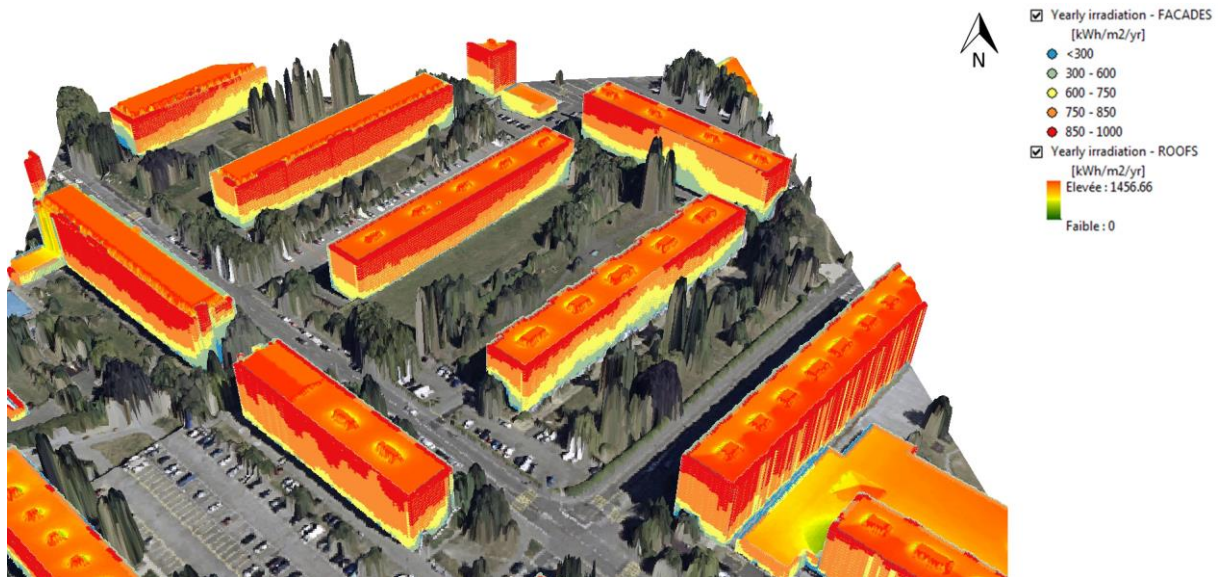


## Solar cadaster as a decision support tool for sustainable energy management in urban areas. From the State of Geneva to the cross-border Agglomeration.



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### Zusammenfassung

### Résumé

### Abstract

The development of solar energy is particularly relevant in cities that consume the major part of energy demand. Dense areas limit the incoming sunlight and the deployment of urban solar power plants. Therefore, it is essential to make available tools that model the solar energy accessibility in the urban fabric. Today's availability of 3D information about cities offers the possibility for such modelling, involving a whole procedure from data acquisition from Airborne Laser Scanning (ALS), also called Light Detection and Ranging (LiDAR), to the environmental analysis through the image processing of digital urban models. Building roofs, but also potential usable surfaces like car-port or highways roofs and walls are considered for potential energy production. Vertical or building facades, which are particularly interesting for the production of solar energy during the winter months, are becoming more and more promising through the improvement of solar panel efficiency and the innovative concepts of Nearly Zero Energy Buildings (nZEB) and Building Integrated PhotoVoltaics (BiPV) concepts. However, facade modelling for solar analysis is not as explored as for roofs, since it requires much more complex tools based on 3D GIS data. In this framework, the paper introduces a tool for assessing solar radiation and energy production on building rooftops and vertical facades of the inner-city. This integrated tool is based on the use of LiDAR, 2D and 3D cadastral data. The paper first presents the methodological background of the tool, its application in Geneva (solar cadaster available through a Web-based interface customized for the public). Then, it discusses about the opportunities and constraints for making the tool useful for the different stakeholder and practitioners involved in urban, energy and building planning.

## 1. Scope

In order to contribute to global targets in terms of reduction of carbon emission, cities need to improve their capability to evaluate local renewable energy sources available, thus promoting and generalizing their use. Related to this topic, solar energy is a major driver of energy transition. Therefore, it is highly relevant to target house and building roofs located in urban areas for producing solar energy (both thermal and photovoltaic). From 2011 to 2016 a step-by-step solar cadaster was developed for the State (Canton) of Geneva (area of about 300 km<sup>2</sup> which is wider than the area of most of solar cadaster restricted to urban areas). It was based on the use of LiDAR data for 3D urban models construction, solar modelling, computational models and digital image processing techniques. First stage (2011) permitted to make publicly available a new solar cadaster emphasizing raw solar radiation on building roofs. Second stage (2014) allowed to extract several rooftop indicators related to energy production, economical investment/payback and environmental assessment. Third stage (2016) made an update of 2011 solar cadaster using new LiDAR data, 3D urban models, refined solar modelling algorithms and improved computational models. Updated outputs are displayed on both the Geneva official geoportal (SITG – Geneva Territorial Information System) and a novel public web interface (please consult Section 3). The geoportal<sup>1</sup>, mainly addressed to professionals of solar energy, has the ability to extract the whole solar database (as open data) on any perimeter or group of buildings, hence allowing to support solar energy planning at different scales.

