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APERTURE

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a cura di Carmen Giannino

PODCAST BIENNALE ECTP-CEU

NUOVE TECNOLOGIE E INTELLIGENZA ARTIFICIALE. SFIDE PER LA PIANIFICAZIONE

a cura di Adriano Bisello e Michele Grimaldi

Post carbon cities: A geospatial assessment for the solar potential of Turin

Hashem Alsibai

With rapid changes in sustainable development and incentives from the European Union, the energy sector, governments, and private companies were encouraged to use solar-powered sources in urban areas. Analysis using satellite-derived images has given some values for solar irradiance but images alone are not sufficient for long-term solutions. To achieve more accurate results, the work combines satellite images with modeling solutions. This paper presents findings from a regional to a city-scale analysis, exploring the energy potential of Torino.

Introduction

The United Nations and the World Bank predict an increase in the percentage of the world population living in urban areas in the 21st century (Angel *et al.* 2005). This change is anticipated due to the rise in the number of cities, migration from rural to urban areas, and transformation of some rural settlements into urban areas (UN-DESA 2019). Recently, making "cities and human settlements climate resilient and sustainable" has been highlighted as one of the sustainable development goals by the UN (2030). Hence, research on sustainable habitats and related topics is becoming the center of attention and will continue to do so in the coming years (Martos *et al.* 2016).

Perera *et al*. (2020) argue the impact of climate change on cities and urban areas and emphasizes the need for a sustainable energy supply in the face of increasing extreme climate events. Climate change influences urban energy use by affecting energy demand, production, systems, and infrastructure (Nik and Sasic Kalagasidis 2013; Stern, Sovacool and Dietz 2016), and the generation of renewable energy is also susceptible to these changes, with variations depending on the type of renewable source such as wind, hydropower, or solar (Pryor, Schoof and Barthelmie 2006; Sailor, Smith and Hart 2008) according to their geographical location (Wang *et al.* 2014), especially in cities.

Cities are rapidly expanding their boundaries and populations, and as noted, "from a climatological perspective, human history is essentially the history of urbanization" (Santamouris *et al*. 2001). Trends of industrialization and urbanization have significantly increased the number of buildings in urban areas, which in turn affected energy consumption trends. Moreover, the urban population has already grown from 600 million in 1920 to 2 billion by 1986, if this trend continues more than half of the global population will reside in cities by the end of the century (Santamouris *et al.* 2001).

A century ago, only 14% of people lived in cities, and by 1950, less than 30% of the world was urbanized. Currently, at least 170 cities each have populations exceeding 1 million (Santamouris *et al.* 2001).

The shift in population affected energy trends in buildings, in a report by the IEA (Garde and Donn 2014), the average annual growth in energy demand for buildings has been slightly over 1%. In 2022, there was an almost 1% increase in energy demand compared to 2021. Electricity constituted approximately 35% of total building energy use in 2022, marking a rise from 30% in 2010. Despite a shift towards alternative energy sources like electricity and renewables, the use of fossil fuels in buildings has been steadily increasing at an average annual growth rate of 0.5% since 2010 (Garde and Donn 2014). Yet rising solutions like solar technologies, hold significant potential for generating sustainable energy in cities that mainly rely on the amount of solar radiation available (Šúri and Hofierka 2004).

However, modeling solar radiation in urban areas is more challenging than in open spaces due to the complex shading created by varying building heights, densities, and roof slopes. To estimate the energy that solar technologies can produce in cities, two key factors must be taken into account (Compagnon 2004): the urban solar availability, i.e. the total incident irradiation on building roofs and facades, and the utilization factor that assesses the area suitable for installation as well as technical characteristics.

Literature review

The complexity of the urban environment makes techniques like spatial interpolation using data from meteorological stations unreliable (Tovar-Pescador *et al*. 2006). Additionally, satellite imagery processing (e.g. Martínez-Durbán *et al.* 2009) is often unsuitable for cities due to its low resolution, typically 1 km or more (Tovar-Pescador *et al.* 2006).

As a result, modeling has become the primary method for obtaining solar radiation data at an urban scale, with various approaches depending on how buildings are represented (Jonsson *et al.* 2012). There are two main methods: raster digital elevation models (DEM) and vector-based computer-aided design (CAD) data. A DEM consists of a grid where each cell has an elevation value and is often integrated into a geo-information systems (GIS) environment to leverage geospatial data storage and analysis. Models that use CAD vector data are more labor-intensive and generally less accessible (Jonsson *et al.* 2012).

