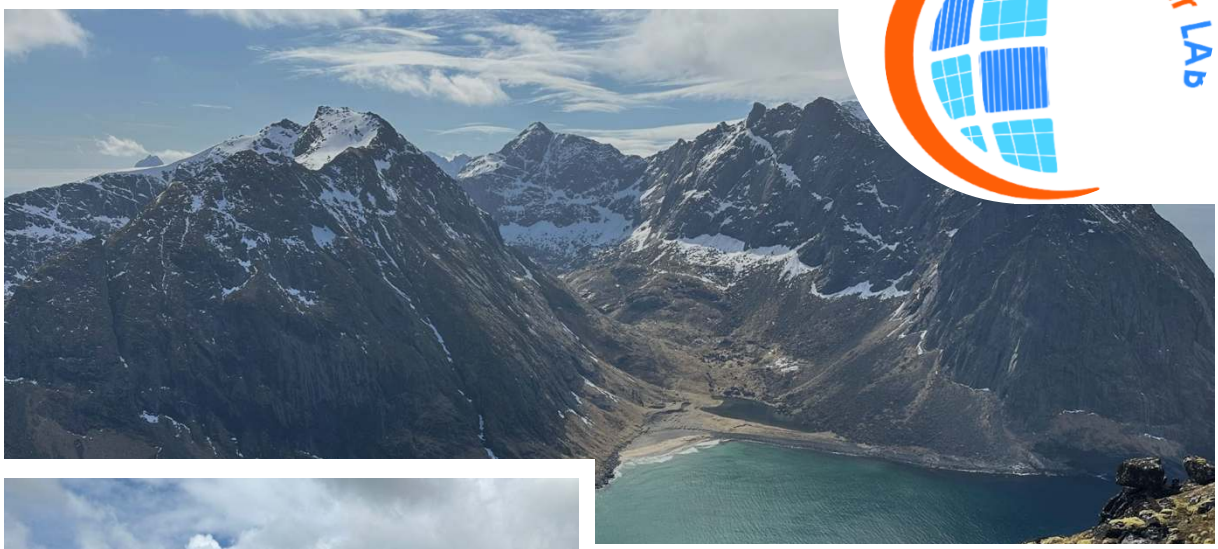
Final activity report, Solar Lab
January – June 2025







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Høgskulen på Vestlandet

icam

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1. Introduction

A. Internship Context

As part of my engineering studies at ICAM, I had the chance to spend a semester abroad at the Western Norway University of Applied Sciences (HVL) in Bergen. This internship gave me the opportunity to explore an exciting topic quite different from what we usually see in France: the study of passive houses and renewable energies, in a particularly challenging Nordic climate.

Beyond the technical aspect, this experience pushed me to face several personal challenges: overcoming the language barrier, adapting to a new culture, and working in an international environment. All of these helped me grow both professionally and personally. I will come back to this in more detail in the conclusion of this report.

The internship took place at the SolarLab, a solar laboratory designed to study solar energy production and consumption in Bergen, a city known for its wet climate and low sunlight. This project is part of HVL's educational program, allowing students to experiment and work on real solutions around renewable energy. Every year, one ICAM student is selected to join this lab and contribute to its continuous improvement. My role was to optimize the existing system, meet the expectations of my supervisor, Richard, and collaborate with Norwegian students working on related projects.

This report presents the tasks I completed, the challenges I faced, and the solutions I found, while highlighting the importance of this project for research and teaching.



B. Objectives of the SolarLab

The SolarLab aims to replicate how a passive house works that is, a home designed to minimize energy consumption through high-performance insulation, optimized management of renewable energy production, and control of usage.

Located in Bergen, which has one of the wettest climates in Europe, the lab is an ideal testing ground to analyze the performance of a solar installation under very challenging conditions. The goal is to gather precise data on electricity production and consumption to evaluate the feasibility and efficiency of such a system in a Nordic context.

This data not only helps identify weaknesses and areas for improvement but also serves as a concrete resource for students to deepen their knowledge of solar energy and the design of highly energy-efficient buildings.

C. Importance of the Study

As climate issues become more urgent, research on renewable energy and energy autonomy is essential for building sustainable solutions. In Norway, where nearly 90% of vehicles are electric and many isolated homes (like cabins) are not connected to the grid, projects like this have a very practical significance.

The SolarLab aims to prove that it is possible to maintain a comfortable living standard while minimizing external energy input, even in a city with low sunlight like Bergen.

On a personal level, this experience made me realize that producing and consuming your own energy is not limited to large industrial projects — it is also accessible on an individual scale.

Finally, beyond the technical aspect, the SolarLab also plays a key role in raising awareness and training future engineers about more responsible and sustainable consumption habits.

D. Report Structure

This report is organized as follows:

- An introduction to the SolarLab and its main equipment
- An explanation of the system access methods and monitoring tools (SMA EnnexOS, Sunny Portal, Raspberry Pi)
- A review of the problems encountered and the actions taken to address them
- An analysis of the SolarLab's efficiency through data study and a comparison with simulation results from PVGIS
- A detailed overview of the tasks I completed during my internship
- A general discussion and recommendations for the future of the project
- Finally, a conclusion summarizing the main lessons learned from this experience
- And annexes including data, graphs, and diagrams related to the project

2. Presentation of the SolarLab

A. History and previous work

The SolarLab is the result of an evolving project started about four years ago. Over time, several students have contributed one after another to improve its performance and scientific value. To give a clearer picture of how the lab has developed, I've summarized here the main phases of the project, which you can also find in the annex.