The Geneva's solar cadaster, as updated and improved in 2016, aimed at providing decision makers with relevant indicators for city planning and energy management. Two key goals of this project were to: (i) - improve the visibility of how much energy can be produced, by both photovoltaic and thermal technologies, thus allowing citizens to check the potential of their building; (ii) - promote the installation of solar panels and linked infrastructures, therefore giving the opportunity to increment business strengthened by solar energy and to boost energy transition from nuclear to "green technologies".

## 2. Methods

### 2.1 Methodological background

The methodological background is based on previous works carried out by some of the authors of the present paper [3] [4] [5]. "Solar Energy Potential" consists of evaluating the potential of building roofs and facades located in urban areas for producing solar energy using both thermal and photovoltaic technology. Hence, the creation of solar maps of cities allowing to accurately evaluate areas that can be used for the installation of renewable energy, such as solar panels on building roofs, is currently considered as highly relevant.

Solar energy potential is calculated by summing the estimated value of the solar radiation in kWh for every hour during a time span at a given place. It is computed using: location (latitude); average solar radiation parameters; 3D surrounding relief and landscape; hourly shading (at a given position); ratio of the visible sky (at a given position), also called "Sky View Factor" (SVF). The three first points above are input data, whilst the two last are calculated using a Shading Algorithm. Data needed for processing is stored in georeferenced TIFF raster format (GeoTIFF), presented as follows:

1. Digital Surface Model (DSM), here entitled 2.5-D Digital Urban Surface Model (2.5-D DUSM), describes the elevation on each point (pixel) of a raster image with specific resolution (Figure 1). It is constructed from LiDAR data and represents the structure of the city, such as buildings and houses.
2. The slope matrix, produced from 2.5-D DUSM using common GIS software tool, describes the slope of each point (value between 0 and 90°).

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<sup>1</sup> [https://www.etat.ge.ch/geoportail/pro/?mapresources=ENERGIE\\_SOLAIRE](https://www.etat.ge.ch/geoportail/pro/?mapresources=ENERGIE_SOLAIRE)

3. The orientation matrix, produced from 2.5-D DUSM using common GIS software tool, describes the orientation of each point (value between 0 and 360°).

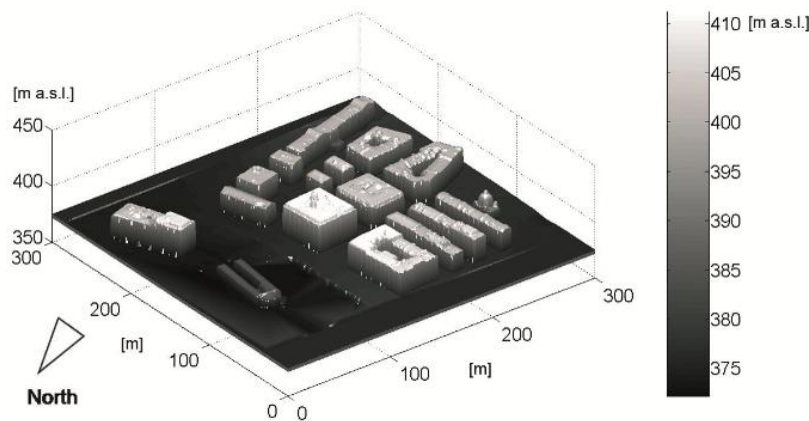


Figure 1 Example of a Digital Surface Model (2.5-D DUSM) for a neighborhood of Geneva: meters above sea level (m.a.s.l.) are illustrated in a grey scale

Solar radiation is calculated by summing its three main components: direct radiation, direct use radiation and reflected radiation. Direct radiation is directly proportional to sun visibility; reflected radiation depends on the ground and the nearby object reflection; diffuse radiation is derived from sky visibility. The used shadow casting routine is based on the algorithms developed by [8]. It calculates the shadow map of a given 2.5-D DUSM according to a given light source. Therefore, this map contains boolean values that represent the shading of each point (0 for shaded, 1 otherwise) for a given light/signal source position.

