Towards a Solar Cadastre For The Monitoring of Solar Energy Urban Deployment: The Case of Geneva

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Abstract

The current climate and energy context makes that solar energy power generation is increasing quickly. It is expected to drastically increase in the coming years in urban areas. This study subscribes to this context and deals in particular with the relevance of using a conventional solar cadastre for capturing the information that are useful for the planning and monitoring of solar energy production objectives achievement. Indeed, such cadastres remain for now mainly incitement tools for the different concerned actors to invest in the solar energy systems in urban cities. Hence, the idea of the presented work is to analyze the concept of solar cadastre as both a planning tool and a monitoring tool for the cities and local collectivities. The particular case of the photovoltaic large scale deployment is considered, in coherence with the national energetic transition goals. The focus will be made on the cadastre of the Geneva Agglomeration, a French-Swiss cross border metropolis for which massive solar deployment policies have been implemented. Some remarks and prospects will thus conclude this study.

Key-words. Solar energy, Cadastre, Urban city, Photovoltaic deployment, Planning and Monitoring

1. Introduction

In the first decades of the 21st century, increasing concerns on environmental issues caused by anthropogenic global warming have spurred a rethinking of both the generation and the consumption of energy, as well as the management of local resources. In 2015, worldwide nations took commitments at the COP 21 in Paris to reduce their Green-House Gas (GHG) emissions to limit the global warming. This will be achieved through respectively, the reduction of the use of fossil energy, the reduction of the energy consumption and the increase of the use of the renewable energies. As a consequence, it is expected that solar energy, which is abundant, low carbon and renewable, and in particular for electricity, solar PhotoVoltaic (PV) panels will lead future renewable electricity capacity growth in the next decade (International Agency of Energy, 2017). It follows that many countries are developing a strategy at national scales to massively deploy solar energy, as it is the case in France and Switzerland.

Because solar energy is distributed, its deployment is highly relying on the concerned region, namely its local topology as well as its economic, environmental and political situations. Besides, there are two main ways to increase solar production. The first way consists of installing solar farms in the countryside while the second way consists of integrating solar energy systems on the existing infrastructures and buildings, namely the so-called Building Integrated Photovoltaic (BIPV) System. BIPV systems are more appealing in dense areas such as Europe because solar farm deployment requires a lot of lands that could be used otherwise, for agriculture or preservation of the biodiversity (Palmas et al., 2015).

In order to achieve a massive solar deployment in urban and semi-urban areas, it is necessary to integrate solar systems on a great amount of buildings including façades (i.e. vertical surfaces). Because these buildings have many different purposes (residential, tertiary, professional, etc.) and ownerships (public, private, rented buildings etc.), it is crucial for all the different urban actors, the citizens, the businesses, the stakeholders, the urban city planners or the local collectivities to be implied in this deployment.

doi:10.18086/swc.2019.51.04 Available at http://proceedings.ises.org

In that context, solar maps or solar cadastres have been developed to provide these different actors information about the local urban solar resource (Kanters et al., 2014). A solar map of a city illustrates information about how much a piece of roof, a building, or a home experiences a certain amount of sunlight. The appellation of "solar cadastre" may be more relevant for a solar map of a city which is coupled with the local land register i.e. the local ownership of the house/building part. Such a cadastre takes the form of an open access Geographic Information System (GIS) tool and is often managed by the local collectivity.

The number of solar cadastres have consequently increased in the last decade providing different levels of detail about the urban solar potential in different cities (Freitas et al., 2015). In their great majority, solar cadastres aim at providing user-friendly communication or incitement tools to help and prompt the different urban actors developing solar energies. However, given the ambitious solar goals announced which will make its share in the energetic mix growing from an actual marginal share to one of the main source of energy, it is necessary to develop tools for the planning and monitoring of the corresponding action plan. Corollary, this study proposes to assess the possibility for the solar cadastres to evolve from an incitement/informative tool to a planning and monitoring tool for the local deployment of solar energy.