Phase 1: Installation and initial setup

The project began with setting up a complete photovoltaic system:

- 12 solar panels, including 6 monocrystalline and 6 polycrystalline, for a total power of 3.36 kWp
- Sunny Boy inverters to convert the solar energy into usable electricity
- An electrical distribution board to distribute the produced electricity
- A Power Oak ES5048 battery with a capacity of 20 kWh, used to store energy and power the lab when there's not enough sunlight

Phase 2: Monitoring and optimizing energy production

The next step focused on monitoring and optimizing production:

- Developing a real-time data display system using a Raspberry Pi
- Setting up the Modbus TCP protocol to allow communication between the Raspberry Pi and the inverters
- Studying how to integrate the Sunny Island system to better manage stored energy and improve autonomy

Phase 3: Studying solar irradiation and storage management

This phase aimed to improve production and storage management:

- Installing Tigo optimizers to get more detailed monitoring and better performance for each panel
- Researching and selecting a better battery to replace the Power Oak, to fix compatibility and autonomy issues
- Launching a first version of the website: solarlab online, to make the collected data available

Phase 4: Detailed analysis of sunlight

To better understand how the local climate and sunlight affect the system in Bergen:

- Creating 3D simulations using SketchUp and the Skelion plugin to analyze solar exposure and optimize the placement of the panels
- Installing a pyranometer to measure real-time solar irradiance received by the SolarLab
- Developing Python scripts to collect, store, and visualize this data, which remains available on the project website

Phase 5: Energy management and final battery choice

The goal of this step was to secure energy continuity:

- Choosing and validating the new Tesvolt TS25 battery, which is more reliable and compatible with existing equipment
- Improving the data monitoring scripts to make them more precise and clearer

Phase 6: System optimization and generator management

Finally, the latest work focused on overall optimization:

- Improving how the backup generator works by configuring the Sunny Island system
- Installing and configuring a double flow ventilation system (Flexit CI 600) to reduce heat loss and keep the inside temperature comfortable
- Reorganizing and improving the hardware interface, mainly by setting stable IP addresses to make remote access and maintenance easier

B. Description of the SolarLab

The SolarLab is mainly an experimental passive house, designed to test and show how a home can run almost entirely on solar energy, even in tough weather conditions like those in Bergen. Here's how it's built and equipped.

The building follows the main principles of passive houses:

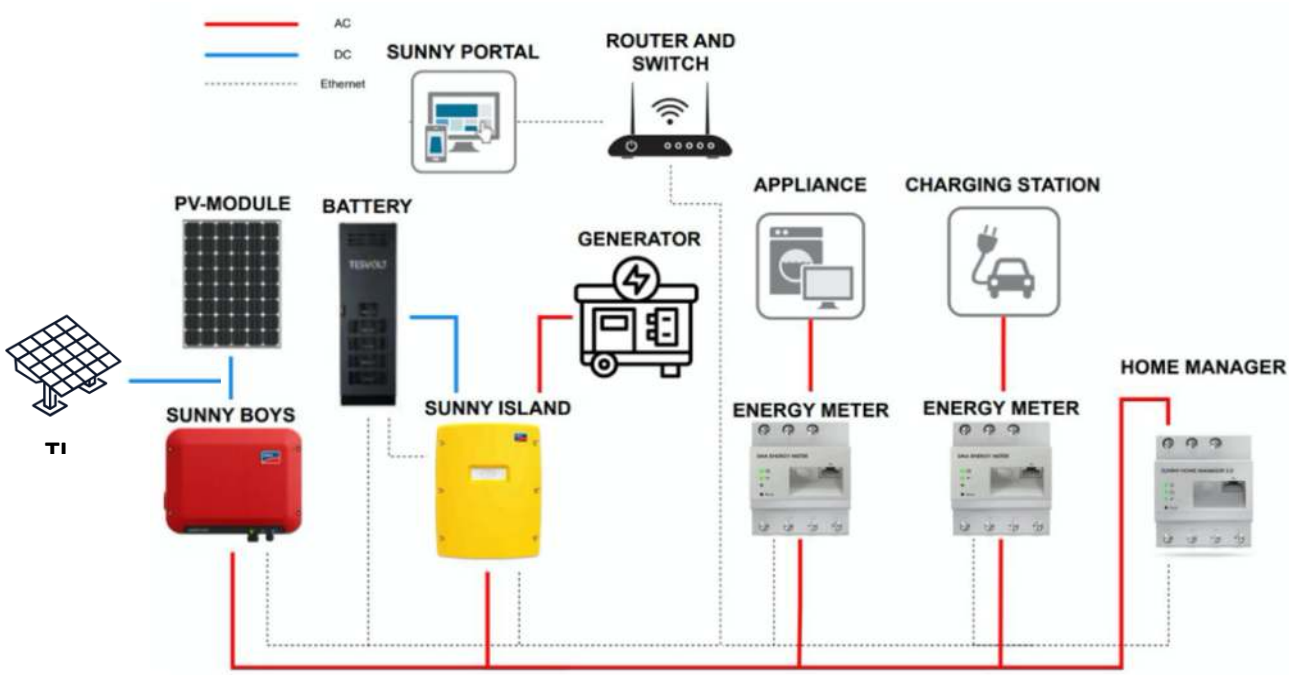
- Improved thermal insulation to reduce heat loss as much as possible, which is essential in a region with low temperatures and lots of humidity
- Better airtightness to reduce leaks and improve overall energy efficiency
- A design and orientation that help capture as much sunlight as possible, despite many cloudy days

The goal is twofold: to keep the indoor comfort stable while cutting down external energy needs as much as possible.

C. Main equipment

The SolarLab has a set of complementary devices:

- 12 solar panels (6 monocrystalline and 6 polycrystalline) to capture solar energy
- Sunny Boy inverters to convert the electricity into usable AC power
- A Tesvolt TS25 battery (recently installed) to power the building at night or during bad weather
- A Sunny Island inverter that manages the system by controlling when the battery charges or discharges, and handling the backup generator if needed
- A Kipp & Zonen SMP11 pyranometer to measure real-time sunlight for analysis
- A Flexit CI 600 double-flow ventilation system, which recovers heat from outgoing air to preheat fresh incoming air, helping to save on heating



D. How the system works and energy management

The whole system is based on a simple idea: to produce, store, and use solar energy in a smart way.

- The extra energy produced during sunny periods is stored in the Tesvolt battery.
- When production isn't enough, the SolarLab can use this stored energy, or if needed, turn on a backup generator (connected to the grid), which is set to run only when really necessary.
- The different energy meters measure and send their data to the SMA Ennexos portal.