## 2.2 Shadow algorithm

According to Figure 2, the purpose of Shading Algorithm is to assess, for each point (pixel)  $P_0$  that belongs to a 2.5-D DUSM, which other point  $P_1$  is shading it according to a given light/signal source. Figure 2 shows the algorithm explained above. When the light source is in position 1,  $H_1$  is higher than  $P_1$  and  $P_0$  is lighted. On the other hand, when the light source is in position 2, the height  $H_2$  is less than that building (point  $P_1$ ) and  $P_0$  is shaded. The Shading Algorithm uses three input data: light/signal source position (azimuth and altitude); 2.5-D DUSM and latitude of the location of the given model. The output of this algorithm is a shadow map that contains the shading state of each point that belongs to the 2.5-D DUSM under analysis.

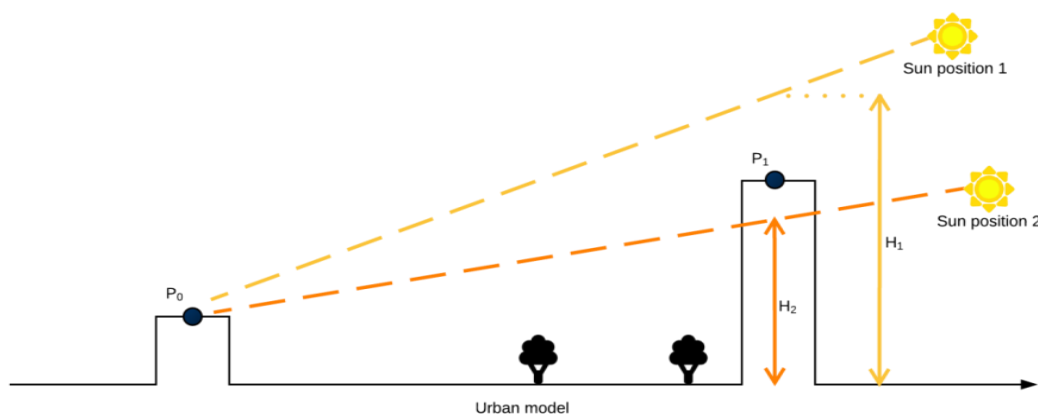


Figure 2 Principle of the Shading Algorithm

The value of direct solar radiation at P depends on shading algorithm for a given sun position (azimuth and altitude). Thus, if P is shaded its value is zero, one otherwise. Fig. 3 shows three calculated shadow maps for an area of Geneva at 4 pm, 5 pm and 6 pm (September 15th).

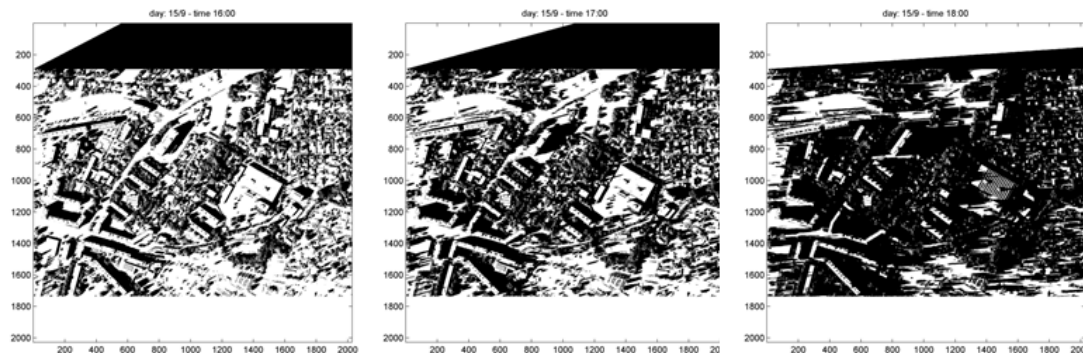


Figure 3 Calculated shadows for a neighborhood of Geneva at three times of the same day

The sky visibility (or “Sky View Factor: SVF”) is used to compute shadowing on diffuse radiation. SVF describes the amount of visible sky from a point P - it is calculated by using a sky model. The latter represents the sky as a vault composed of different light sources. As for the sun, a light source position is given by its azimuth and altitude component. For instance, a point located in an urban area can have SVF near zero; whereas a point located in a rural area mostly have SVF close to 1.

For the SVF calculation, a sky vault with 580 light sources is used as input data, based on the Tregenza sky subdivision model [10]. It involves 580 shadow processes as Shading Algorithm is repeated the same number of times.