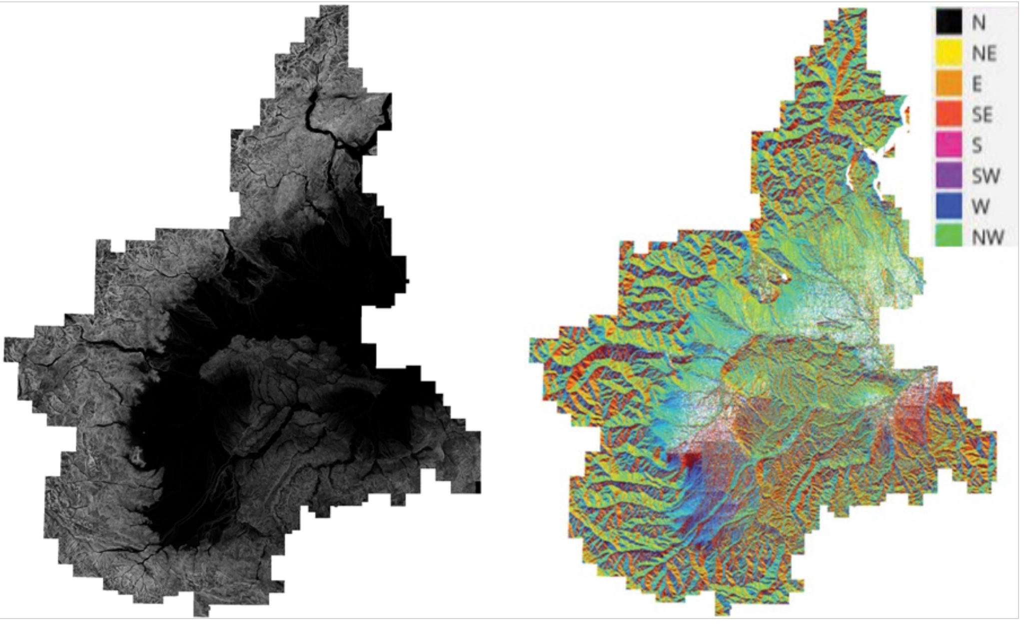
While determining the total roof or façade area is straightforward with both DEM and vector representations, obstructions like antennas and chimneys are often excluded. To account for this, correction factors are applied to reduce the total area to the usable area. These factors include shading coefficients (considering shade from trees, etc.), roof pitch coefficients (adjusting for installations on one side of a double-pitched roof), and feature coefficients (adjusting for areas occupied by windows, chimneys, etc.) (Bergamasco and Asinari 2011).

To further refine the usable area, additional criteria are applied, such as minimum area availability, slope restrictions (e.g., areas with slopes below a certain threshold), aspect suitability (e.g., avoiding north-facing surfaces), and solar radiation thresholds (Bergamasco and Asinari 2011; Jakubiec and Reinhart 2013).

Two of the most commonly used tools are "Solar Analyst", developed by Fu and Rich (1999), and "r.sun", based on work by Šúri and Hofierka (2004). Both tools require a DEM as input, along with values for atmospheric transmissivity and the diffuse ratio. The total radiation for each DEM cell is calculated using a basic transmission model for direct radiation and two different models for diffuse radiation. However, a major limitation of these models is that they do not account for reflected radiation from the ground or nearby structures, which is particularly important in urban settings.

The r.sun model is integrated into the open-source GRASS GIS (Neteler and Mitasova 2002) environment. In addition to a DEM, r.sun requires other parameters, which can either be internally computed or user-defined, such as Linke atmospheric turbidity, ground albedo, beam and diffuse components of the clear-sky index, and the sampling density for evaluating raster cell visibility. A key feature that sets r.sun apart from other models is its ability to spatially distribute input parameters and define them through a series of raster maps, allowing for the modeling of large areas with varying climatic conditions. Other tools that use DEMs to calculate solar radiation include Solar Energy from Existing Structures (SEES) and Shortwave (Kumar, Skidmore and Knowles 1997).

This study tries to assess the methodology based on DEM and r.sun while considering the need and fill the gap of development in solar radiation models that integrate a wider variety of factors such as atmospheric conditions, urban morphology, and material properties (e.g., albedo) to better reflect the unique characteristics of urban environments.



