community using AHP," Energy 299 (July 1, 2024): 131478, https://doi.org/10.1016/j.energy.2024.131478.

El Hammoumi, Aboubakr et al., "Solar PV energy: From material to use, and the most commonly used techniques to maximize the power output of PV systems: A focus on solar trackers and floating solar panels," Energy Reports 8 (November 1, 2022): 11992–10, https://doi.org/10.1016/j.egyr.2022.09.054.

ENERGY COMMUNITIES REPOSITORY | European Commission Directorate-General for Energy, "BARRIERS AND ACTION DRIVERS FOR THE DEVELOPMENT OF DIFFERENT ACTIVITIES BY RENEWABLE AND CITIZEN ENERGY COMMUNITIES," January 24, 2024, accessed September 6, 2024.

EU Science Hub. "PVGIS data sources & calculation methods," n.d. https://joint-research-centre.ec.europa.eu/photovoltaic-geographical-information-system-pvgis/getting-started-pvgis/pvgis-data-sources-calculation-methods_en#ref-3-calculation-of-solar-radiation-on-inclined-planes.

European Commission, "The European Green Deal," European Commission - December 11, 2019, accessed August 20, 2024, https://ec.europa.eu/commission/presscorner/detail/en/ip_19_6691.

European Commission, Clean energy for all Europeans (Publications Office of the European Union, 2019), https://doi.org/10.2833/21366.

European Commission, Energy. "In focus: Energy communities to transform the EU's energy system," December 13, 2022. Accessed August 22, 2024. https://energy.ec.europa.eu/news/focus-energy-communities-transform-eus-energy-system-2022-12-13_en.

Florida Atlantic University. "Climate Science Investigations South Florida - Angle of Solar Radiation and Temperature," April 3, 2023. Accessed August 29, 2024. https://www.ces.fau.edu/nasa/module-3/why-does-temperature-vary/angle-of-the-sun.php.

Gazzetta Ufficiale, "Decreto Milleproroghe 162/2019, art 42bis," December 30, 2019, accessed August 25, 2024, https://www.gazzettaufficiale.it/eli/id/2020/02/29/20A01353/sg#.

GeoRoma, n.d., https://geoportale.comune.roma.it/georoma/#/viewer/4224.

GSE, "ENERGIA E CLIMA IN ITALIA - Rapporto Periodico - Primo semestre 2023" February 12, 2024, accessed August 30, 2024.

GSE, “Le Comunità Energetiche Rinnovabili ‘In Pillole.’” Accessed August 30, 2024. https://www.gse.it/servizi-per-te/autoconsumo/le-comunita-energetiche-rinnovabili-in-pillole.

GSE, “Ritiro dedicato,” https://www.gse.it/servizi-per-te/fotovoltaico/ritiro-dedicato.

International Monetary Fund Climate Change Dashboard, “Climate Change Data”, https://climatedata.imf.org/pages/climatechange-data.

Kakoulaki, Georgia, Martinez, Ana, and Florio, Pietro, “Non-commercial Light Detection and Ranging (LIDaR) data in Europe,” Publications Office of the European Union (Publications Office of the European Union, 2021), https://doi.org/10.2760/212427.

Libretto Dei Simboli, “Informazioni geodetiche e fotogrammetriche,” (Regione Lazio).

Lucibello, Serena, “Aggregatore,” ENEA - Dipartimento Unità per L’efficienza Energetica, n.d., https://www.efficienzaenergetica.enea.it/glossario-efficienza-energetica/lettera-a/aggregatore.html#:~:text=In%20ambito%20energetico%2C%20si%20parla,Unit%C3%A0%20virtuali%20di%20aggregazione%20miste).

MASAF, “Decreto Agricoltura (DECRETO-LEGGE 15 maggio 2024, n. 63),” May 15, 2024, accessed September 2, 2024.

Ministero dell’Ambiente e della Sicurezza Energetica, “Decreto Mase n. 414 del 7.12.2023” December 7, 2023, accessed August 26, 2024.

Ministero Dell’Ambiente E Della Sicurezza Energetica, “Geoportale Nazionale”, accessed September 1, 2024, http://www.pcn.minambiente.it/viewer/.

Moscatelli, Maria Cristina et al., “Soil properties changes after seven years of ground mounted photovoltaic panels in Central Italy coastal area,” Geoderma Regional 29 (June 1, 2022): e00500, https://doi.org/10.1016/j.geodrs.2022.e00500.

National Oceanic and Atmospheric Administration. "What is LIDaR?" Accessed September 1, 2024. https://oceanservice.noaa.gov/facts/LIDaR.html.

Official Journal of the European Union, "DIRECTIVE RED II (EU) 2018/2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the promotion of the use of energy from renewable sources (recast)", December 21, 2018, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001.

Ordnance Survey "Great Britain's national mapping service," Ordnance Survey, n.d., https://www.ordnancesurvey.co.uk/.

PDOK, "Introductie - PDOK," , https://www.pdok.nl/introductie/-/article/actueel-hoogtebestand-nederland-ahn.

Sandulli, Maria Alessandra et al., Diritto e Società, vol. III serie-4/2022

Sentinel Hub, "Urban Areas Script," accessed September 2, 2024, https://custom-scripts.sentinel-hub.com/sentinel-1/urban_areas/.

Slootweg, Mike et al., "Identifying the geographical potential of rooftop systems: Space competition and synergy," Urban Forestry & Urban Greening 79 (January 1, 2023): 127816, https://doi.org/10.1016/j.ufug.2022.127816.

SunSPOT, "Solar and Battery Calculator for Councils | Solar Savings | ," Sunspot Website, June 28, 2024, https://www.sunspot.org.au/solar-calculator-for-councils/#dashboard.

Tahir, Z.R., and Muhammad Asim. "Surface measured solar radiation data and solar energy resource assessment of Pakistan: A review." Renewable and Sustainable Energy Reviews 81 (January 1, 2018): 2839–61. https://doi.org/10.1016/j.rser.2017.06.090.

U.S. Geological Survey, "What is a geographic information system (GIS)?," November 18, 2004, https://www.usgs.gov/faqs/what-geographic-information-system-gis.

Usoltsev, Alexander , "Deep Learning for Roof Detection in Aerial Images in 3 minutes," Medium, April 9, 2019, accessed September 4, 2024, https://medium.com/nam-r/deep-learning-for-roof-detection-in-aerial-images-in-3-minutes-8d845f6d7f25.

Van De Ven, Dirk Jan et al., "The potential land requirements and related land use change emissions of solar energy," Scientific Reports 11, no. 1 (February 3, 2021), https://doi.org/10.1038/s41598-021-82042-5.

Yan, Wai Yeung , Ahmed Shaker, and Nagwa El-Ashmawy, "Urban land cover classification using airborne LIDaR data: A review," Remote Sensing of Environment 158 (March 1, 2015): 295–310, https://doi.org/10.1016/j.rse.2014.11.001.

Yang, Xuebo et al., "Application and Validation of a Model for Terrain Slope Estimation Using Space-Borne LIDaR Waveform Data," Remote Sensing 10, no. 11 (October 26, 2018): 1691, https://doi.org/10.3390/rs10111691.