The Greater Geneva is following an energetic transition policy aiming at drastically increasing the share of renewable energy production in the energy mix. To that aim local authority of the Greater Geneva plans to massively increase the PV electricity production on their territory. It is in that context that the project G2Solaire "Grand Genève Solaire" (Greater Geneva Solar) has been launched in 2019. This project aims at developing an improved version of the actual solar cadastre which, obviously guides the deployment of PV or solar thermal systems not only mapping solar radiation on roof but also allow to consider different range of time (week, seasons...), consider different solar technologies of PV and Solar thermal, building integration configuration and local climate, economical aspects including self-consumptions or grid connection costs. G2 Solar is also developed in such a way that all the urban actors can use the cadastre and that it becomes a real urban planning tool. The aim of this study is therefore to assess the relevance of the actual version of the cadastre to be used for the planning and monitoring of the PV deployment in the Greater Geneva.

To achieve an efficient deployment of the solar production power, the first step will concern, as it is practiced in conventional industrial continuous improvement approaches (Deming and Edwards, 1982) (*Plan-Do-Check-Act*), the identification and the planning of the intrinsic characteristics of the solar energy production. The deployment does effectively allow energy transition goals to be achieved. The different point for which the solar cadastre could be a support tool are the following:

- To which extent is this goal achievable?
- What are the available data? What data are missing?
- How to achieve it without infringing on other environmental strategies?
- How to help the local authorities in the planning of the solar deployment?

This paper will be organized as follows. First, the energetic context of the Geneva agglomeration will be presented. Then the current version of the solar cadastre will be used in order to assess its relevance to provide a strategy for the energy transition goals of the metropolis. Finally, the Plan-Do-Check-Act methodology will be reviewed and the suitability of the current version of the cadastre to address each of these steps will be shortly discussed.

2. Energetic context in the Geneva agglomeration

In 2018, in Switzerland and France, the PV power generation has represented respectively 3.6 % and 2.2 % of the share of total electricity consumption of the country (PVPS, 2019). However, according to the French and Swiss governments energy transition roadmaps, a massive deployment of solar PV is planned, leading to great increase of the share of PV energy production in the final energy mix (Département fédéral de l'environnement, des transports, de l'énergie et de la communication, 2018-; Ministère de la transition écologique et solidaire, 2018).

At the local level, it is planned for the PV installed capacity to be multiplied by more than 10 times by 2035 in the swiss part of the Great Geneva agglomeration, making the yearly generated PV energy grows from 35

GWh to 380 GWh. This will make the share of local PV energy production growing from actual 1.2 % of the electricity consumed in the Geneva canton to an expected 15 % of the electricity consumption. As a matter of comparison, in 2018, the two countries with the highest PV share were Honduras and Germany for which the PV electricity production represented respectively 14 % and 7.9 % of the total electricity consumption. This deployment implies for a great amount of building surfaces of the Geneva agglomeration to be equipped with PV systems.

2 countries, 2 legislations
2 French Departments, 2 Swiss Cantons
2000 km²
211 Towns/villages
Urban and Rural areas
900 000 inhabitants
480 000 housings
Mountainous terrain with elevations between 300-1700m

Tab. 1 Main characteristics of the Greater Geneva

It is in that context that the EU INTERREG French-Swiss "G2Solaire" project, has been launched ("SITG Lab | Cadastre Solaire de Genève," n.d.). The aim of this project is to develop an improved solar cadastre of the Greater Geneva, in order to provide to local actors, from the citizens to the local authorities through energy providers and urban planners, an efficient support tool for the integration of PV system on the territory.

The Greater Geneva is a cross-border mountainous area which the main characteristics are summarized in Tab. 1. The improved cadastre to be developed will take the form of a collaborative platform with objectives that are respectively related to:

- the intensification of the use of solar energy;
- the economic development of solar-related activities;
- the energy transition goals in a context of urban densification.

In Fig. 1, an illustration of the solar cadastre (Desthieux et al., 2018) is presented.