Figg. 1-2. From the left: Slope layer of Piedmont region; Aspect layer reclassified of Piedmont region (author's elaboration).

Methodological framework

The study begins by developing a database that starts from the regional level and focuses on the city level, which mainly includes the Digital Terrain Model (DTM) and the Digital Surface Model (DSM) as a starting point. By plugging in this data in QGIS, the solar potential for Torino, Italy, in this specific study is then calculated. The accuracy of the database significantly influences the study's results, as solar potential is closely tied to the geographical characteristics of the area (Jonsson *et al.* 2012). Integrating satellite images into numerical values is also essential.

Geographical data (Database)

Slope and aspect

The first step is the conversion of the image, The output obtained is the DTM, a raster file (in .tif format) where every cell is associated with the altitude value (meters above sea level, mASL).

In Geographic Information Systems, slope and aspect are two fundamental concepts used to understand and analyze terrain, Chang and Tsai (1991) showed that the accuracy of slope and aspect decrease as a DEM resolution decreases (coarsens), and that the larger slope differences occur in areas of steep relief, while larger aspect differences are in low relief areas. The slope is the steepness or the degree of incline of a surface. It represents the rate of change of elevation for each digital elevation model (DEM) pixel, measured in degrees. Slope can be expressed either in degrees or as a percentage (Li *et al.* 2021).

Aspect, on the other hand, is the orientation of the slope, measured clockwise in degrees from 0 to 360, where 0 is north-facing, 90 is east-facing, 180 is south-facing, and 270 is west-facing (Li *et al.* 2021). Aspect identifies the downslope direction of the max rate of change in value from each pixel to its neighbors.

Using this raster the slope can be generated which is an algorithm that calculates the angle of inclination of the terrain from an input raster layer, expressed in degrees, as shown in Figure 1.

Then combined with the aspect it calculates and generates a raster layer that contains values from 0 to 360 that express the slope direction: starting from North (0°) and continuing clockwise (Fig. 2).