## 2.3 Cloud computing (iCeBOUND project)

Most of urban solar cadasters widely available in Europe are made on rather restricted areas, generally less than a hundred square kilometers. Differing from this trend, Geneva’s solar cadaster presented in this paper is not limited to the city of Geneva but instead covers the whole State of Geneva, reaching an area of around 300 km<sup>2</sup>. Such an area is challenging with regards to computation time. Indeed, shadow process is an irregular and time consuming algorithm and iteratively executed several times. In the framework of the first Geneva’s solar cadaster (2011) calculation, computed by a single server machine hosted at the University of Applied Sciences, Western Switzerland (HES-SO/HEPIA), Geneva, took around 2’000 hours (with sky vault of only 140 light sources; with 580 lights sources as for the updated cadaster in 2016, it would have taken much more than 2’000 hours).

Therefore, in order to boost computation time for forthcoming solar analysis on large built areas, cloud computing use has been identified as highly priority by all stakeholders involved in the solar cadaster. For this purpose, iCeBOUND project (*Cloud Based Design Support System for Urban Numeric Data*), supported by the Swiss Federal Agency for the Promotion of Innovation Based on Science (CTI<sup>2</sup>), was launched in 2013. Its goal was to design and develop a cloud-based decision support that puts forward the use of 3D digital urban data and state of the art computing skills in order to facilitate environmental analyses in cities, such as an assessment of solar energy potential. The computational design and architecture used the Cloud infrastructure hosted in HEPIA. Nevertheless, other cloud systems like Amazon could be also used. For more information on technological specifications of the Cloud infrastructure, the reader can refer to [1] et [2]. The use of cloud computing resulted to decrease the overall computation time on the whole Canton to about 350 hours, using the sky vault of 580 light sources.

<sup>2</sup> Among other things, CTI aims to bring cutting-edge companies closer to academic research, thus allowing to create a strong dynamic in R & D promotion and to enhance the potential for innovation. Involved partners are Geneva energy agency, Geneva facility agency-SIG, Geneva geomatics agency, Geneva topographic, agency, CTI, Arx iT, HEPIA, CERN, EPFL and POLIMI.



## 2.4 Facade component

As the 2.5D approach based on DUSM does not allow dealing with facades, it is further necessary to add the third dimension in order to model the facades. The “hyperpoint” approach is thus introduced here, similarly to [9], as highlighted in Figure 4. First of all, building outline points are generated from 2D vector data of building outlines. Then, from each point of a given height (defined by the 2.5 D DUSM) at the top of the building (defined by the 2.5 D DUSM), hyperpoints are generated every 1 meter along the facade until reaching the height of the ground defined by the DTM. Finally, it is worth mentioning that in our research we propose an innovative and more truthful procedure for the detection and calculation of orientation of each building facade, which is based on the use of vector building outlines (each of them representing a single facade). Redweik et al. [9] proposed another method for detection of building facades based only on the analysis of pixels of the DSM with a slope higher than  $72^\circ$ . Main disadvantage of this method is that the delimitation of facade is not accurate: local shadowing effects are created when facades are not straight. Moreover, it is not suitable for urban areas presenting tall vegetation because it is not possible to distinguish which pixels with slope higher than  $72^\circ$  belong to buildings or trees.

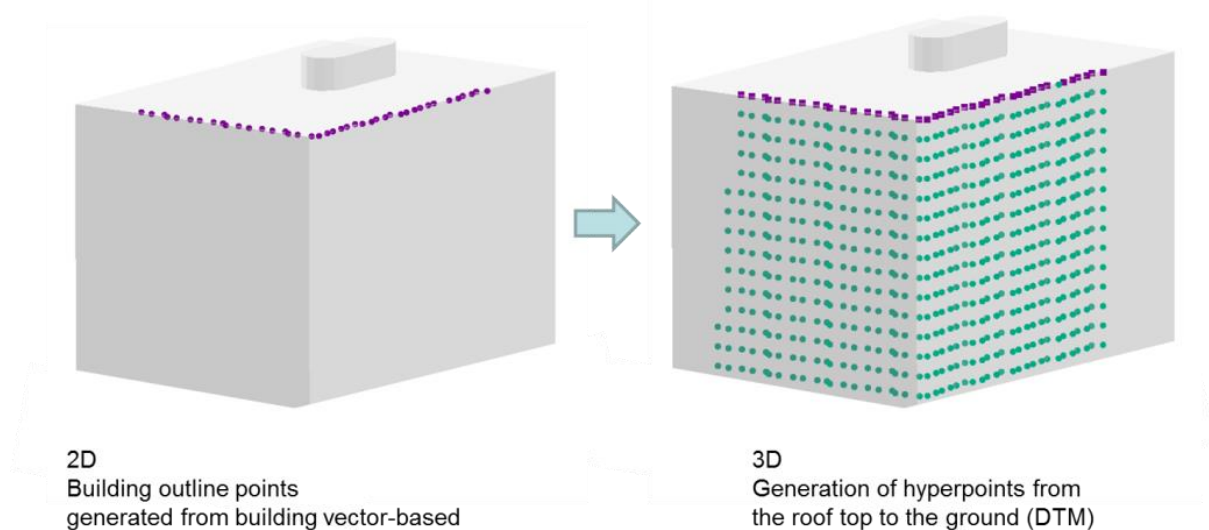


Figure 4 Generation of facades' "hyperpoints" using 2D vector data of building outlines

