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# Solar energy potential at the Great St Bernard Pass

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**Abstract.** The historical site of the Great St Bernard Pass, situated in the Alps at an elevation of 2469 m, records very high electricity consumptions. This study aims at evaluating the photovoltaic potential at the pass. The analysis was performed on the envelope surfaces of the building complex, taking into account the topography as well as typical climate data issued from a weather station located on site. It is found that during the months from June to October, each year, 54 MWh of electricity could potentially be generated, which is more than what could be produced by the same system in the climate of Geneva.

## 1. Introduction

It is well established that in most cases a photovoltaic (PV) system in Switzerland provides a significant amount of electricity with a break-even point achieved before the end of the lifespan of the modules [1]. The setting of the Great St Bernard is, however, profoundly different to that of a common installation in the lowland. Located 2469 meters above sea level on the border between Switzerland and Italy, the historic site of the Great St Bernard centered around its medieval hospice is situated in a distinctive environment. Studies already show the bright side of installing PV systems at this altitude [2]. This paper explores the particular case of the Great St Bernard Pass, with special attention to the climatic, cultural and infrastructural constraints imposed by the nature of the site.

First of all, it should be noted that the site as well as the individual buildings are listed in the ISOS inventory (Federal Inventory of Swiss Heritage Sites) as a place of national importance. The energy refurbishment of historical buildings is nowadays a real topic of interest. Overcoming the barriers for the renovation of culturally important buildings represents a great challenge but is nonetheless possible [3]. In the case of the Great St Bernard Pass particular attention must be paid to the architectural integration of the PV installation in order to limit its visual impact as much as possible.

Located just below the limit of eternal snow, the Great St Bernard Pass is subject to a harsh climate. Except for a few months, snow constantly covers the landscape of the pass. This must be analyzed in detail in order to know the conditions under which the solar modules will have to operate.

Finally, the electricity consumption of the three main buildings of the pass, namely the hospice, the church and the inn, far from being negligible, is mostly due to lightning and appliances. The high electricity needs result not only from the massive size of the buildings but also from the considerable number of lodgers.

## 2. Method

The electricity consumption of the inn, the hospice and the church was calculated by averaging the consumption from 2018 to 2020 issued from the electricity bills provided by the administrator of the

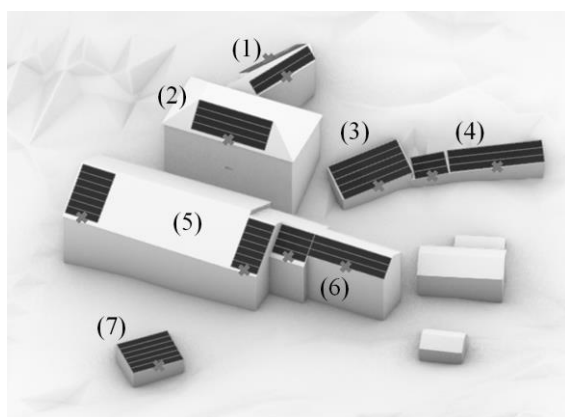


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complex. Electricity is supplied at a special rate by the Great St Bernard Tunnel which connects the site to the Swiss electricity grid.

The solar potential analysis was performed on the envelope surfaces of the building complex, taking into account the topography as well as typical climate data issued from a weather station located on site. The computation was carried out with the software Rhino and its parametric environment Grasshopper using the Ladybug and Honeybee plugins. The 3D models of the buildings and the elevation profiles were issued by Swisstopo [4], made available by the ETH domain.

For the analysis of the solar potential, the roofs shown in black in Figure 1 were considered. It was decided to analyze as many roofs as possible in order to get the most exhaustive look at the solar energy potential. Only the morgue and the restaurant have not been studied. The former is historically too important to allow any form of alteration and the latter has too many dormers on its roof to properly hold a PV system. For the same reason, the middle stretch of the hospice roof was not analyzed.



**Figure 1.** 3D model of the buildings used in this analysis. The roof surfaces evaluated in the study of the energy production are in black. These include the kennel (1), the inn (2), the shed (3), the old stables (4), the hospice (5), the church (6) and the garage (7).

In addition to the analysis of those roofs, the energy production that could potentially be produced on three buildings of the Great St Bernard Pass was compared with the energy that would be produced by the same system in the same environment but with Geneva climate conditions. This allows for a comparison between the PV production potential in two typical climates of Switzerland, the Alpine and the lowland climates respectively.