Altogether, this creates an intelligent ecosystem where each device is connected to help maximize autonomy and improve overall energy efficiency.

3. Access to the system

A. Managing interfaces and configurations

Access to the SolarLab's data and control system relies on several tools that let us monitor, analyze, and configure the installation.

The first and probably the most useful on a daily basis is the SMA EnnexOS portal. Thanks to this online platform, we can track the SolarLab's energy production and consumption in real time. It collects all the data and displays it clearly so we can quickly see how the system is doing.

A second, more technical access is through the SolarLab's local network. By connecting a computer with an Ethernet cable to the Wi-Fi router in the lab, we can enter the IP addresses of the different devices directly in a web browser. This access is very important because it lets us change advanced SMA system settings (for example, setting charge priorities, checking each inverter, or adjusting alert thresholds).

The exact IP addresses are listed in the appendix at the end of this report.

The TIGO portal is also very useful to monitor each individual solar panel. Each panel has a TIGO optimizer on the back, which records data during the day: current produced, instant power, total energy, and so on. These data can be exported as a CSV file, which helped me do detailed panel-by-panel analysis and spot possible anomalies or differences in performance. The login and link to the TIGO portal are also included in the appendix.

Finally, the pyranometer measures the actual solar irradiance on the lab. Installed on the SolarLab's roof, this sensor constantly records the available solar power. A former student created a Python script to automatically save and display this data as graphs, which are available on the internal SolarLab website. These data can also be exported and compared to the panel data to calculate the overall efficiency the ratio between the solar energy received and the energy actually converted into electricity.

For all these accesses, you can find a sheet with all the passwords at the end of this report.

4. Problems encountered on arrival

Even though the SolarLab was already technically advanced, I noticed several issues when I arrived that limited its efficiency and daily use.

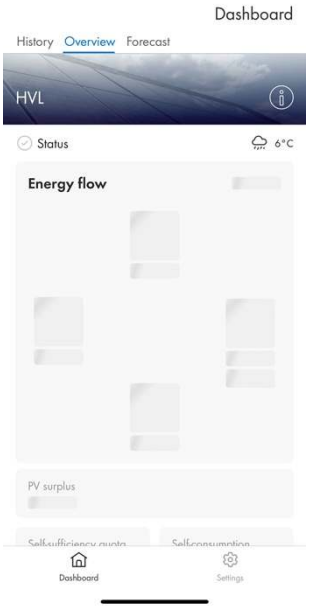
A. Problems identified

No real-time monitoring of generator contribution:

The first and probably the most critical issue was that we couldn't directly see how much energy was being provided by the generator. On the SMA EnnexOS portal, we could monitor solar production and battery state of charge, but there was no way to know exactly how much energy the generator was supplying to the lab. This information is essential. Without it, it's hard to create a complete energy report and to know whether the house is really self-sufficient or still partially dependent on the generator, especially during periods of low sunlight.

Poor display of energy consumption on the app:

The second issue was with the SMA 360 mobile app, used for quickly checking energy consumption and production. The app wasn't working properly: some data didn't display, or appeared incomplete, which forced us to use the SMA EnnexOS web portal for a more detailed view. This made quick, daily monitoring more complicated because the web interface is harder to use on a smartphone.





B. Actions taken and current status

To fix these issues, we took several steps:

- Installed a dedicated energy meter to directly measure the generator's contribution. This meter sends its data to the SMA system, improving the completeness of the portal's information.
- Set up a controlled meter to automatically manage excess energy when the battery is full (especially in late spring and summer). The idea is to use this surplus to power a useful load (like a heater) instead of wasting it.
- Checked and adjusted settings on the SMA EnnexOS portal to try to improve the display of missing data.

Finally, one particularly tricky issue to manage was the gradual increase in solar production between January and June. At the start of the internship, the battery rarely reached its maximum capacity, but as summer approached, it filled up very quickly. This triggered an automatic shutdown of the solar production for safety reasons, leading to a significant loss of valuable data. The initial solution was to manually plug in a heater to consume the surplus energy, but this wasn't sustainable in the long term, especially during weekends or outside working hours. That's why it was so important to install an automated system to handle this surplus and ensure continuous production even when the battery is full.

5. Tasks completed

A. Meter for the generator

When I first arrived, one of the main problems was the inability to distinguish, in the production data, the energy supplied by the generator (which is actually the school's electrical grid used as a backup generator) from the energy produced by the solar panels. The Sunny Island system was supposed to make this monitoring possible through its internal settings, but in practice, it didn't work: on the SMA EnnexOS portal, the production appeared as a single undifferentiated total, with no clear indication of the energy source.

This lack of visibility created a real issue: it was impossible to know exactly what share of consumption came from solar energy and what share came from the generator. For example, we could see electricity production at night… which by deduction could only come from the generator, but there was no direct representation of this on the charts.



To address this problem, I first explored the Sunny Island settings. In theory, it is possible to assign specific inputs to different energy sources and configure the system to recognize a distinct contribution from the generator. After several tests and adjustments, we realized this method didn't work, probably due to a hardware limitation that we couldn't overcome.

The chosen solution was therefore to install an additional energy meter (an SMA-branded energy meter) dedicated exclusively to the generator. This meter, integrated into the system and configured as the "generator" source in the Sunny Island, now makes it possible to directly and precisely track the amount of energy drawn from the school's grid. Concretely, this new meter generates a separate curve in the data logs, which immediately shows the actual contribution of the generator compared to the solar production.

This step was not without practical difficulties: in Norway, purchasing and shipping electrical equipment can be complicated, especially due to specific regulations, import taxes, and sometimes quite long delivery times. Despite these constraints, we managed to implement this monitoring system, which today represents a key improvement for managing energy and analyzing the balance between solar energy and external energy.

B. Controlled meter for surplus energy

One of the problems I encountered when I arrived was how to manage the surplus solar energy, especially in spring and summer. When the battery reached 95% charge, the SMA system would automatically stop production, which resulted in lost data and wasted available energy.