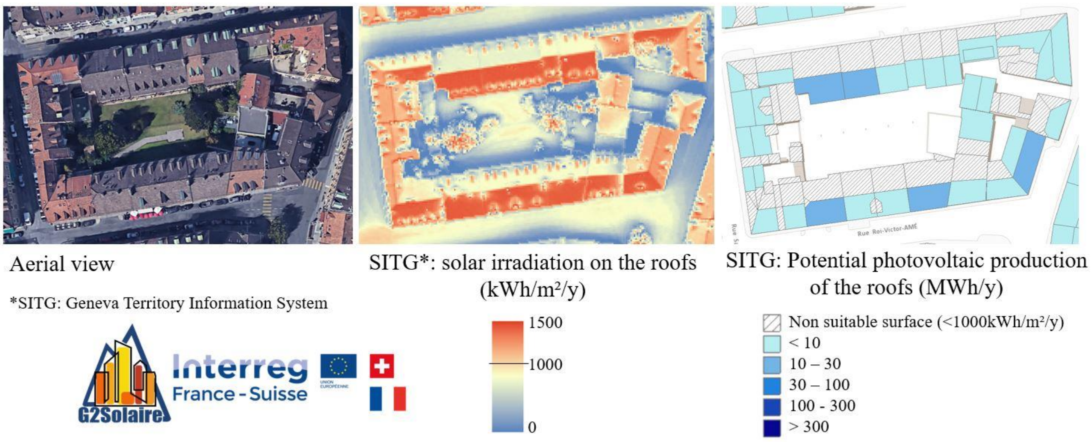

Fig. 1 Illustration of the current cadastre in Greater Geneva available on the SITG (Système d'Information Geographique de Genève) website

3. Current cadastre

3.1 Overview of the current situation

As it was mentioned earlier, a solar cadastre is available on the Geneva area. However, up to now it does not cover the entire Greater Geneva but is restrained to Geneva city and the District of Nyon which are colored in orange in Fig. 2. As a first step, the present study will focus on these geographical areas for which data are available, before extending to the whole agglomeration when the additional data will be available.

In its current version, the cadastre pieces of information that could be relevant for this study’s outputs are the followings:

- The location of the roofs.
- The surfaces of the roofs.
- The monthly solar energy received by each roof.
- The PV production potential of each roof.

In the current cadastre, a minimum value of annual solar energy is set at 1000W/m2. As a consequence, all the surfaces which receive less energy are disregarded because they are considered as not energetically and economically viable. All these pieces of information are available in open access and can be obtained through the solar cadastre website. Moreover, the current cadastre does not inform about the already equipped roof so that in the present work, the roof which are already equipped with PV systems will be considered as well. However, given that the part of the PV production is currently very low in the Geneva energy mix, it can be neglected at first.

Once all this data is gathered the investment price corresponding to the installation of the PV system on each of the considered is calculated. This investment price is calculated, as if the whole identified roof surface was equipped, based on an averaged estimation. This estimation of the investment prices correspond to all-inclusive prices for an integrated PV system, for which only minor necessary electrical modifications of the grid have

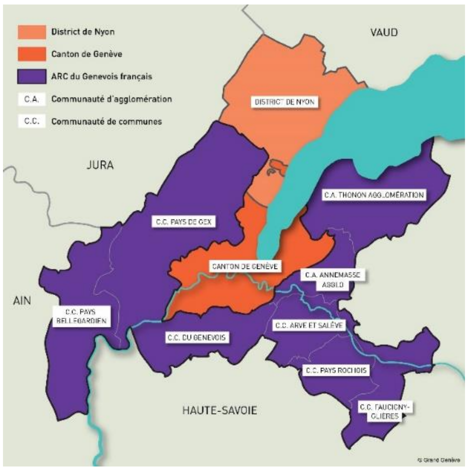

Fig. 2 Map of the Greater Geneva . The purple areas correspond to the French part and the orange areas correspond to the Swiss parts