In parallel, a study of the snow cover on the Great St Bernard throughout the year gave precious information on the production curtailment. The typical weather data from the meteorological station located on the pass was obtained with the software Meteonorm [5]. Concerning the region of Geneva, the weather data was retrieved from EnergyPlus™ [6].

Finally, a visibility analysis was carried out in Grasshopper to identify to which extent the buildings are visible from the surrounding roads and hiking trails. This was achieved by using the same 3D models as for the solar potential analysis.

### 3. Results and Discussion

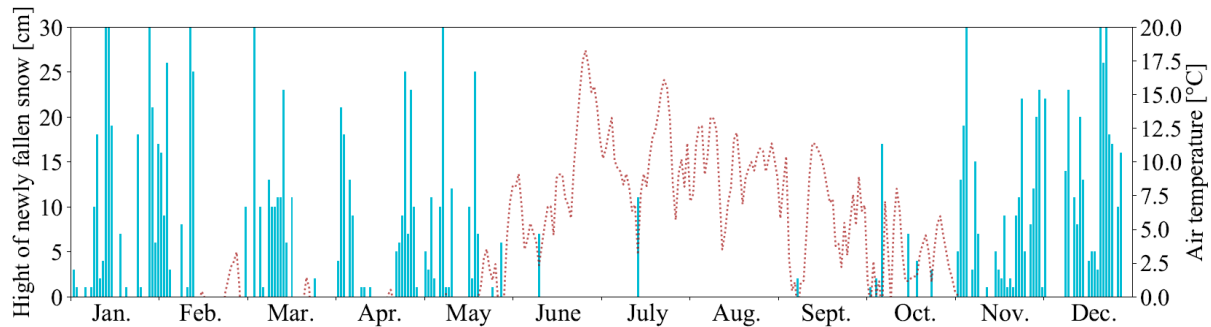
#### 3.1. Weather conditions

The weather conditions in the Alps are far from trivial. Snow is present at the pass during more than 280 days a year. This has two consequences on the electricity production of PV systems. First, if the modules are covered with snow, production is greatly reduced or even stopped depending on the thickness of the layer [7]. Secondly, the snow covering the ground in front of the roofs increases the albedo of the surrounding surfaces [8]. Thus, more solar radiation is reflected by the ground and captured by the solar panels.

The analysis of the snow cover at the pass demonstrates that the ground is practically devoid of snow, in August and September as well as in the second half of July and the first half of October.

During the rest of the year, however, there is a layer of snow on the ground which increases considerably the surrounding's albedo.

When the ground is covered with snow, the modules may remain clear. In Figure 2 it can be seen that from June until the end of October it rarely snows at the pass. In addition, the temperature during these same months is generally above 0 °C, thus favoring the melting of the snow. It is therefore reasonable to consider the roofs of the buildings to be free of snow during these months. In practice, it may be necessary to clear the roofs once or twice in October, in order to maximize the energy production.



**Figure 2.** Height of new snow per day (bars) and the air temperature at 2 m from the ground (dotted line) for the year 2019.

During the month of June along with part of July and October, the modules are free of snow but the ground is covered with it. This means that the diffuse radiation impinging on solar cells is increased by the albedo of the environment.

Then, the amount of snow, falling between the period extending from November to May, is too high to suggest any significant electricity production, especially on the less pitched roofs. However, the roofs may remain clear of snow for periods of several days. For the calculations, the most pessimistic scenario, which considers all the roofs covered with snow from November to May, is selected.