To avoid this, I first explored the solutions offered in the SMA software and even contacted the supplier directly, but without success: there was an integrated feature designed to automatically turn on an extra load, but once again, the system proved resistant, and we couldn't modify the settings.

So, we installed a simple and temporary solution: a Shelby brand Wi-Fi electric relay connected to a radiator. Thanks to the dedicated app, it's possible to switch this radiator on or off remotely whenever the battery approaches 100%, in order to consume the surplus and keep production active.

I did the wiring and installation with the help of Harald, fixed the relay inside an insulated box, and configured the Shelby app.

This system remains manual, but it allows us to react quickly, even remotely. For the future, I had started thinking about a fully automated solution using the Raspberry Pi, which could trigger the radiator automatically based on the battery's state of charge. Unfortunately, this would have required an API key from the suppliers to access real-time data, which I couldn't obtain during my internship.

The current solution therefore serves as a transition and will make it easier for the next student to move towards more advanced automation.

C. Analysis and comparison of real data with simulations

One of the main parts of my internship was dedicated to the detailed analysis of the SolarLab's energy production data. The goal was to understand and optimize the system's performance, but also to compare the real data with the theoretical predictions given by simulators like PVGIS, developed by the European Commission.

To do this, I first collected and gathered data from different sources:

- Data from the TIGO portal, which measures the production of each solar panel individually.
- Data from the pyranometer, which measures solar irradiance in real time.
- Overall production and consumption data from the SMA EnnexOS portal.

These data came in different formats and were often messy. So, I created macros and tools in Excel to sort, organize, and standardize these files, making everything usable.

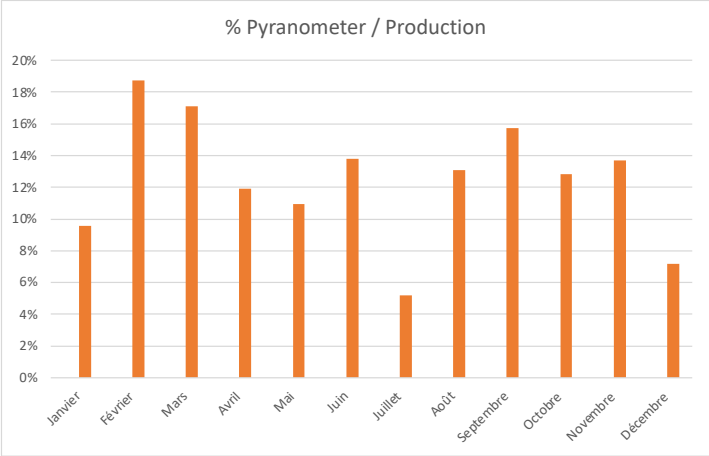
Date	W/M^2	NB Value	kWh/M2	Date	kWh/M2	kWh	Time line	PV generation [kWh]
01/01/2024	14096	7833	0,04318958	01/01/2024	0,04318958	0,78777799	1/1/2024	0
02/01/2024	23589	7817	0,07242369	02/01/2024	0,07242369	1,32100814	1/2/2024	0
03/01/2024	28042	7807	0,08620571	03/01/2024	0,08620571	1,5723922	1/3/2024	0
04/01/2024	39149	7796	0,12052027	04/01/2024	0,12052027	2,19828967	1/4/2024	0
05/01/2024	53386	7783	0,16462341	05/01/2024	0,16462341	3,002731	1/5/2024	0
06/01/2024	56779	7765	0,17549208	06/01/2024	0,17549208	3,20097554	1/6/2024	0
07/01/2024	50821	7755	0,15727969	07/01/2024	0,15727969	2,86878156	1/7/2024	0
08/01/2024	47868	7736	0,14850465	08/01/2024	0,14850465	2,70872488	1/8/2024	0
09/01/2024	83167	7725	0,25838291	09/01/2024	0,25838291	4,71290433	1/9/2024	0
10/01/2024	81424	7706	0,25359149	10/01/2024	0,25359149	4,62550873	1/10/2024	0
11/01/2024	61160	7700	0,19062857	11/01/2024	0,19062857	3,47706514	1/11/2024	0
12/01/2024	66960	7681	0,20922276	12/01/2024	0,20922276	3,8162231	1/12/2024	0
13/01/2024	39226	7662	0,12286922	13/01/2024	0,12286922	2,24113466	1/13/2024	0
14/01/2024	61647	7650	0,19340235	14/01/2024	0,19340235	3,52765892	1/14/2024	0
15/01/2024	41898	7641	0,13159953	15/01/2024	0,13159953	2,40037541	1/15/2024	0
16/01/2024	8026	7635	0,02522908	16/01/2024	0,02522908	0,46017836	1/16/2024	0

Once this database was ready, I studied the efficiency at different stages:

- Between the solar energy measured by the pyranometer and the energy actually captured by the panels.
- Between the electricity produced by the panels and the electricity actually used or stored.

Next, I compared these real results with the estimates from the PVGIS simulator. This comparison showed notable differences depending on the months and seasons: sometimes the real production was higher than the simulator's prediction, sometimes lower, especially because of Bergen's very variable climate. These differences allowed us to calculate monthly correction factors to improve the forecasts and make energy monitoring more accurate.

Output Average	
Janvier	10%
Février	19%
Mars	17%
Avril	12%
Mai	11%
Juin	14%
Juillet	5%
Août	13%
Septembre	16%
Octobre	13%
Novembre	14%
Décembre	7%
Year	12%



This work made me realize the importance of having a longer data history: with only one year of data, some averages are still unstable. For the future, it would be interesting to continue this analysis with more data to get stronger and more representative conclusions.

I summarized all this work, the methods used, and the results in a specific report included in the appendix, which can serve as a base and reference for the next students who will continue this project.

D. Collaboration with other students

This was probably the part I enjoyed the most during my six-month internship: working alongside other students and groups involved in the SolarLab. As the lab manager, I was often asked to answer their questions and share my knowledge of the system. For example, I helped a group responsible for calculating the lab's energy production by explaining in detail how the SolarLab works and giving them all the data they needed. We then compared our results and discussed our methods, which was rewarding for everyone.

