Lucerne University of Applied Sciences and Arts

Engineering and Architecture
B.Sc.. Energy and Environmental Systems Engineering
Bachelor-Thesis

Solar Project

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1. Introduction, Goals and Research Questions

Photovoltaic (PV) systems play a central role in the global transition toward renewable electricity generation. While PV technology is mature, the energy yield of a solar installation depends strongly on geometric factors such as geographic latitude, seasonal solar motion, panel tilt angle, and local shading conditions. In practice, panel orientation is often chosen using empirical rules or simplified assumptions, which may lead to suboptimal performance, especially in complex terrain or urban environments.

This project investigates photovoltaic energy production from a geometric and analytical perspective. By modelling the sun's position and its interaction with tilted surfaces, the study aims to quantify how panel orientation and shading geometry influence annual solar energy yield under clear-sky conditions.

2. Method Overview and Materials

The methodology is based on a deterministic, geometry-driven modelling approach implemented in Python. The sun's position is calculated analytically using solar declination, hour angle, and geographic latitude. From this, solar elevation and azimuth are derived for every hour of the year.

Incident solar irradiance is separated into direct (beam) and diffuse components. The irradiance on a tilted photovoltaic surface is calculated using the angle of incidence between the solar rays and the panel normal. Local shading effects are included through a geometric horizon model and a sky view factor that reduces both direct and diffuse radiation.

Annual and monthly energy yields are obtained by numerical integration of hourly irradiance values. The optimal tilt angle is identified by evaluating annual energy production for tilt angles between 0° and 90°.

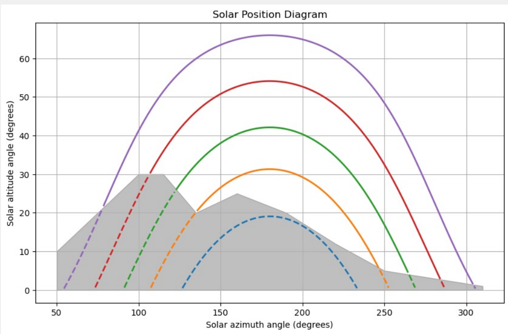

Figure 1: Solar Position Diagram

The baseline test results, shown in the accompanying graphs, illustrate the relationship between panel tilt angle and photovoltaic energy yield under clear-sky conditions and a fixed geographic latitude representative of Switzerland. The annual energy yield as a function of tilt angle exhibits a smooth, unimodal curve with a clearly defined maximum, confirming the expected theoretical behaviour derived from solar geometry.

Industry Partner

CC Fluidmechanik und numerische Methoden

3. Results and Discussion

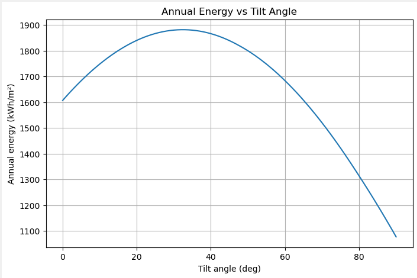

Figure 2: Ideal tilt angle Graph

The energy–tilt graph demonstrates that horizontal panels significantly underperform compared to inclined configurations, particularly due to reduced winter irradiance capture.

As the tilt angle increases, annual energy yield rises steadily until reaching an optimum at approximately 35°, after which the yield decreases due to reduced summer irradiance and increased angular mismatch. This behavior confirms that a single optimal fixed tilt angle exists for maximizing annual energy production at a given latitude.

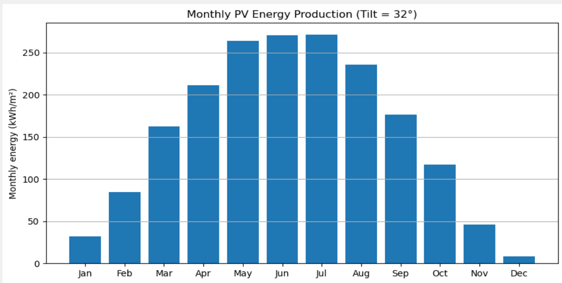

Figure 3: Monthly Energy Production

4. Conclusion and Recommendations

This project demonstrates that a geometry-based analytical model is sufficient to describe the dominant effects governing photovoltaic energy production. Panel tilt optimization based on solar geometry leads to measurable improvements in annual energy yield without additional system costs. The findings highlight the importance of considering local horizon geometry in PV system design, particularly in complex terrain or built environments.

References

Duffie, J. A., & Beckman, W. A. (2013). *Solar engineering of thermal processes* (4th ed.). Wiley

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