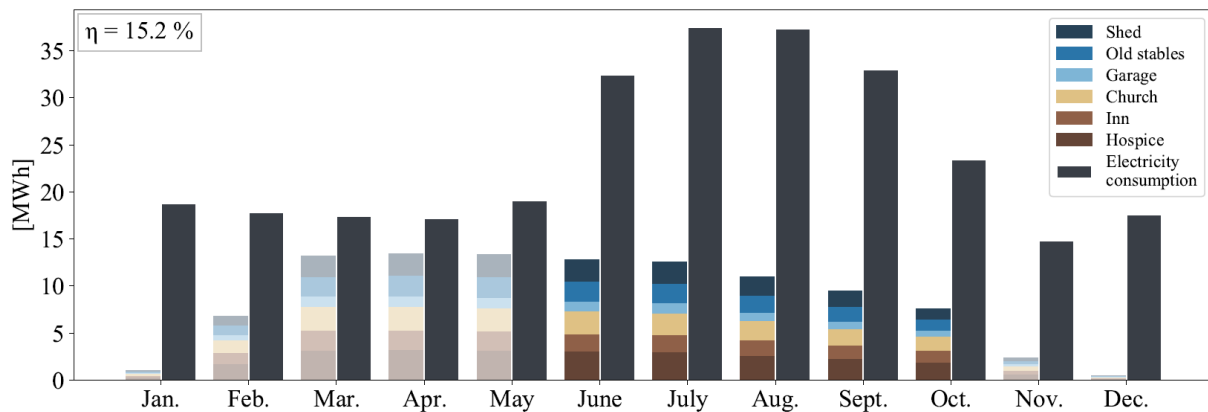
### 3.2. PV production

Table 1 summarizes the value chosen for technical parameters used for the calculation of the electricity production by a PV system.

**Table 1.** PV system characteristics.

System parameter	Value
Modules efficiency	0.152
Inverters efficiency	0.850
Modules active area	0.930
Temperature coefficient	-0.258

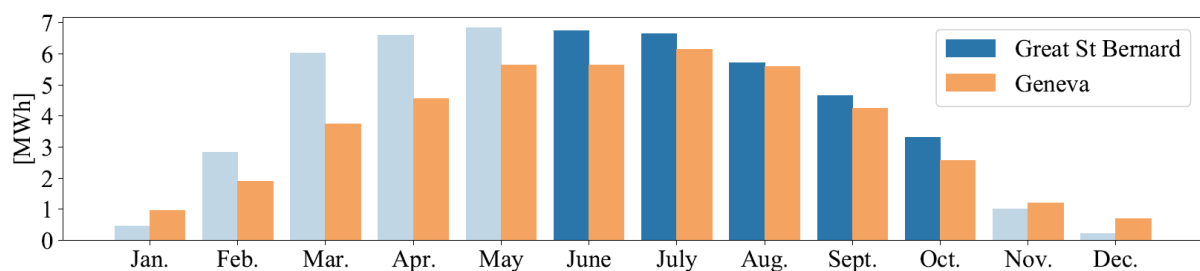
The diversity of roofs implies a wide range of energy production and production efficiencies. Figure 3 compares the electricity needs of the buildings with the production from their respective roofs. Only the kennel was left out of this plot because it is the least profitable roof considering the cost per unit area of energy, due to its poor orientation and its numerous windows. As can be noted in this Figure, a considerable amount of electricity is produced between the months of March and July. However, due to the snow cover on the solar panels between the beginning of November and the end of May, a significant quantity of solar radiation cannot be harvested.



**Figure 3.** Photovoltaic production from different roofs from June to October in comparison with the annual electricity consumptions of the buildings. The discolored bars represent the electricity production potential lost due to the snow cover.

With a 723 m<sup>2</sup> surface equipped with photovoltaic modules distributed on six roofs and by considering a module efficiency of 15.2 %, 54 MWh of electricity would be produced each year. This means that 18.7 % of the annual needs could be covered. This value may be reduced due to the mismatch between instant energy demand and supply. Without batteries, the electricity created by the solar panels must be consumed immediately. Depending on the size of the installation, this would not be a problem. In fact, if the production is low compared to the needs, all energy produced is instantly consumed. Otherwise, the excess production will have to be sold on the Swiss electricity grid.

Then, the comparison between the PV potential in the highlands and lowlands of Switzerland highlights some key elements. The potential electricity production of the same system if it were to be installed once in the climate of Geneva and once in the climate of the Great St Bernard Pass is shown in Figure 4. Except during the months of January, November and December, the estimated production at the pass is higher than that of Geneva. This difference in production is especially pronounced during the months from March to June when the energy produced at the Great St Bernard Pass is between 38 % and 16 % higher than in Geneva.



**Figure 4.** Comparison between the photovoltaic productions of the same fictitious installation modelled with the climate data of the Great St Bernard Pass and of Geneva. The discolored bars represent the electricity production potential lost due to the snow cover at the pass.