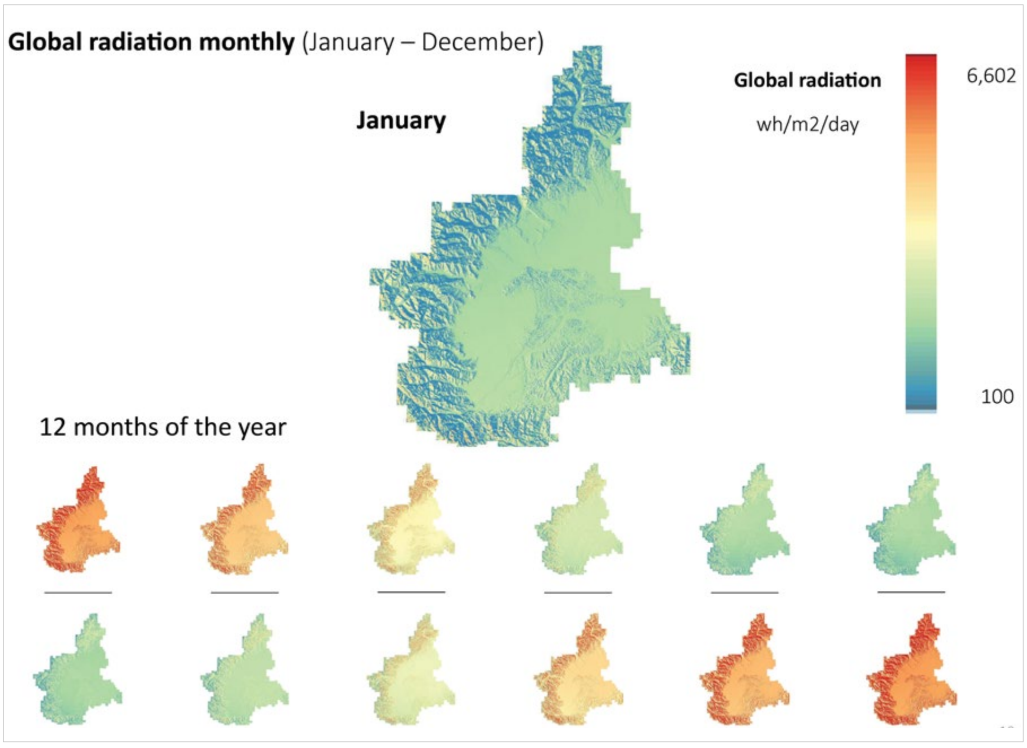
Turbidity factor

The Turbidity Linke factor (TL, for an air mass equal to 2) is a very convenient approximation to model the atmospheric absorption and scattering of solar radiation under clear skies. It describes the optical thickness of the atmosphere due to both the absorption by the water vapor and the absorption and scattering by the aerosol particles relative to a dry and clean atmosphere (Kasten 1996; WMO 1981). The larger the TL, the larger the attenuation of the radiation by the clear sky atmosphere. It is a convenient parameter to summarize the turbidity of the atmosphere. It is a key input to several models assessing solar irradiance under clear skies which is used by several communities in the fields of renewable energies, climatology, agro-meteorology, and atmospheric pollution (Kasten 1996; WMO 1981).

To generate the radiation data it needs various aspects which are mainly, the average day of each month, diffused global radiation, link turbidity data, and the diffused part of the global radiation (D/G ratio), Table 1 provides the data types along with their sources.

The data is extracted taking into account the region of study, in this specific case, it is the Piedmont region containing the city of Torino.

DATA	SOURCE
Average Day	Duffie and Beckman 2013; Klein 1977
Diffuse to global radiation ratio UNI 10349-1 (2016)	ENEA Renewables 2006
Linke Turbidity data raster	MINES ParisTech/Vaisala 2014
Link sky diffuse radiation coefficient raster (D/G)	World Bank Group 2019
Digital Terrain Model	Regione Piemonte 2015
Building shapefiles	OpenStreetMap contributors 2015
Slope	Generated from QGIS
Aspect	Generated from QGIS



From the top: Tab. 1. Data sources required for the solar Irradiance simulation (author's elaboration); Fig. 3. Monthly global radiation from January to December (author's elaboration).

Energy production calculation

Incoming solar radiation (insolation) originates from the sun, is modified as it travels through the atmosphere, is further modified by topography and surface features, and is finally intercepted at the earth's surface as direct, diffuse, and reflected components. Direct radiation is intercepted unimpeded, in a direct line from the sun. Diffuse radiation is scattered by atmospheric constituents, such as clouds and dust. The reflected radiation is reflected from surface features. The sum of the direct, diffuse, and reflected radiation is called total or global solar radiation (Muneer, Younes and Munawwar 2007).

As previously mentioned in the literature the solar geometry incorporated in the model is derived from the research conducted by Krcho (1990), which was later enhanced by Jenco (1992). The model's equations, which describe the position of the Sun-Earth and the interaction of solar radiation with the atmosphere, are primarily based on the formulas proposed by Kitler and Mikler (1986). Significant updates to this model were made following the recommendations and findings of the working group led by Scharmer and Greif (2000). The current model calculates all three components of global radiation – beam, diffuse, and reflected – under clear sky conditions, without accounting for the spatial and temporal variations of clouds.

Simulation

The simulations are done on the average days of the 12 months (r.sun.insoltime) processing will be done 12 times, changing the average day indication and the Linke turbidity factor raster data (one for each month of the year). Data for the locality Lat=45°04′ Long=7°41′ is provided in order to understand how the calculation works in the specific month and which day to take.

Since the number of days is variable for each month, it is considered useful to calculate the monthly data. The value of the radiation monthly derives from the product of the previously obtained values relating to daily radiation and the exact number of days of the month considered.

Both steps were performed using a specific QGIS software tool that allows you to perform calculations based on the raster pixel values entered into the project, called "Raster Calculator". Once this data conversion phase has been completed, it is possible to extract the twelve raster files referring to solar radiation in the assigned municipality to have an in-depth look. The global solar radiation of the Piedmont region is determined and depicted in Figure 3.

The resulting rasters will be converted to monthly rasters (EQ,1), which are expressed in Wh/m2/month dividing it by 1000 will convert it to kWh/m2/month, and finally with this information the global radiation can be calculated using the following formula:

$$\mathit{Global\ Radiation\ Year}\left[\frac{kWh}{\frac{m^2}{month}}\right] = \mathit{Global\ Radiation\ January}\left[\frac{kWh}{\frac{m^2}{month}}\right] + \mathit{Global\ Radiation\ Year\ Febuary}\left[\frac{kWh}{\frac{m^2}{month}}\right] + etc$$

The software facilitates the transformation of raster values into points by converting pixels into corresponding points. Upon completion of this process, each point retains the exact value of its originating pixel. Upon completion of the shapefile, it can be integrated with the building data. This allows for the assessment of each building's value and solar potential in Turin.