Shadow algorithm is applied in the same way as for the horizontal surfaces (rooftops) as presented in Section 2.2. But instead of using a matrix approach (where P is pixel of the DUSM), a point by point approach is processed (where P is a hyperpoint of the facade).

## 2.5 Summary

To sum up this methodological section, solar radiation calculation is based on four distinct processes and data (Figure 5):

1. Raw data collection (heights information by remote sensing and building or rooftop footprints);
2. Raster mask inputs for solar modelling (pre-processing): building of 2.5-D DUSM from height data and its derived masks – roof cell slope and orientation. Subdivision of the large studied areas in tiles (3 x 3 km in Geneva) as processing unit;
3. Use of “Meteonorm” historical worldwide database for assessing solar radiation along the urban fabric. It provides radiation values (global, diffuse and normal) with a time step of one hour;
4. Solar radiation modelling based on cloud computing: (a) SVF calculation based on 2.5-D DUSM and the sky subdivision model of 580 light sources, (b) hourly shading calculation based on the 2.5-D DUSM and sun positions as input data (one shadow process per hour during for establishing the direct sun visibility), (c) for every cell of the 2.5-D DUSM (rooftop) and hyperpoint (facade), computation of hourly solar radiation, based on statistical meteorological data of the studied area (hourly global, diffuse and direct solar radiation on flat surface), integrating shadow (SVF and direct) from outputs a) and b), as well as slope and aspect of the cell or the hyperpoint. As a result, monthly and yearly solar radiation values are calculated for

each cell or hyperpoint. An example of yearly and monthly irradiation values ( $\text{kWh/m}^2/\text{year}$ ) calculated for Geneva's downtown is illustrated in Figure 6. Pixel-based solar radiation values are then aggregated by vector polygons (e.g., roofs and parts of roofs);

5. Mapping and communication (post-processing): from outputs of solar modelling, calculation and mapping of indicators on building roofs and facades, and communication through the official geoportal and public web interface (see Section 4).

The outputs from the method proposed here were scientifically validated by an international expert on solar modelling [7]. All the methodological approach and its updated validation is described in details in [6].

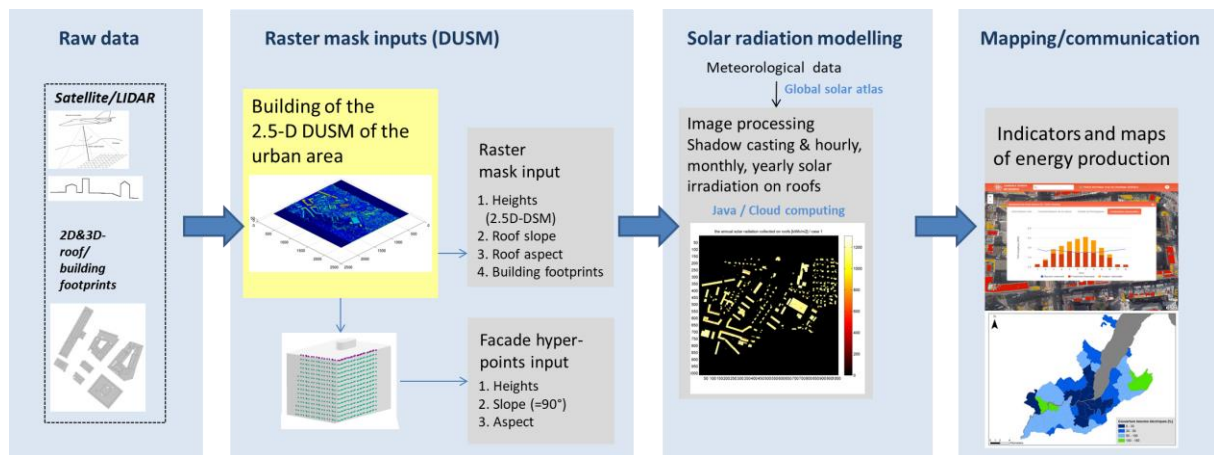


Figure 5 Whole process of solar modelling and mapping from raw data acquisition to solar mapping