I also worked with another group of students who installed additional solar panels facing East and West. I was present during some testing phases and shared production data so they could analyze the impact of this change.

Finally, I was contacted by email to take part in broader discussions about improving the lab, bringing ideas and technical information.

These exchanges were very rewarding, especially since they sometimes continued outside the university, for example in my student residence, where some thanked me for the help I gave. This really made my experience even richer and more friendly.

6. Discussion and Recommendations

A. Summary of results

At the end of this semester, the main contribution of my work at the Solar Lab was mostly to keep the solar lab running and operational. More than making a big technical change, I ensured continuous presence, which allowed us to guarantee data collection and analysis of the system. Practically, this resulted in better visibility of the data and a first real evaluation of the lab's efficiency. These results provide a valuable foundation for future students to go further, with organized data and a working system.

B. Remaining challenges

Several important limitations remain. First, the lab still doesn't have a real automatic system to manage production and consumption: some elements, like the heater, still need to be monitored and controlled manually, even if it can be done remotely. Getting an API key to access data directly from the SMA or batteries was also very difficult, due to long procedures, administrative complexity, and some reluctance from suppliers to provide access. Finally, the data history is still short: the analysis only covered one year, which is not enough to draw fully solid conclusions. More time is needed to smooth averages and confirm trends.

C. Recommendations for future students

For the future, I strongly recommend focusing on developing smarter and more autonomous management of the Solar Lab. For example, replacing the current Wi-Fi relay with a system that, in real time, considers the battery charge level, weather forecasts, and consumption habits to decide whether to turn on power-hungry devices. Why not imagine a solution with artificial intelligence in the long run? Another interesting project would be to create a simple interface (like a display screen) to inform users if they can plug in their electric vehicle, and integrate this specific consumption into the overall system. Finally, on the data processing side, it would be useful to create Excel macros or a more user-friendly tool, designed to be easily reused by others, to speed up and improve analysis and avoid starting from scratch each time.

D. Outlook for the Solar Lab

In the coming years, there are many exciting possibilities. Besides smart management, it would be interesting to give the lab a more “real” dimension, for example by setting up a coworking space or another daily activity that really uses the energy produced. This would allow studying scenarios closer to normal use and testing the system’s efficiency and stability in real conditions.

It would also be relevant to think about winter production: either by optimizing existing production despite snow or by considering other types of storage or complementary production. These ideas could give even more meaning and real value to the Solar Lab, beyond just data monitoring.

7. Conclusion

This Erasmus project at the Solar Lab was a very rewarding experience, both personally and professionally. On a personal level, it helped me gain confidence in a completely new environment, with a big language barrier. Working in a place where English is the main language, despite the initial difficulties, pushed me out of my comfort zone. Thanks to the valuable support of Richard and Harald, I was not only able to adapt but also enjoy intercultural exchanges with Norwegian students, which opened my mind to new ways of working and thinking.

Technically, this project helped me develop my data analysis skills, especially with Excel and the rigorous work methods suggested by Richard. Even if I didn’t make major technical innovations in the Solar Lab, I played an important role in keeping it running and in organizing and making the collected data visible. Contributing to a reliable data base is an essential foundation for future students who can deepen the analysis and development of the lab.

Looking back, I wish I had collaborated more in a team with Norwegian students to share thoughts and ideas, which probably would have helped me overcome some personal limits, especially related to language and feeling isolated while working. I believe closer collaboration is a path to focus on for future projects.

Finally, this project sparked a personal interest in solar energy, making me want to consider installing panels at my home in the future. Beyond the technical side, this Erasmus stay gave me an international outlook and more confidence in my ability to work in multicultural environments, which will probably influence my future choices, both professional and personal.

8. Acknowledgements

I want to warmly thank HVL University for welcoming me in such a wonderful environment. A big thanks to Elina, the Erasmus liaison student, who helped us a lot throughout the semester. I also want to express my deep gratitude to Richard, with whom I had many varied discussions and from whom I learned a lot… but also laughed a lot. He felt like a friend during this internship, and every meeting was a moment of joy. Thanks also to Harald, who made me think hard while trying to solve complex situations. He taught me a lot, both about how the SolarLab works and technical aspects in general. I also thank Icam for allowing me to do this internship in Norway. Finally, thanks to everyone who, near or far, contributed to this rewarding experience.

9. Appendices

- N°1 : List of equipment's IP addresses
- N°2 : Passwords and access details
- N°3 : PVGIS Studry
- N°4 : SolarLab progress document

A. Appendice n°1 :

SOLARLAB IP ADRESS		
DEVICES	**SERIAL NO.**	**IP ADRESS**
Sunny Island	3013232271	192.168.1.10
Inverter 1	1930084389	192.168.1.11
Inverter 2	1930082576	192.168.1.12
Inverter 3	1930083676	192.168.1.13
Home Manager 2.0	3013349660	192.168.1.14
Energy Meter Lab local grid	1901450192	192.168.1.15
Energy Meter charger	1901449948	192.168.1.16
Raspberry Pi 3 Power Supply	5036793835	192.168.1.20
Tigo	22396T2005982	192.168.1.19

C. Appendice n°3 :

Report –
Comparison of Solar Lab Data with the Online PVGIS Software

CHOURY Théo
GRANT Richard
HVL – 2025

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Introduction

Context

Since 2020, HVL University in Bergen has taken a serious interest in research in the field of solar energy. To support this, it has set up a solar laboratory that continuously collects data—both on energy production and consumption—throughout the year. At a time when renewable energy is gaining ground, this project aims to answer a key question: Can we really rely on solar energy to live in Norway?

After a year of collecting information, we now have enough data to analyze. We decided to put our results into perspective by comparing them with those from a simulation tool—PVGIS, a platform developed by the European Union that estimates solar production based on location and the type of equipment used.

Objective of this Report

The aim of this report is to compare the measurements we gathered in the field with the Solar Lab over one year to the estimations provided by PVGIS for the same location and equipment. Why? To see if this tool is reliable and accurate enough to be used in the planning of solar projects in Norway.