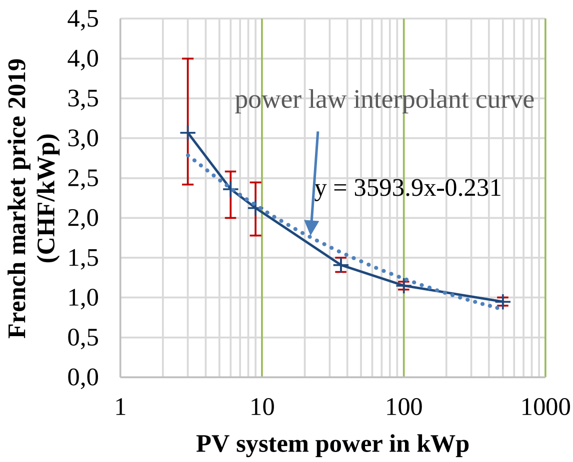

Fig. 3 PV system investment price as a function of the total power installed, the red bar represents the uncertainty

been done and for which no reinforcement of the roof structure are required. It depends on the size of the PV system installation which is directly proportional to the power installed in kWc. These prices are reported in Fig. 3

In order to assert the economic viability of the PV system, an economic indicator is defined. There are different types of economic indicators that are proposed. The Economic Profitability (EP) is calculated on the basis of the ratio between the investment price and the yearly produced energy in MegaWatt hour (MWh).

Note that from the final user point of view, this indicator is not the most relevant and the Return On Investment (ROI) will be preferred. Indeed, the ROI highly depends on the local policy, and the subsidies (which corresponds to a certain percentage of the investment price in Switzerland and feed-in tariffs in France for example). However, as mentioned in the introduction, the present work aims at developing a tool that can be used by local authorities for the planning and monitoring of the PV system deployment. It should consequently provide an overview of the economic situation without any subsidies, and in a second step subsidies policies could be decided from this overview.

The overview of the PV deployment potential is presented in Fig. 4. On this figure the roofs are ranked according to their EP value, indicated on the left vertical axis, which range here from 1100 CHF/MWh (CHF being the Switzerland money) to slightly more than 10000 CHF/MWh. On the horizontal axis is reported the cumulative capacity of the PV systems. For example, 40% on the horizontal axis corresponds to the percentage of the total Geneva PV production capacity if all the system with an EP below approximately 3100 CHF/MHh. The scale for the yellow curve is on the right hand side. It corresponds of the cumulative investment of the PV systems. Finally, the red dots correspond to the surface of the considered surface. The surface in m² can be read on the same scale as this for the EP, on the left hand side.