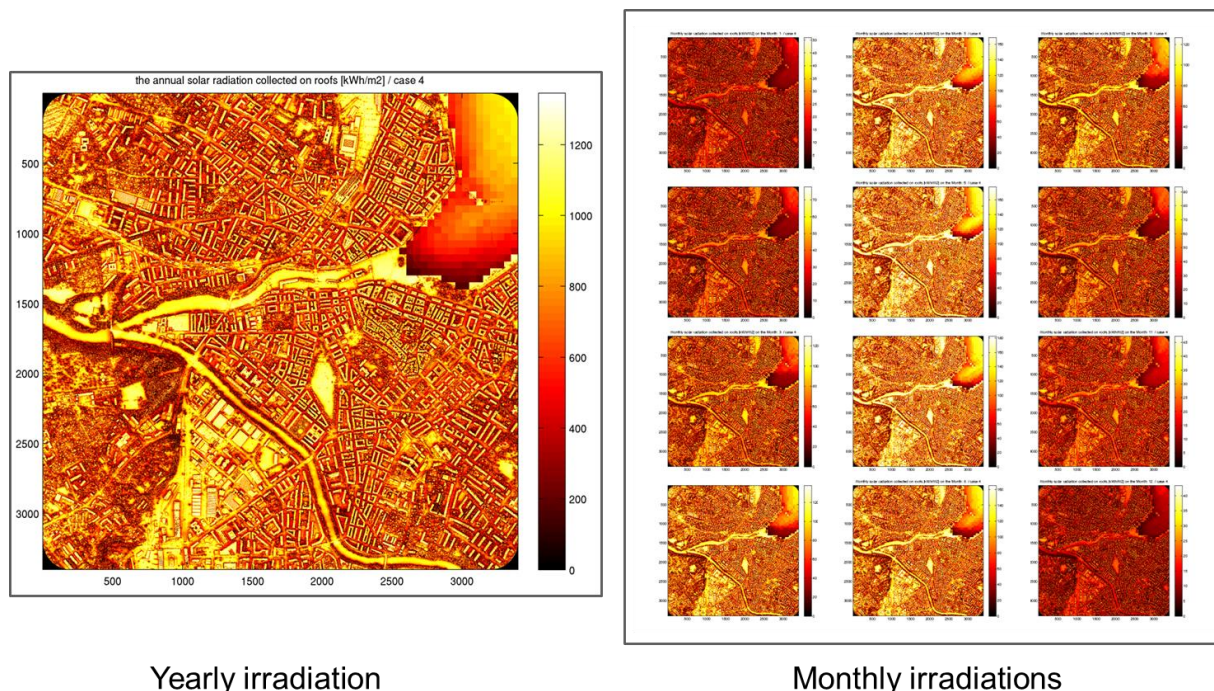


Figure 6 Yearly (left-hand side image) and monthly (right-hand side image) irradiation values ( $\text{KWh/m}^2$ ) calculated for Geneva's downtown

### 3. Results

Globally, the solar cadaster of Geneva highlights that a potential solar electricity production of 700  $\text{MW}_e$  could be reached if all the suitable and well irradiated roofs of the Canton were installed, which would not be realistic. However considering that at the end of 2016, about 45  $\text{MW}_e$  were installed, it remains a very important action margin for boosting the PV solar market.



To that end, a specific public web interface<sup>3</sup> (Figure 7) were provided in order to communicate about the solar energy potential of the State of Geneva's building roofs. In particular, maps and information are published in an interactive way for different types of end-users (e.g. authorities for energy planning, energy companies for marketing and investing, and public for awareness and encouragement in solar PV installing).

Main functionalities expected for the public web interface are presented as follows:

- Identification of suitable roof parts for thermal and PV panel installation considering yearly radiation thresholds (e.g. 1000 kWh/m<sup>2</sup>/year);
- Detailed assessment of rooftop solar energy potential for thermal and PV technology, in terms of available suitable rooftop area (m<sup>2</sup>), total installed capacity (MW), total potential generation (MWh) and economic and environmental indicators (saved CO<sub>2</sub> emission);
- Visualization of maps with color classification related to electric solar map potential and display of graphics with regards to energy and money savings by rooftop;
- Make viewable (afterward user request) information about main rooftop characteristics, such as orientation, slope, available area, etc., for initial design of thermal and PV installation projects;
- Generation of summary PDF and export data to CSV format (or XML).