Plan of the Report

We will structure this report in several steps. First, we'll discuss PVGIS—what it is used for and how it works. Then, we'll dive into the details of the Solar Lab—its features, how it operates, and the data we were able to gather.

After that, we'll conduct a simulation where we recreate the lab's conditions in PVGIS.

Once we have all that, we'll compare the two sets of results to answer a central question: Can we trust PVGIS to estimate annual solar production in Norway? We will also take a look at the additional insights provided by the Solar Lab.

Finally, we'll suggest some ideas for improving our approach and advancing this type of research further.

Simulation

PVGIS (Photovoltaic Geographical Information System) is a free online tool created by the European Commission to estimate the electricity production of solar panels anywhere in the world. It relies on climate data such as sunlight, temperature, and cloud cover to give an idea of what a solar system can produce. Accessible via https://re.jrc.ec.europa.eu/pvg_tools/en/, it's very useful for planning solar installations—whether for a house, a cabin, or a lab like ours in Bergen.

The Photovoltaic Performance section of PVGIS is the core of the tool. It allows users to simulate energy production over a year or by month by entering information such as:

- The location (for example, Bergen, Norway)
- The panel capacity (in kWp)
- The orientation and tilt angle of the panels
- The type of system (off-grid or grid-connected)

You can also adjust parameters like losses due to cabling or dirt on the panels. At the end, PVGIS provides detailed results: electricity production, solar irradiation received, and even graphs to visualize how these values change throughout the year. This is the tool we use to compare simulated figures with what we actually measure in the Solar Lab.

Solar Lab

Context

The Solar Lab was set up behind HVL University in 2020. Its goal is to give students in renewable energy and technology a physical tool to demonstrate the effectiveness of solar energy production—even in Norway. The Solar Lab is also designed to resemble a passive house model, capable of producing its own energy and using it intelligently.

So, the Solar Lab has a dual purpose: to test modern equipment, both for solar energy production and for energy-efficient technologies that help reduce overall consumption.

Overview

The laboratory operates on a simple concept. We can identify two main energy flow loops: **production** and **consumption**.

Energy Production

The energy production relies on two main systems. The first—and most important—is solar electricity generation using photovoltaic panels. The Solar Lab is equipped with two rows of solar panels:

- One row consists of 6 polycrystalline panels (REC Solar 275 – 275 W per panel)
- One row consists of 6 monocrystalline panels (ASM6610M 285 – 285 W per panel)

These panels are grouped into two "strings," and each is connected to a Sunny Boy inverter that converts the direct current (DC) generated by the panels into alternating current (AC) that can be used in the building.

The electricity produced is then fed into the Solar Lab's internal network, where it can either be consumed directly or stored in a battery for later use.

The second energy production system is a backup generator. It is mainly used during the winter, when solar production is too low. This generator can be automatically activated by the Sunny Island—a device that manages energy flows between the battery, production, and consumption.

Energy Consumption

The energy produced is used to power the internal equipment of the house, including:

- Lighting
- Ventilation system (Flexit CI 600)
- Computers and monitoring tools
- Electric vehicle charging system

A set of meters, sensors, and monitoring software (Sunny Portal, Tigo Cloud, Raspberry Pi) makes it possible to track production, consumption, solar irradiation, as well as the status of the battery and various components.

Data

The Solar Lab enables the collection of precise energy data thanks to the integration of several measuring and monitoring tools. This data is essential for analyzing the system's performance, identifying areas for improvement, and better understanding the energy behavior of the passive house.

Data Collection Period

The data currently available covers a full year, from February 28, 2024, to February 28, 2025. This allows for a complete seasonal analysis, taking into account local weather variations and sunlight duration throughout the year.

SMA EnnexOS

The SMA EnnexOS monitoring system is a tool developed by SMA, the manufacturer of the Sunny Boy inverters and the Sunny Island.

Thanks to this platform:

- We have access to detailed data on production, consumption, and energy management (storage, grid injection, grid usage, etc.).
- The data can be viewed per device or globally, providing a clear overview of the entire system's operation.
- This enables cross-referencing of data and segmented analysis (by day, by device, or by period), depending on the needs of the study.

Tigo

The Tigo Cloud Connect system allows for detailed monitoring of solar panel production. Each panel is equipped with a Tigo TS4 optimizer, which makes it possible to:

- Analyze the performance of each individual panel independently of the others
- Compare the two strings (polycrystalline / monocrystalline) to observe production differences
- Optimize energy production by detecting losses caused by shading or technical faults
- Access raw solar production data before any energy conversion, providing a direct and unfiltered view of solar output

Pyranometer

The Kipp & Zonen SMP11 pyranometer, installed on the roof of the Solar Lab, provides accurate measurements of solar irradiation in W/m².

It serves as an independent reference that allows us to:

- Compare actual sunlight levels with the expected output of the panels
- Assess the efficiency of photovoltaic installations in relation to weather conditions
- Study the impact of seasons and local weather on energy performance

Data from the pyranometer is collected continuously via a Raspberry Pi, using the Modbus RTU protocol, and stored in files for later analysis.

PVGIS Simulation

Input

The part of the software that concerns us is the **OFF-Grid** section. Its use is quite simple, and we need to provide various inputs, which we will detail below.

Solar Radiation Database - Differences Between the Two Models:

- **PVGIS-ERA5**: A global database based on weather models (ECMWF). It covers Bergen (60.39°N), with a resolution of approximately 30 km, and provides data from 2005 to 2023. It's useful for high latitudes but may overestimate sunlight in the northern regions.
- **PVGIS-SARAH3**: A satellite-based database (METEOSAT), covering Europe up to 65°N, with a finer resolution (~5 km) and data from 2005 to 2023. It is more accurate for cloud cover, making it ideal for Bergen.

Installed Peak PV Power [Wp]: Maximum power of the solar panels (in watts peak).

- Solar Lab Value: 3600 Wp

Battery Capacity [Wh]: Total battery capacity.

- Solar Lab Value: 14400 Wh

Discharge Cutoff Limit [%]: Minimum battery charge percentage before the system shuts down.

- Solar Lab Value: 21%

Consumption per Day [Wh]: Average daily electrical consumption.