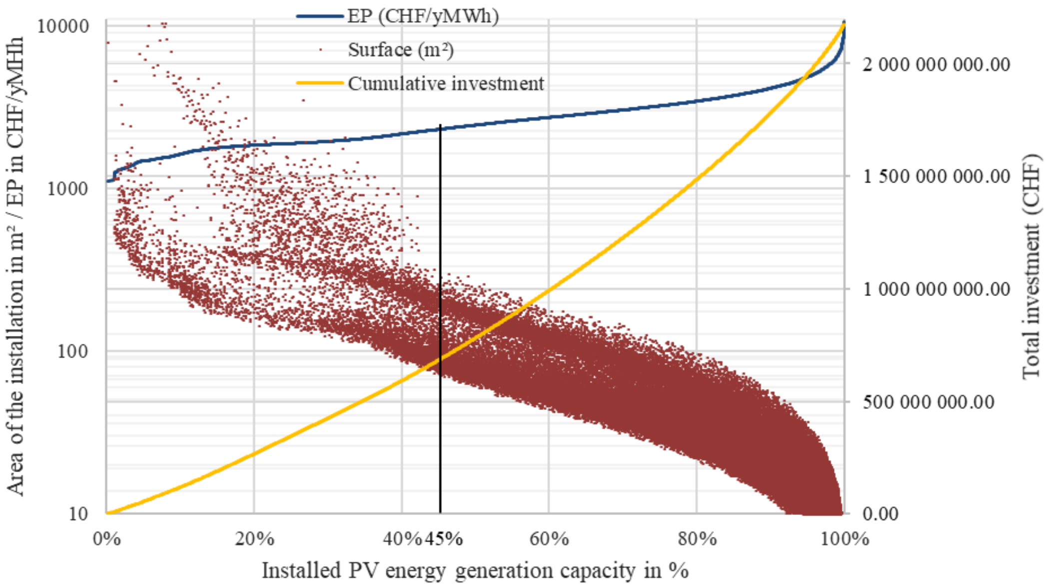

Fig. 4 Overview of the Geneva PV situation

According to the data extracted from the solar cadastre, the maximum PV capacity corresponds to a yearly production of 840 GWh. This is calculated considering the monocrystalline technology which efficiency is around 15 %. However, the cadastre has a threshold as it disregards any surface which received less than 1000 W/m², in addition only the roofs are considered and the vertical surface are therefore excluded. As a consequence, 840 GWh does not represent the total potential of PV energy production of Geneva but it represents the full capacity of the roofs which have been considered as suitable in the current version of the cadastre. As could be expected, because of the investment prices which are more interesting for bigger surfaces, the most economically profitable roofs also correspond to the bigger surfaces.

Considering now the Geneva objectives in 2035 to produces 380 GWh of PV energy, this corresponds to 45 % of the capacity of the roofs considered as suitable to be equipped. This is plotted in Fig. 4 by a vertical line. It could be noted that a very great part of the most EP roofs that would need to be equipped to reach Geneva PV objective have an area between 100 m² and 1000 m². However, it may occur for many of these roofs not to be suitable to host PV equipment, either because they are heritage buildings or because the structure of the building needs to be reinforced. Moreover, in longer term objectives, it is highly likely for the Geneva area to plan to reach higher goal regarding the PV penetration in the energy mix. For all these reasons, it appears that it is necessary to allow the cadastre considering lower solar irradiation level per m², incuding building façades.

Considering now the PV system price of 2019, the Geneva PV objective would correspond to a total investment of 650 MCHF. As a matter of comparison the total investment of the Geneva city in public policies was of 785 MCHF in 2019 with 12 MCHF being devoted to environment and energy policies.

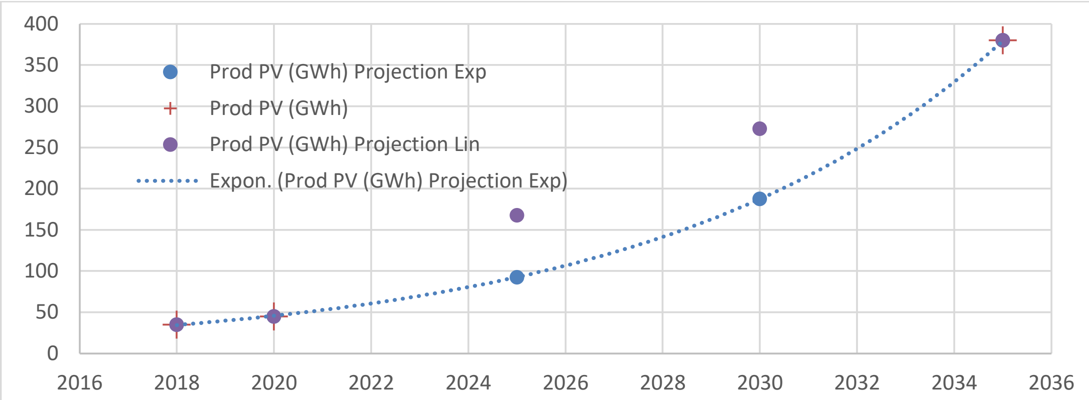

Fig. 5 PV deployment roadmaps to achieve Geneva energetic objectives.

In that context it appears that it is almost impossible for the city to support the investment for the PV deployment. For this reason, the implication of all the different potential contributors, from the citizen to the business is needed. However, even in that case, the investment remains huge and must be planned over several years as it was done in Geneva.