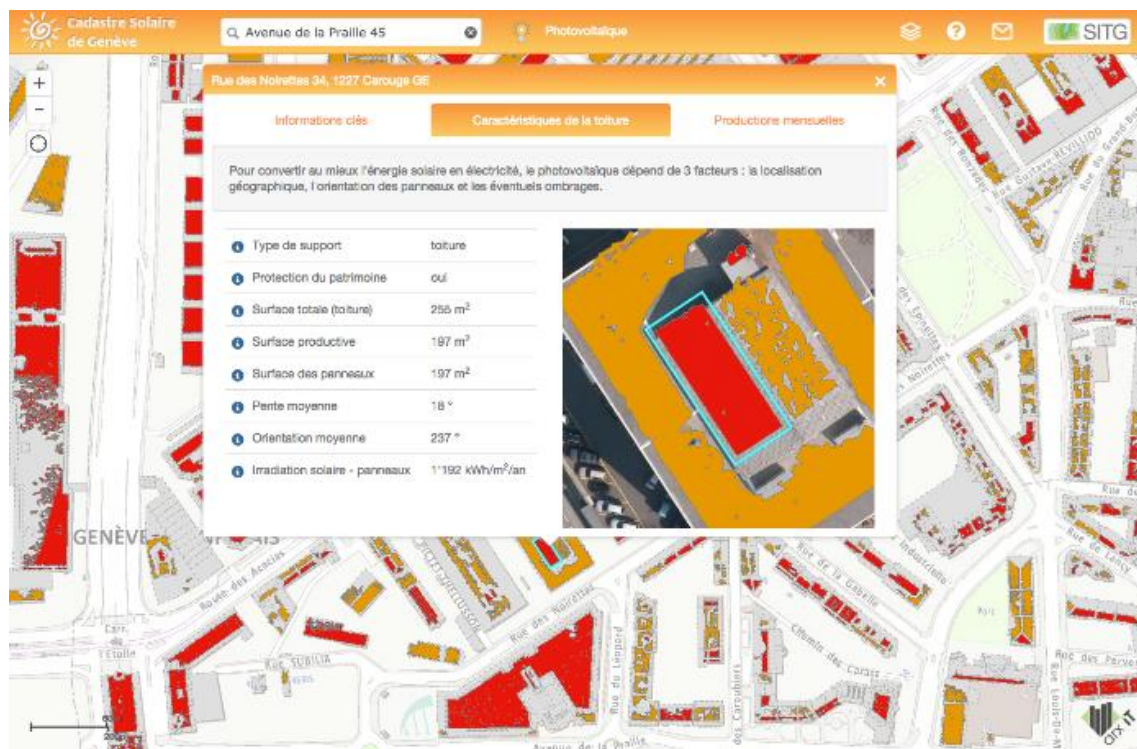


Figure 7 Geneva's public web interface: example of display for main rooftop characteristics

So far, no solar cadaster on building facades has been made in the Canton of Geneva. Nevertheless, hepia's model introduced in this paper is ready to be used for this purpose. It is worth mentioning that due to different buildings' topology, a full cover of the Canton with such a cadaster is not considered relevant. Hence, specific and appropriate areas should be first targeted. Indeed, the use of already built building facades for active solar energy purpose is not as systematic as for roofs, as only some elements of facades, like balconies, may remain available. In general, industrial areas offer more and better opportunities for solar panel installation on facades.

The Figure 8 highlights solar radiation outputs calculated for an urban area of Geneva (Carouge), mixing a new set of buildings and existing industrial areas. Both of them are particularly suitable for installing PV panels on facades.