On an urban scale of the whole region (Figure 4), the solar potential in Torino is mostly the same as it is a flat land however including the mountains on the east side of the city the values range from 900 to 1900 kWh/m2.

To make this data more usable, it should be integrated with the building shape file of Torino which will allow the calculation to be more accurate according to each building, however, because Torino is mostly flat the variation of values is low, Figure 5 shows the integration of the point layer with the building layer.

Results

The building potential of Turin ranges between 874 and 1551 kWh/m2, with this information, solar production can be calculated using the following equations (Suri *et al.* 2008):

$$E = PR \times Hs \times S \times \eta$$

Where:

E is the electrical energy produced by year [kWh/y];

PR is the performance index of the system (≈ 0,75);

Hs is the solar potential (cumulative annual solar radiation) [kWh/m2/y];

S is the working surface of the panel [m2] (about 30-40% of the roof area);

η is the conversion efficiency, that is the ratio of incident solar energy to produced energy:

$$\eta = Wp \frac{Wp}{S \times Istc}$$

Wp is the peak power of the panel (equal to 1 kWp that corresponds to about 6-8 m2 of PV surface).

To maintain the authenticity of the findings, 40% of the available area is utilized assuming that the roofs on the south side are only taken into account and 10% for movement space. The solar panel is typically used in production. Given the amount of data, a comprehensive visualization strategy is required. A geospatial representation of Turin is proposed, with the height of buildings proportionate to their respective production levels. This approach could be represented in appropriate maps that present an isometric view of Turin, annotated with the corresponding production values.

Discussion

The total amount of energy produced in Torino using 40% of the roof surface area amounts to 20.642 GWh, putting that into perspective, the total annual electric consumption of Torino is 79.6 GWh (Jarre, Macagno, and Noussan 2017), the main variable that makes all the difference is the area, the rural areas are the highest due to the availability of roof surface area.

There is an evident direct correlation between the area and production (Figure 6), which is logical considering that larger areas provide more space for the installation of solar panels. This also accounts for the higher production values in areas outside the city center.

Considering the information above, Torino can theoretically cover 25% of its electric energy consumption using this method. However, that is only abstract. The means of creating a sustainable city is not achieved in this way per se, there are many factors to take into account, such as the times of heavy loads on electric consumption, electric-cabins connection, and many more, all that is part of creating an energy community that functions in not only creating energy but distributing it efficiently.

Conclusion

In conclusion, creating sustainable cities using solar means is one of the main sources that makes it economically and operatively tangible. The analysis showed how to asses the solar irradiance of a city by combining GIS and satellite imagery and produce more accurate results that can be translated