3.2 Yearly planning of the PV deployment according to the current cadastre

The council of the state of Geneva have settled an objective to reach an annual production of 380 GWh by 2035. No detailed precisions are proposed regarding the annual goals and therefore, two approaches are considered here. The first consists in considering a linear deployment of PV systems in which the PV energy production is increased of 24 GWh each year until 2035. The second planning strategy consists in considering an exponential deployment. These two strategies are plotted in Fig. 5.

It is very likely for the price of energy and even more this of PV energy to drastically evolve in current years as it has been the case in precedent years (Ray, 2018). Some specialized institute forecast for the prices of PV energy to be divided by approximately 2 by 2035 (Kost et al., 2018). Considering this evolution, the prices forecasted for PV systems is calculated each year until 2035. It follows that the yearly investments in order to

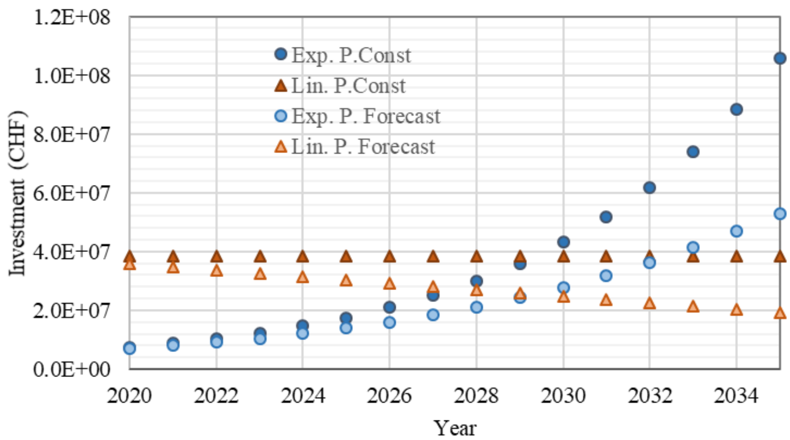

Fig. 6 Yearly investment following different PV deployment plan and different prices evolution. Lin. and Exp. refer to the linear and exponential approaches described above. Const. mean that a constant price is considered and Forecast means that the price evolution is considered

follow the deployment roadmap of Fig. 5 can be obtained and are displayed in

By considering the forecast of the PV price evolutions, the cumulative investment in 2035 for the linear and the exponential approach are respectively 450 MCHF and 380 MCHF. This represents a total investment significantly lower to those with fixed price.

It becomes therefore possible to provide a yearly plan for the PV deployment in the Geneva city based on the current cadastre.

4. Evolution of the cadastre toward a planning and monitoring tool

4.1 Alternative planning through multi-objective optimization and multi-criteria analysis

As it can be seen in Fig. 4, for the same EP, the surface of the roofs can widely vary from few hundreds of m² up to tens of thousands of m². Given that the investment prices largely decrease with the size of the installation, this implies that very large roof may have a very good EP only because of their large size, but are not the most efficient regarding energy production. This aspect becomes crucial when considering that the integration of PV systems should not infringe with other environmental policies, such as the vegetalization of the roofs in order to reduce urban heat island effect (Santamouris, 2014) or with urban comfort such as access to daylighting (Naboni et al., 2019). To that aim another performance indicator can be defined, this time based on the most productive surfaces.

As it can be seen in Fig. 7, by considering PV system prices of 2019, an investment of 900 MCHF would be necessary to reach the Geneva 2035 objectives. This represents an investment almost 40% greater than this considering optimal EP defined above.