- Solar Lab Value: 6200 Wh

This value represents the yearly average, as we are limited here by the fact that we cannot input a different average for each season. This initial value will constrain the results.

Slope [°]: The tilt angle of the panels relative to the horizontal.

- Solar Lab Value: 60°

Azimuth [°]: The orientation of the panels (0° = north, 180° = south).

- Solar Lab Value: 0°

Operating Procedure

We will conduct three different simulations. Since we cannot input the system efficiency directly into PVGIS, we will adjust it ourselves:

- **Simulation 1**: We input the raw data (power, battery, etc.) without making any changes.
- **Simulation 2**: We apply an average efficiency of 80% (over the year) to the panel power (3600 W).
- **Simulation 3**: We use the raw data, then adjust the results based on the monthly efficiencies.

We calculated these efficiencies by comparing the solar energy measured on the panels (via Tigo) to the actual production, month by month, in order to integrate them into the results.

Output Tigo / Production	
January	66%
February	78%
March	80%
April	87%
Mai	87%
June	88%
Jully	84%
August	84%
September	88%
October	76%
November	74%
December	50%

Figure 1: Output calculated between Tigo and final production

Input data :

	Simulation 1	**Simulation 2**	**Simulation 3**
Provided inputs:			
Location [Lat/Lon]:	60.368,5.351	60.368,5.351	60.368,5.351
Horizon:	Calculated	Calculated	Calculated
Database used:	PVGIS-SARAH3	PVGIS-SARAH3	PVGIS-SARAH3
PV installed [Wp]:	3600	2688	2688
Battery capacity [Wh]:	14400	14400	14400
Discharge cutoff limit [%]:	21	21	21
Consumption per day [Wh]:	6200	6200	6200
Slope angle [¬∞]:	60	60	60
Azimuth angle [¬∞]:	0	0	0
Simulation outputs:			
Percentage days with full battery [%]:	28,38	31,04	31,04
Percentage days with empty battery [%]:	49,43	49,07	49,07
Average energy not captured [Wh]:	6571,57	6791,05	6791,05
Average energy missing [Wh]:	3986,3	4052,03	4052,03

Figure 2: Input data in PGVIS software

Results

PVGIS provides two types of data per month: energy output (production of energy) and energy not captured (energy not stored), which is represented in same color but less powerfull. For our three simulations, the results are displayed as follows: Simulation 1 in blue, Simulation 2 in yellow, and Simulation 3 in green.

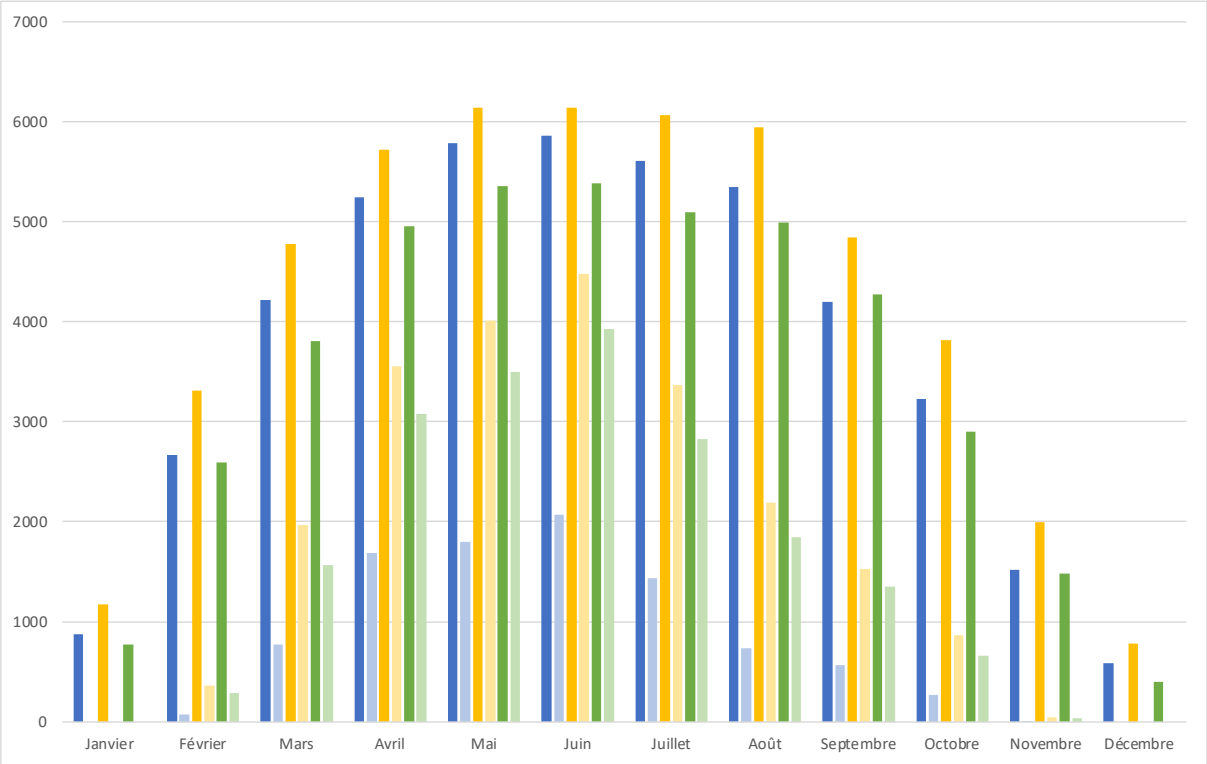


Figure 3: Chart result of the simulation from PGVIS

The results obtained are the daily averages in Watt-hours per month.

