Ski Green Challenge

Project Report

Computational methods and tools
ENG-270

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1 Deviations from project proposal

We faced different challenges during the first steps of the project. The main problem was the lack of accessible data on the watershed's inflows, particularly information on the rates of glacier melt. Furthermore, the lack of open source models directly related to our topic limited our ability to build on existing research.
This lack of resources made it impossible to proceed with our initial plan. We were unable to accurately model seasonal changes of water inflow or predict the energy potential of the Grande Dixence reservoir. Therefore, we decided to reconsider our approach and find a project that was doable with the available resources we could find. We chose to model the energy produced by a fictional dam that would be filled only by rainfall. We then decided to add solar panels to our model, to compensate energy production during low rainfall seasons. Green energy is the future, especially in mountainous places, where glacier melt, precipitation, wind and radiation are the greatest in the country.

2 Introduction

Renewable energy is becoming increasingly important as we work to reduce the environmental damage caused by fossil fuels. In mountainous regions, cable cars are widely used for tourism and transportation, but they can consume a lot of energy. Finding a sustainable way to power these systems is a significant challenge, especially in areas where energy infrastructure may be limited.
For our project, we focused on powering a cable car system located in Le Säntis, Switzerland. This location was chosen because it has one of the highest precipitation rates in the country(1), making it ideal for evaluating the potential of a hydroelectric dam. In addition, the combination of sunny and rainy days allows us to explore the feasibility of integrating solar panels and hydropower into one system.
As environmental engineering students, our task is to design a sustainable energy solution that could not only support the cable car's energy demand but also serve as a model for similar applications in other regions, like ski resorts. The goal is to determine how large the retention basin of the dam should be and how many solar panels are needed to supply the energy demand of the system.

3 Approach used

To calculate the energy needs of the cable car system and the energy produced by the solar panels and the dam, we used simple physics equations. These equations helped us find the minimum size of the dam's retention basin and the number of solar panels needed.

Cable Car Energy Demand

The cable car requires energy to lift people and itself to a higher altitude. The energy demand is calculated using this formula:

$$E_{\text{cabin}} = \frac{(m_{\text{cabin}} + m_{\text{persons}} - m_{\text{cabin}}) \cdot g \cdot H}{\eta_{\text{motor}}}$$

Where:

- m_{cabin}: Mass of the empty cabin [kg]
- m_{persons}: Total mass of the passengers [kg]
- g: Gravitational acceleration (9.81 m/s^2)
- H: Height difference the cabin travels [m]
- η_{motor}: Efficiency of the motor (accounts for friction and other losses)

This formula gives the energy needed for one trip up the mountain. Since the cabin's return trip down cancels the energy needed for the empty cabin's weight, we only consider the passengers' mass. We multiply this energy by the number of trips per day to find the total daily energy demand.

Minimum number of panels

The energy produced by the solar panels depends on their power, sunlight hours, and efficiency. We calculated the number of panels needed with this formula:

$$\text{Panels}_{\text{min}} = \frac{E_{\text{consumption\_day}} \cdot 0.5}{P_{\text{panel}} \cdot 0.001 \cdot \eta_{\text{solar}} \cdot t_{\text{average daylight}}}$$

Where:

- $E_{\text{consumption\_day}}$: Daily energy needed by the cable car [J]
- P_{panel}: Power of one solar panel [W]

- η_{solar}: Efficiency of the solar panels
- $t_{\text{average daylight}}$: Average number of sunlight hours per day [hours]

This gives the minimum number of solar panels required to meet half the energy demand ("x0.5"), assuming the other half is supplied by the dam. The "0.001" gives kW instead of W.