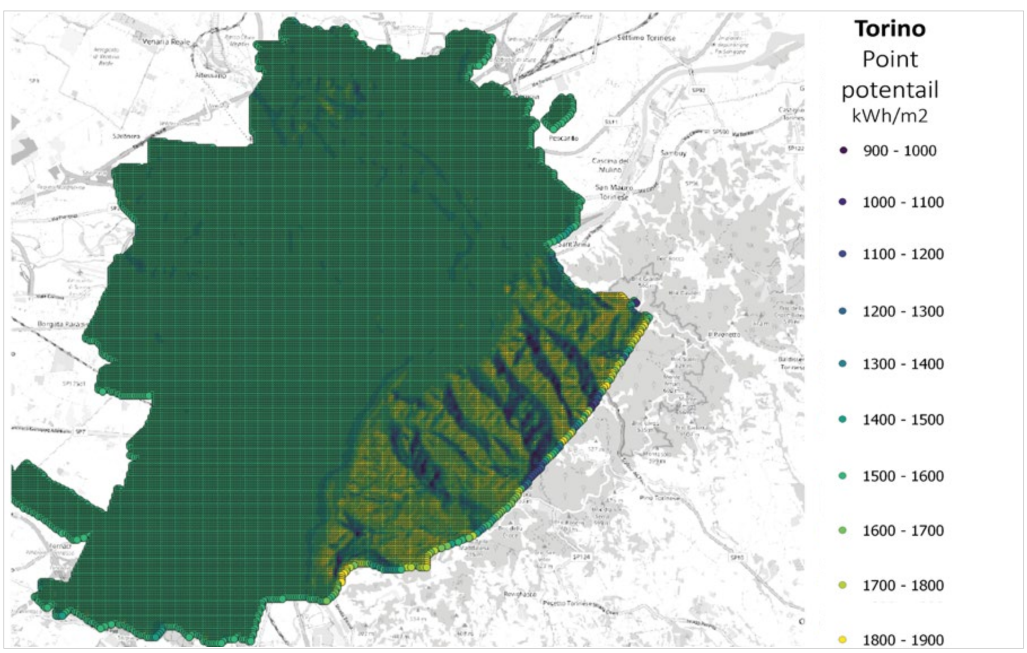


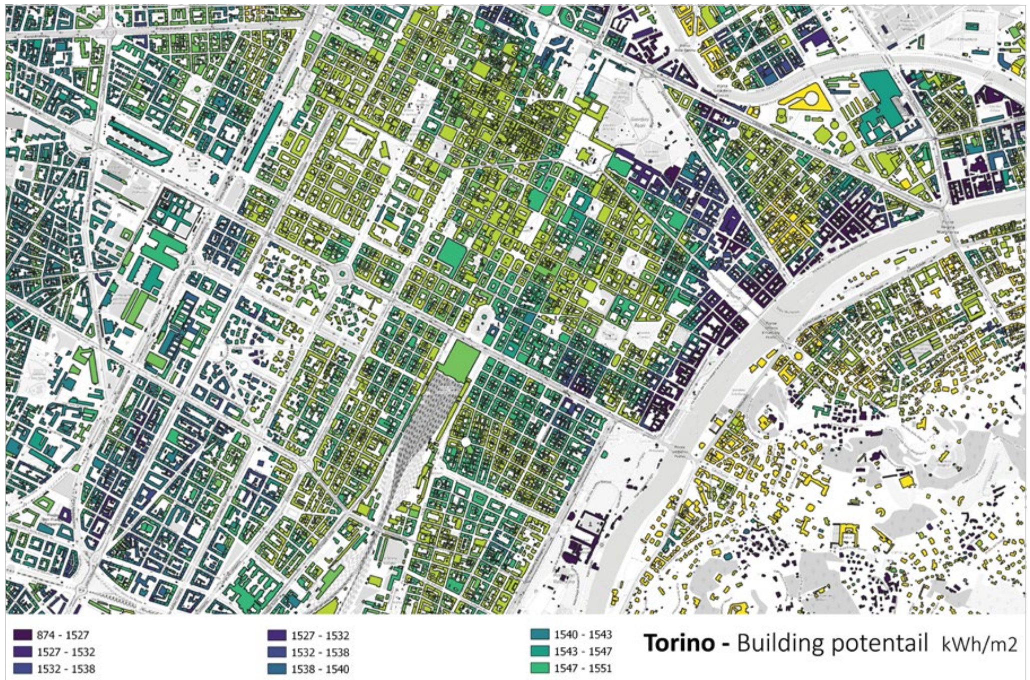
Fig. 4. Torino point potential in the metropolitan area (author's elaboration).

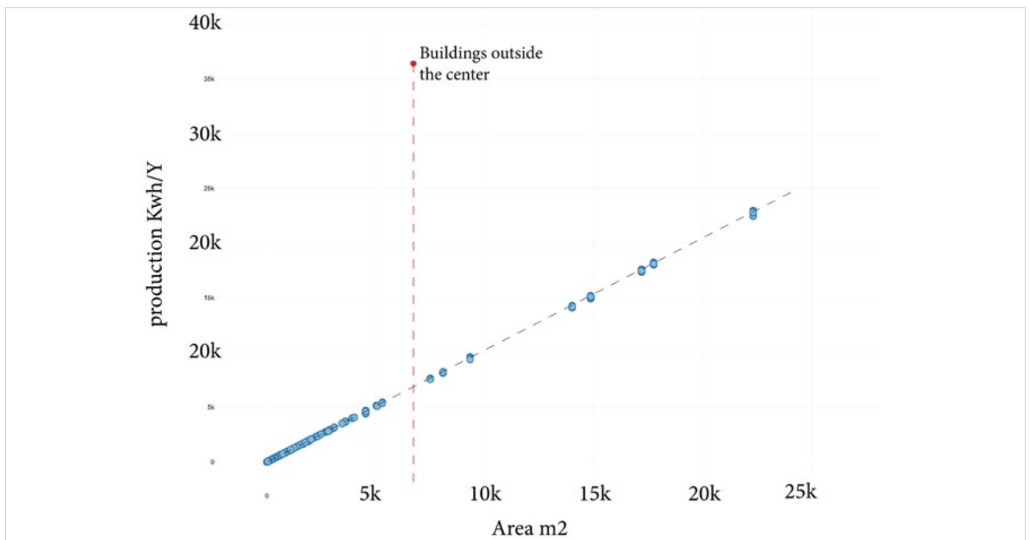
into numerical values and illustrated visually on maps.