<sup>3</sup> <https://sitg-lab.ch/solaire/>

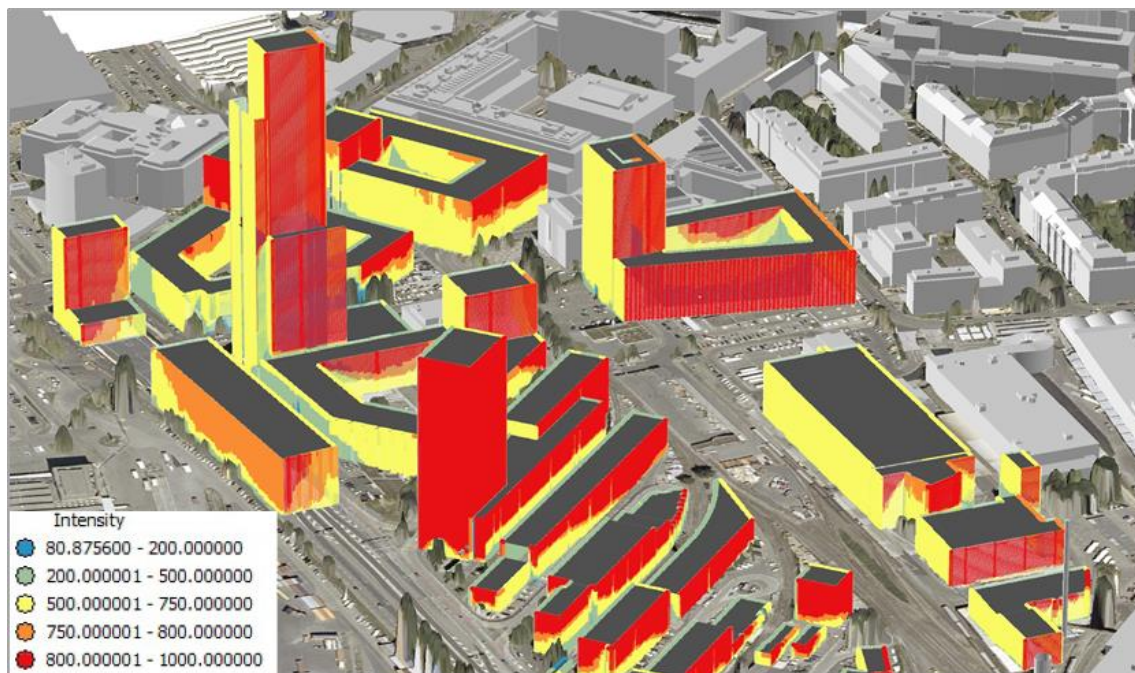


Figure 8 3D representation of the solar radiation outputs (intensity in kWh/m<sup>2</sup>/yr) on building facades in a sector of the Municipality of Carouge, mixing new building developments (top) and existing industrial areas (bottom).

## 4. Discussion

A decision support tool based on cloud computing has been developed with iCeBOUND project, thus allowing to accurately assess the effective thermal and PV technology production for different end-users, such as citizens and solar panels installers, and support decision making on launching installation projects. The system quantifies the solar power that a roof or vertical façade can generate by taking into account local weather parameters and 3D urban digital data, thus allowing to evaluate how much shade falls on each roof from nearby trees and buildings. Moreover, Geneva's solar cadaster is made publicly available through both the official geoportal (extraction of open data for professionals) and the public web interface (general public awareness).

Sharing data and information this way is indeed crucial for promoting an open Swiss energy transition strategy from nuclear to "green technologies". Hence, available data strengthen important decision with regards to solar installation investment: they help design projects and provide to real estate owners financial evaluation before applying for public incentives and contacting companies specialized on solar panel installation. The monitoring of the public web interface shows between 80 and 100 consultations per week, which is mostly in line with the number of applications for public funds (in particular in the framework of the Geneva funding program for renovation of buildings).

However, as shown in Section 3, a small proportion of the global potential (45 over 700 MW<sub>e</sub>) in terms of solar electricity production were mobilized by 2016 in the Canton of Geneva, considering only the potential on rooftops. Adding the potential on vertical facades (which has been unknown so far on the whole Canton), the global potential would result in being much higher.

It shows that any solar cadaster, even if it offers an attractive public interface as presented above, and a support for political decisions in energy management, is not enough in itself to boost the solar panels installations. It is also important to reinforce the appropriation of the solar cadaster by the concerned actors through other means like workshops, seminars, training sessions, targeted information on the Web, etc, and to mobilize them in order to boost the solar market. This is the scope of the perspective of the extension of the solar cadaster to the cross-border agglomeration of Geneva, as shortly presented in the next section.



## 5. Perspectives

Next step will be to: (i) develop a wide-ranging communication to potential stakeholders: remarks and ideas should be collected for enhancing the public web interface in line with their needs; (ii) extend the solar cadaster to the whole agglomeration of Geneva, which includes French municipalities (a cross-border solar cadaster is undoubtedly a challenge in terms of energy management); (iii) speed up calculation time through the use of novel GPU (Graphics Processing Unit) accelerated computing particularly adapted to matrix processing.

Concerning the perspective of the extension to the Geneva agglomeration ("Grand Genève"), this project under preparation called "G2-SOLAIRE" aims to:

1. Deploy the solar cadaster on the entire territory of Greater Geneva (including the three entities: Nyon Region, Canton of Geneva, Pôle métropolitain du Genevois français).
2. Establish and communicate at building scale (roofs and facades) an effective and operational solar potential, taking into account the possibilities of self-consumption (in compliance with regulatory and financial frameworks), the injection capacities of the electrical energy produced on the networks, the building heritage and other issues.
3. Facilitate the appropriation of the solar cadaster among the various target groups, as a support to raise awareness among these groups, accelerate the development of the solar energy sector, encouraged by Swiss and French legislation, and ultimately contribute to the energy transition of the cross-border territory.

The solar cadaster that will be produced will not be limited to mapping the solar potential on the territory, as was done for the Canton of Geneva. But it will constitute a collaborative platform aiming to mobilize all the actors around solar energy and thus contribute to boost the solar market and the number of installations.

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