Minimum size of the retention basin

The dam produces energy by using the water in the retention basin. To make sure the basin has a large enough volume, we calculated its minimum area using this formula:

$$\text{Area}_{\text{basin}} = \frac{E_{\text{consumption\_day}} \cdot 0.5}{(\text{average precipitation} \cdot 0.001 \cdot \rho_{\text{water}} \cdot g \cdot h \cdot \eta_{\text{t}} \cdot \eta_{\text{f}})/3.6 \cdot 10^6}$$

Where:

- $E_{\text{consumption\_day}}$: Daily energy needed by the cable car [J]
- ρ_{water}: Density of water (1,000 kg/m^3)
- g: Gravitational acceleration (9.81 m/s^2)
- h: Height difference the water falls [m]
- η_{t}: Yield of the turbine
- η_{f}: Yield of the pipe due to friction

We assume that the height of the basin is large enough to retain heavier rainfall. The "0.001" gives meters instead of millimeters. The "$3.6 \cdot 10^6$" gives "kWh" instead of "J" for every following equation.

Energy Generation Over Time

To calculate how much energy is produced each day, we used data for sunlight and rainfall from 2023 in Le Säntis.

Dam Energy Each Day:

$$E_{\text{dam}}(day) = \frac{\text{Precipitation}(day) \cdot \text{Area}_{\text{basin}} \cdot \rho_{\text{water}} \cdot g \cdot h \cdot \eta_{\text{f}} \cdot \eta_{\text{t}}}{3.6 \cdot 10^6}$$

Solar Panel Energy Each Day:

$$E_{\text{solar}}(day) = \text{Daylight}(day) \cdot P_{\text{panel}} \cdot 0.001 \cdot \eta_{\text{solar}} \cdot \text{Panels}_{\text{min}}$$

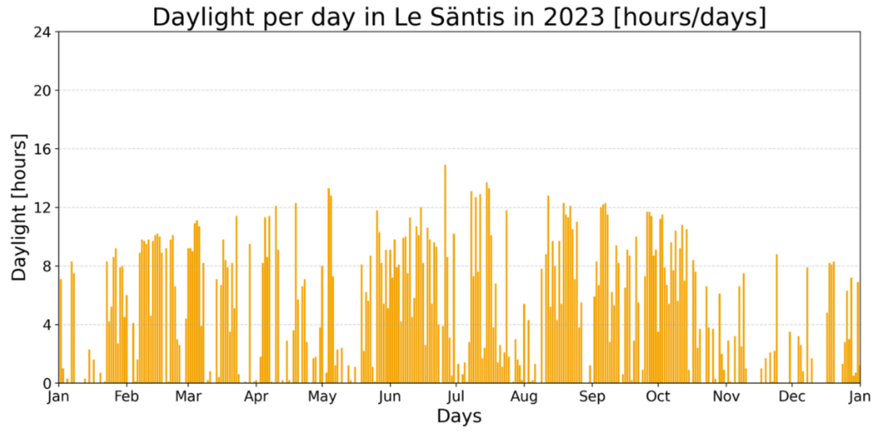
We designed the system so that the dam and the solar panels contribute to 50% of the total energy demand in 2023.

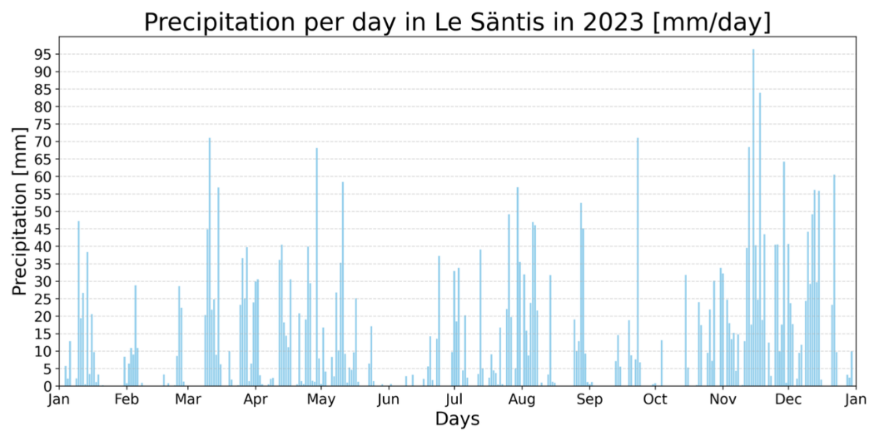
Cable Car Energy Each Day:

$$E_{\text{cablecar}}(day) = \frac{E_{\text{cablecar}} \cdot \text{departures}}{3.6 \cdot 10^6}$$

In our case, there are 16 departures per day.