This is because the study employs geoinformation systems in conjunction with satellite imagery to investigate the potential solar energy production in the city of Turin, in the context of assessing solar radiation reaching the Piedmont region. By leveraging GIS technology, more accurate measurements of solar exposure are obtained, serving as an input for subsequent energy production calculations due to the separations of the values on a grid 1mx1m as mentioned in the methodology section.

The results show the exact numerical values of solar irradiance reaching a specific point on the surface of the earth and in this case, the rooftop values.

After applying the calculation, the results show the value of energy production using solar PVs utilizing 40% of the available surface area taking into account the south-facing side of the rooftops. This study provides insight into the complex relations between energy, cities, and sustainable development on a city scale. However, it is only part of a bigger scope on the possible future that cities can prosper into.





Figg. 5-6. From the top: Torino's building potential; the correlation between Area and PV Production (author's elaboration).

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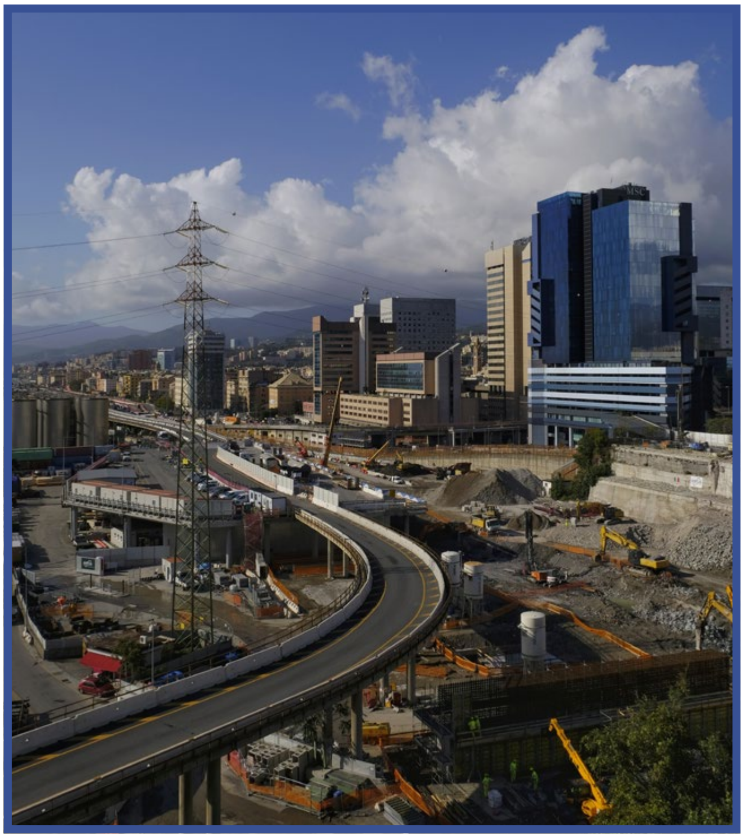
UNO SCATTO CONTRO IL CONSUMO DI SUOLO

a cura di ISPRA-Istituto Superiore per la Protezione e la Ricerca Ambientale / Michele Munafò