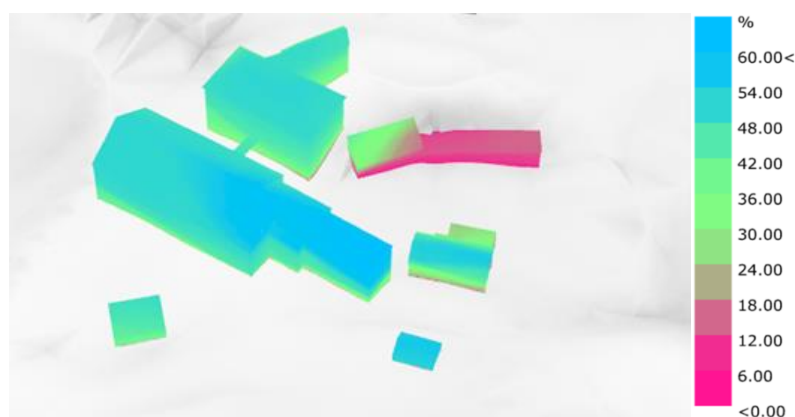
It is necessary to note that the energy production at the Great St Bernard does not take into account the effect of snow cover on photovoltaic panels. If we consider that the modules are covered from November to May, the production at the pass would be reduced by 47 %, which results in a much lower production than that of an installation in Geneva where snow is not such an issue. To obtain an energy production at the pass equivalent to that of Geneva, it would be necessary to clear the solar panels from snow from mid-March to June.

Provided the panels are free of snow, an installation in the mountains is therefore more energy-efficient than in the plains. Be that as it may, it is difficult to plan on clearing the modules after each new snowfall, especially since the volume of fresh snow can be very high at the Great St Bernard Pass.

### 3.3. Context

As explained previously, the Great St Bernard Pass presents a very specific context compared to the settings in which most solar installations take place. The most notable differences are the presence of snow cover in winter and spring and the fact that the buildings are under the protection of the Swiss legislation which minimizes the possible alterations of the site. These do not affect all the roofs to the same extent. The shed and the old stables can totally disappear under the snow during the cold period. This adds a considerable load on the PV system. Moreover, snow will remain on those roofs the longest. On the other hand, with their high steep roofs, the inn, the hospice and the church have less snow accumulating on them. However, they are subject to stronger architectural protection [9]. This means that when selecting roofs to hold a PV system, the potential energy production is not the only criterion that should be taken into account. How snow accumulates on each roof, as well as the visibility of the buildings and the degree of architectural protection are decisive elements to consider.

Figure 5 shows the results of the visibility analysis. The least visible buildings are warm in color. On the contrary, the blue buildings are visible on more than half of the surrounding roads and hiking paths. As can be seen in this Figure, the buildings subject to strong architectural protection, namely the inn, the hospice, the church and the morgue, are particularly visible from the surrounding pathways. Therefore, a system fitting perfectly into the landscape is needed on those culturally relevant buildings. Part of the answer could come from colored solar modules [10] or modules shaped like ordinary tiles [11, 12, 13] which would blend smoothly in the architectural style of the buildings.



**Figure 5.** 3D model of the buildings. The color represents the percentage of sample points on the road and surrounding hiking trails from which these buildings remain in line of sight.

Architectural integration is not the only field of research where great progress could significantly impact the implementation of PV systems at the pass. Indeed, the clearing of snow on solar panels [14, 15] is also an important topic. Following the massive development of solar energy, researchers and promising companies are looking for solutions to face this constraint. Progress in this field of research would be groundbreaking for the Great St Bernard Pass and solar energy in mountain environments in general. Close to half of the production is lost due to the snow cover during the cold season. Having a system that frees the solar modules from the snow would make the regain of this energy possible.

## 4. Conclusion

From this study, it emerges that the Great St Bernard Pass presents a very particular setting for a solar system. Not only is it the subject of strong architectural protection, but it must also face a harsh climate. The pass is covered with snow for more than two-thirds of the year. It is therefore estimated that photovoltaic energy production is only possible during the months from June to October. The rest of the year the solar modules are considered to be covered with snow.

By equipping six roofs with PV systems, up to 18.7 % of the pass's electricity needs could be supplied by renewable energy produced directly on-site. This potential would greatly be increased if the modules could remain free of snow all year round. In that case, the electricity production potential at the Great St Bernard Pass would be greater than an identical system situated in Geneva.

Following this analysis, it is clear that great care must be taken when designing a system in line with the particular context of the Great St Bernard. An appropriate solution could be to use solar cells in the form and color of traditional tiles which integrate perfectly into the landscape and are resistant to strong structural stresses resulting from harsh weather conditions. These requirements should be met while integrating a heating system that can free the roof from the snow. Such an ambitious system would greatly benefit the spread of solar energy production in Alpine environments.

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