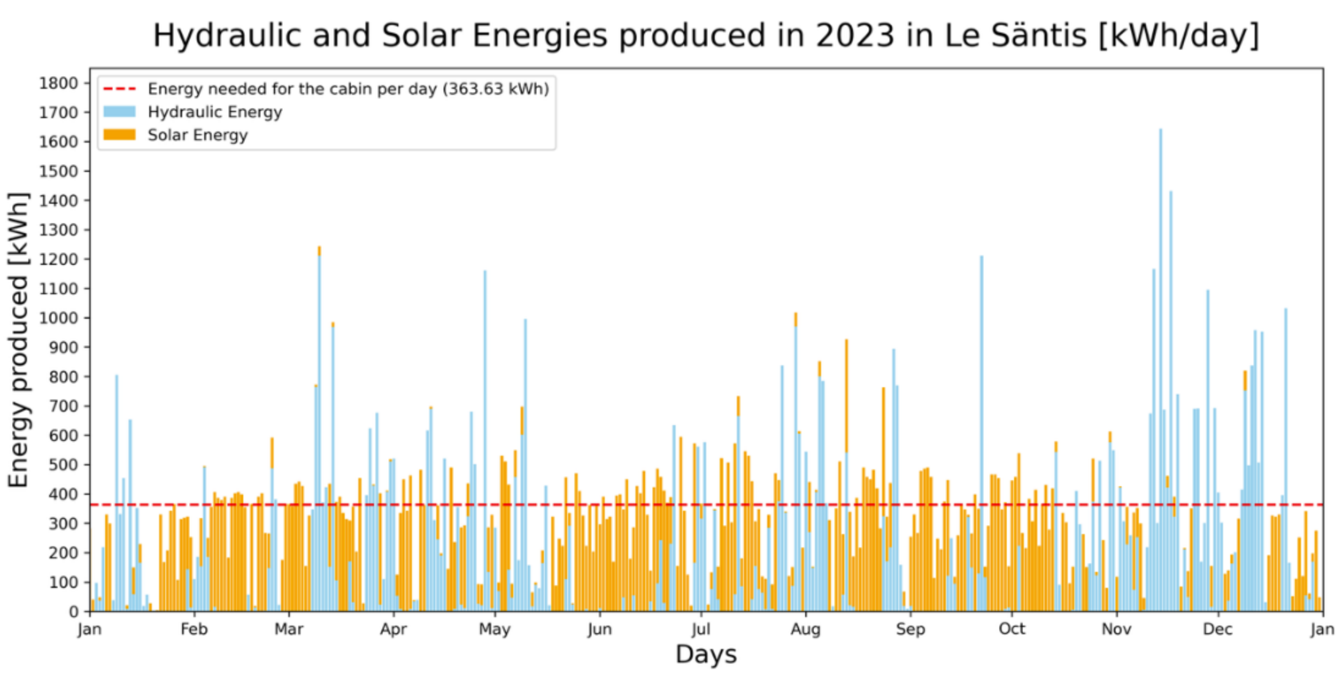
4 Results



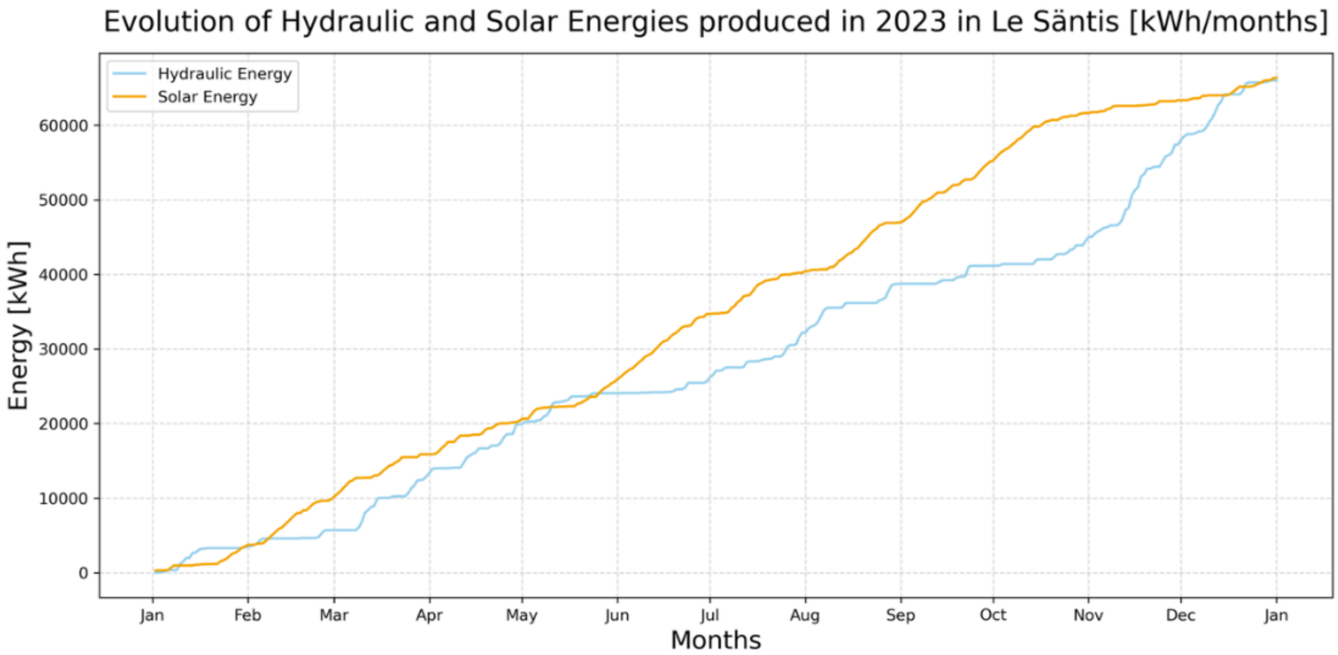


Precipitation values exhibit variability, with occasional peaks corresponding to heavy rainfall events. Sunlight data follows a seasonal pattern, with longer daylight durations recorded during specific times of the year. These inputs are used to calculate the energy outputs of the solar panels and the retention basin.

With regard to those inputs and our initial data, we need a minimum of 117 solar panels to generate 50% of the annual energy demand. This is determined on the basis of average sunlight hours and panel efficiency.
The retention basin must have a square length of 93 meters to store the volume of water needed for the other 50% of the energy production. We design the basin to account for variations in daily precipitation.



This histogram shows the daily energy produced by the solar panels and the dam. Solar energy production varies throughout the year, with noticeable fluctuations in output. The hydraulic energy also changes daily, with distinct peaks and troughs.



This graph shows the total energy produced by the dam and the solar panels in 2023. Both sources provide around 70,000 kWh, which is half of the total energy needed. The solar energy increases more or less constantly through months with a steeper slope in summer. The hydraulic energy is produced largely during heavy rainfall seasons, like Spring and Autumn, and increases slower in Summer and from January to March. Both sources reach the same total by the end of the year, showing a balanced energy contribution.

5 Interpretation

The graphs reveal distinct peaks in energy production for both sources. Solar energy peaks occur during periods of intense sunlight, typically in summer, due to longer daylight hours and clearer skies, which increase the efficiency of solar panels. On the other hand, hydraulic energy peaks are observed during heavy rainfall events, when water inflow into the retention basin is at its highest. In addition to these peaks, seasonal changes play a significant role in energy variation. The solar energy output remains higher and more constant in summer, whereas the hydraulic energy is more reliable during the rainy seasons, such as spring and fall. Despite these differences, the system maintains a close contribution from both energy sources over the year. This complementary relationship ensures that the overall energy demand is met without over-relying on a single source during specific times of the year. These variations emphasize the importance of balancing and optimizing energy production to effectively handle overproduction and underproduction.

However, while the system maintains balance on an annual basis, energy storage is essential to compensate for daily and seasonal fluctuations. There are days when energy production falls below the required level due to low sunlight or insufficient rainfall, such as shorter days in winter with no precipitation. During these periods, stored energy becomes essential to maintain a sufficient supply to the system. However, on days with extra energy production, storage prevents wastage and allows extra energy to be used later.