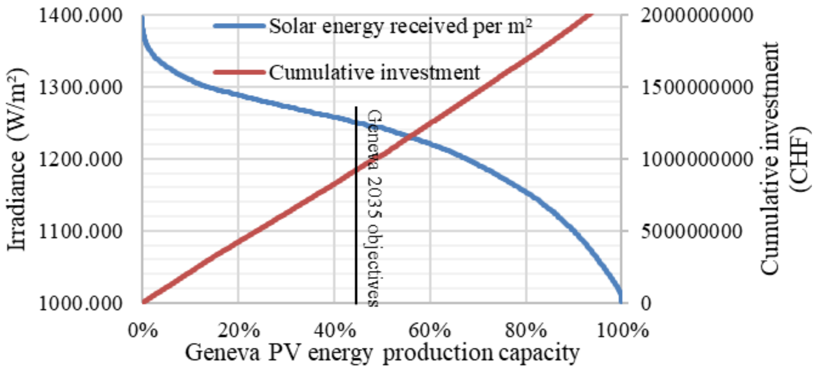

Fig. 7 Geneva energy efficiency of the roofs

Different performance indicator can lead to different planning for the PV deployment. However, despite economic and environmental viability of the PV systems are key criteria in order to decide where they should be implemented, it appears that in urban environment more criteria must be considered in relation with other aspect, such as social or more technical criteria (Thebault et al., 2019). It then appears that taking into account as many decision criteria as possible should be investigated to provide more accurate planning strategy. However, in order to guide public policies or the solar deployment strategies, the relative weights of these criteria must be quantified, which is a complex task.

One must note that recently economical work have been undertaken aiming at taking into account the cost of the variability and intermittency of the PV production into the economic forecast models (see e.g. (Pommeret and Schubert, 2019). Indeed, today in Geneva the PV share of the electricity production is very low and until the PV production additionally to the other intermittent energy production sources reaches a certain share (for which no clear limit has been identified yet, but roughly from 10-30% of the share (PVPS, 2019), almost no additional storage capacity would be required. However, at one-point additional storage systems will be necessary which will make investment cost increases drastically. This aspect should be considered with many care and integrated in planning strategies as soon as possible.

4.2 Towards a monitoring tool

Now in order to have a monitoring tool, other aspects must be considered. In that sense the Plan-Do-Check-Act methodology (Deming and Edwards, 1982) will be followed.

- "Plan" - It appears that despite the improvement and evolution discussed above in section 4.1, the solar cadastre happens to be a relevant tool in order to provide a plan of the PV deployment in the Geneva city for the PV energy production goals of Geneva. Different plans can be obtained depending on the indicator considered.
- "Do" – The solar cadastre is a visualization tools and consequently has no executive feature. However,

it is a relevant tool in order to identify the areas or building that are the most relevant in order to integrate solar system. Therefore, the cadastre can provides decisional support for energetic strategy development at the city scale. For example, based on the EP criteria illustrated in Fig. 4, it could be suggested to facilitate the integration of PV systems on large surfaces through incitement policies.

- "Check" As mentioned above, the current version of the cadastre does not inform about which roofs are equipped with PV systems and which are not. However, this information about is already partially done from the local grid manager (SIG in Switzerland). Indeed, SIG must know how much of PV energy is injected into the grid and where the system is located. However, this information remains confidential. Moreover, it is not possible to know precisely how much of a roof surface is occupied and how much is still available. Given that the Geneva PV deployment objectives imply for 45 % of the buildings to be equipped, it appears crucial for the solar cadastre to include the information about which roofs are already equipped in order to check to which extent the yearly objective have been achieved.
- "Act" The Deming approach is based on a continuous improvement approaches. However, as long as no information is provided about which roofs are equipped or not, then it became not possible to act and adjust the plan based on the previous achievement.

5. Conclusion

This work presents a case study of the use of the solar Cadastre of the Greater Geneva as a planning and monitoring tool. It appears that the current cadastre can provide a relevant tool to define a plan for the solar PV energy deployment, based on the Geneva energetic transition strategy. However, the planning strategy should not only take into consideration the economic criterion as it is also crucial to pay heed to energetic, social or environmental contexts. These layers of information must be integrated in the next version of the solar cadastre in order to provide more adequate planning strategies for the Greater Geneva. Moreover, additional information such as the roofs which are already equipped with PV systems should also be taken into account in order to be able to make the solar cadastre evolve from a planning tool to a monitoring tool for the achievement of solar PV integration goals.

Acknowledgement

Authors would like to thanks the program INTERREG V Suisse-France for providing financial support to conduct this study.

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