L'edizione 2024 del Rapporto "Consumo di suolo, dinamiche territoriali e servizi ecosistemici", a cura di ISPRA e del Sistema Nazionale per la Protezione dell'Ambiente (presentato a Roma, 3 dicembre 2024) certifica, anche per l'ultimo anno, che gli obiettivi di sostenibilità legati alle dinamiche territoriali in Italia sono lontanissimi dall'essere raggiunti. Di fatto, nonostante si continui a richiamare l'arresto del consumo di suolo ormai da tempo all'interno di norme e piani ai diversi livelli, il fenomeno prosegue avanzando a una velocità che, da anni, si mantiene stabilmente al di sopra dei 2 metri quadrati al secondo, oltre 7mila ettari l'anno, senza evidenti segnali non solo di stop, ma neanche di rallentamento, al di là di piccole oscillazioni fisiologiche. Il 2030 è dietro l'angolo e i target dell'azzeramento del consumo di suolo netto, del *no net land take and no net soil sealing*, della *land degradation neutrality,* della *ratio of land consumption rate to population growth rate*, della *land take hierarchy* e di altre formulazioni più o meno articolate sono sempre meno raggiungibili (se lo sono mai stati).
Gli effetti sono sotto i nostri occhi e, con il Rapporto di quest'anno, l'ISPRA ha chiamato a testimoniare anche tutti i cittadini che osservano la crescita dell'urbanizzazione su fertili suoli agricoli invece della riduzione del degrado delle sterminate periferie e delle aree della dispersione insediativa; la realizzazione di nuovi fabbricati residenziali, produttivi, commerciali o logistici, invece della riqualificazione e del riutilizzo di quelli costruiti nel corso della nostra bulimica storia degli ultimi decenni e non di rado abbandonati all'incuria; l'inaugurazione di infrastrutture sottoutilizzate e l'assenza della manutenzione di quelle esistenti; il paesaggio mortificato da cantieri, aree estrattive e impianti di ogni tipo che continuano a modificare profondamente l'assetto del territorio e la quotidianità di chi vive direttamente l'impatto di queste trasformazioni.
La testimonianza dei cittadini si è concretizzata attraverso l'ampia partecipazione al concorso fotografico "Uno scatto per raccontare il cambiamento" e l'invio di moltissime foto, di cui trovate un esempio in copertina e una piccola selezione all'interno della rivista. Sono immagini che descrivono il consumo di suolo da una prospettiva diversa, fornendo un punto di vista nuovo e importante per la rappresentazione del fenomeno. Infatti, accanto all'attività di monitoraggio del consumo di suolo a cura di ISPRA e delle Agenzie per la protezione dell'ambiente, essenziale e imprescindibile per fornire l'adeguata base conoscitiva, riteniamo importante dare maggiore attenzione anche a come i cambiamenti nell'assetto del tessuto insediativo, produttivo e infrastrutturale condizionino la quotidianità e vengano percepiti da parte di tutti coloro che, sempre più, oggi comprendono l'importanza della tutela del paesaggio, del territorio, del suolo e dell'ambiente in cui vivono.

In IV di copertina
"Sotto la lanterna" (Genova, ottobre 2024)
Foto di Silvia Rapisarda
ISPRA Concorso fotografico "Uno scatto per raccontare il cambiamento"



L'ISPRA è ente pubblico di ricerca al servizio dei cittadini e istituzioni e a supporto del Ministero dell'Ambiente e della Sicurezza Energetica (MASE) che persegue l'obiettivo di tutelare l'ambiente tramite monitoraggio, valutazione, controllo e ispezione. Opera sul territorio italiano anche attraverso il coordinamento del Sistema Nazionale per la Protezione dell'Ambiente e quale componente del Sistema Nazionale di Protezione Civile. Collabora con le istituzioni europee a sostegno delle politiche di protezione dell'ambiente; cura la catalogazione, raccolta, accesso, interoperabilità e condivisione, nell'ambito del Sistema Informativo Nazionale Ambientale, dei dati e informazioni geografiche, territoriali e ambientali, che costituiscono riferimento per le attività della pubblica amministrazione, garantendo il raccordo tra le iniziative, mantenimento coerente dei flussi informativi e divulgazione agli enti pubblici, ricercatori, professionisti e cittadini.
Michele Munafò, ingegnere per l'ambiente e il territorio e PhD in tecnica urbanistica. Dirigente ISPRA, è responsabile del SINA, dei rapporti SNPA su consumo di suolo, dinamiche territoriali e servizi ecosistemici. Punto focale nazionale rete Eionet EEA, punto di contatto principale sui temi dell'uso e copertura del suolo e per il monitoraggio del territorio Copernicus, referente nazionale Corine Land Cover, membro Expert Group on Soil Protection EC. Professore a contratto di Tecnica e pianificazione urbanistica, membro Collegio del Dottorato di ricerca in Infrastrutture e trasporti, Università di Roma La Sapienza.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