The results also confirm that solar and hydraulic energy each contribute about 50% of the total annual energy production, with both sources providing approximately 67,000 kWh. This 50/50 split highlights the system's ability to balance contributions from two complementary sources, ensuring that the cable car's energy needs are constantly met through seasons.

Although it is technically possible to design a system that meets 100% of our energy demand, an infrastructure that requires a 93 m wide squared retention basin and 117 solar panels represents a large-scale investment. For practical and economic reasons, it may be more feasible to design a smaller system that produces only a portion of the energy demand. This reduced approach could supplement existing energy sources, reducing the dependence on fossil fuels while avoiding excessive infrastructure. Producing a smaller portion of the energy demand would offer a cheaper and a more sustainable alternative for the future.

An approach like this aligns with the goals of sustainable tourism and energy use in mountainous regions. Many ski resorts and tourism infrastructures are already adopting renewable energy strategies to reduce their carbon footprint and improve energy management(4).

6 Conclusion and outlook

In conclusion, our project provides a basic functional model for integrating solar and hydraulic energy to meet the energy demands of a cable car system. Our approach is basic, especially regarding the dam. We modeled a gravity dam using precipitation as the only water source, which does not include other potential inflows, such as ice melt from glaciers or river incomes. Additionally, the equations we used for energy calculations are simplified to make the model more accessible and straightforward. To complexify the approach, we could use for example the "breaking energy", as it is already done in some cases "l'énergie de freinage des remontées mécaniques est employée pour générer de l'énergie supplémentaire."[3]

Despite these simplifications, the model demonstrates the potential for combining solar and hydraulic energy to meet energy needs. Both energy sources can contribute equally to the system, achieving a balanced output over the year. The simplicity of the model allowed us to focus on feasibility and conceptual design, but also limits the precision of our results.

Looking ahead, this model could serve as a starting point for more detailed and accurate designs in renewable energy applications. The principles of this system could be applied to ski resorts or other transport infrastructures. The simplicity of the equations makes the model adaptable for different purposes. Future work could adapt the model to include additional water incomes, more complex dam designs or detailed energy calculations. Furthermore, integrating other renewable energy sources, such as wind, could improve the overall performance and scalability of the system.

7 Sources

1. *Quelques statistiques sur l'année 2022*, météosuisse, 07.01.2023, https://www.meteosuisse.admin.ch/portrait/meteosuisse-blog/fr/2023/01/quelques-statistiques-sur-l-annee-2022.html, consulted on 08.12.2024.

2. *Portail de données pour l'enseignement et la recherche (IDAweb)*, météosuisse, 2016, https://gate.meteoswiss.ch/idaweb/login.do;idaweb=whXQTQtPkTSbh3dGcrWzyDnBHQ7sJJnQhz01vbZhWhdKTdHkq1h0!-1907983237, consulted on 20.11.2024

3. *Gestion de l'énergie par les remontées mécaniques suisses*, Remontées mécaniques suisses, https://www.seilbahnen.org/fr/themes/gestion-energie, consulted on 27.11.2024.

4. *11 domaines skiables suisses qui misent sur la durabilité*, myswitzerland, 2024, https://www.myswitzerland.com/fr-ca/planification/vie-pratique/la-suisse-durable-par-nature/activites/sustainable-activities-in-winter/11domaines-skiables-suisses-qui-misent-sur-la-durabilite/, consulted on 27.11.2024.

5. *Quelle est la puissance d'un panneau solaire photovoltaïque?*, ENGIE my power, 23.04.2024, https://mypower.engie.fr/conseils/panneaux-solaires/caracteristiques-panneaux-solaires/puissance-panneau-solaire.html, consulted on 27.11.2024.

6. *Quelle quantité d'eau faut-il pour produire 1 kWh ?*, Ville de Genève, 04.10.2022, https://www.geneve.ch/themes/culture/bibliotheques/interroge/reponses/quantite-eau-faut-il-produire-1-kwh, consulted on 28.11.2024.

7. *ChatGPT*, https://chatgpt.com/, consulted for coding during the whole project.