	Simulation 1		**Simulation 2**		**Simulation 3**	
	Energy output	Energy not captured	Energy output	Energy not captured	Energy output	Energy not captured
January	873	0	1170	0	770,9	0,0
February	2665	74	3309	360	2591,0	281,9
March	4218	772	4778	1965	3809,6	1566,7
April	5240	1687	5725	3554	4958,1	3077,9
Mai	5785	1796	6142	4010	5355,1	3496,2
June	5865	2067	6142	4481	5387,6	3930,6
Jully	5611	1436	6068	3370	5095,0	2829,6
August	5346	732	5946	2194	4994,2	1842,8
September	4195	567	4847	1531	4271,5	1349,2
October	3223	270	3817	862	2901,3	655,2
November	1523	3	1997	46	1476,6	34,0
December	585	0	784	0	395,0	0,0

Figure 4: Board result of the simulation from PGVIS

Solar Lab - Operating Procedure

Calculation of the Average Daily Production by Month

To calculate the average solar production per day for each month:

- We use the SMA data, which provides the daily photovoltaic production.
- We sum the daily productions for each month.
- We only count the days when measurements are available (some days are missing due to testing or malfunctions).
- We divide the monthly total by the number of measured days.

This gives us the average daily solar production per month, in watt-hours.

	Energy output
January	555,42
February	3344,37
March	3647,50
April	5695,67
Mai	7244,52
June	6973,21
Jully	4495,16
August	3222,90
September	5589,67
October	2619,33
November	949,26
December	191,11

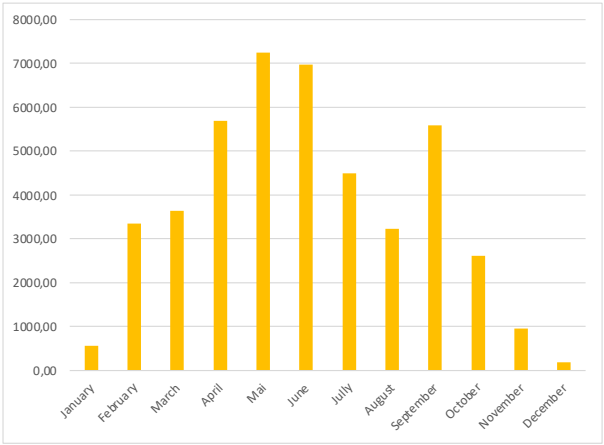


Figure 5: Result Energy captured by the SolarLab on one year

Calculation of the Average Daily Loss per Month

- We take the measurements where the battery is at ≥ 95% (every 15 minutes).
- We count these measurements per day and multiply by 0.25 to calculate the time (in hours) when the battery is at ≥ 95%.
- We retrieve the pyranometer data for those days.
- We calculate the average sunlight for the month.
- We divide the pyranometer measurement by the monthly average sunlight and then multiply by the time when the battery is at ≥ 95%.
- We apply the monthly efficiency (calculated between the pyranometer and solar production).
- We add up the losses for each day of the month.
- We divide this sum by the number of days in the month.

Result: Average daily loss per month, in watt-hours.

	Energy not captured
January	0,00
February	0,00
March	1040,65
April	2115,21
Mai	4442,33
June	1960,43
Jully	3870,82
August	470,54
September	975,20
October	0,00
November	0,00
December	0,00

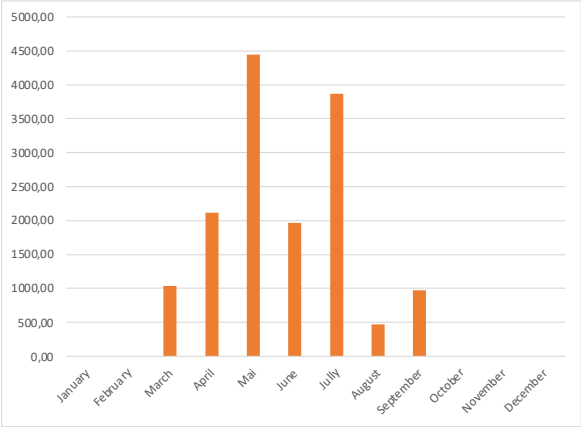


Figure 6: Result Energy not captured by the SolarLab on one year

Results

By following the methods described, we calculated the daily averages of energy output (solar production) and energy not captured (energy not stored) per month, in watt-hours. The results for each month are presented below:

	Energy output	Energy not captured
January	555,42	0,00
February	3344,37	0,00
March	3647,50	1040,65
April	5695,67	2115,21
Mai	7244,52	4442,33
June	6973,21	1960,43
Jully	4495,16	3870,82
August	3222,90	470,54
September	5589,67	975,20
October	2619,33	0,00
November	949,26	0,00
December	191,11	0,00

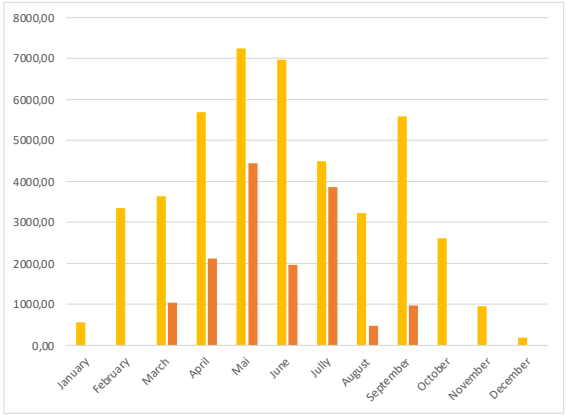


Figure 7: Result Energy captured and not captured by the SolarLab on one year

Comparison laboratory - software

To compare the data from the PVGIS simulations with those from the Solar Lab, we calculate the percentage difference between the monthly energy output of each simulation and the actual measurements. The difference for each month is expressed as a percentage. +% means, the software estimate more than the real and -% means the simulation is under the real measure.

	Simulation 1	Simulation 2	Simulation 3
January	36%	53%	28%
February	-25%	-1%	-29%
March	14%	24%	4%
April	-9%	1%	-15%
Mai	-25%	-18%	-35%
June	-19%	-14%	-29%
Jully	20%	26%	12%
August	40%	46%	35%
September	-33%	-15%	-31%
October	19%	31%	10%
November	38%	52%	36%
December	67%	76%	52%

Figure 8: Differences energy captured between SolarLab and PGVIS

Respectively in this order: Simulation 1, Simulation 2, and Simulation 3 in Blue, Yellow, and Green.

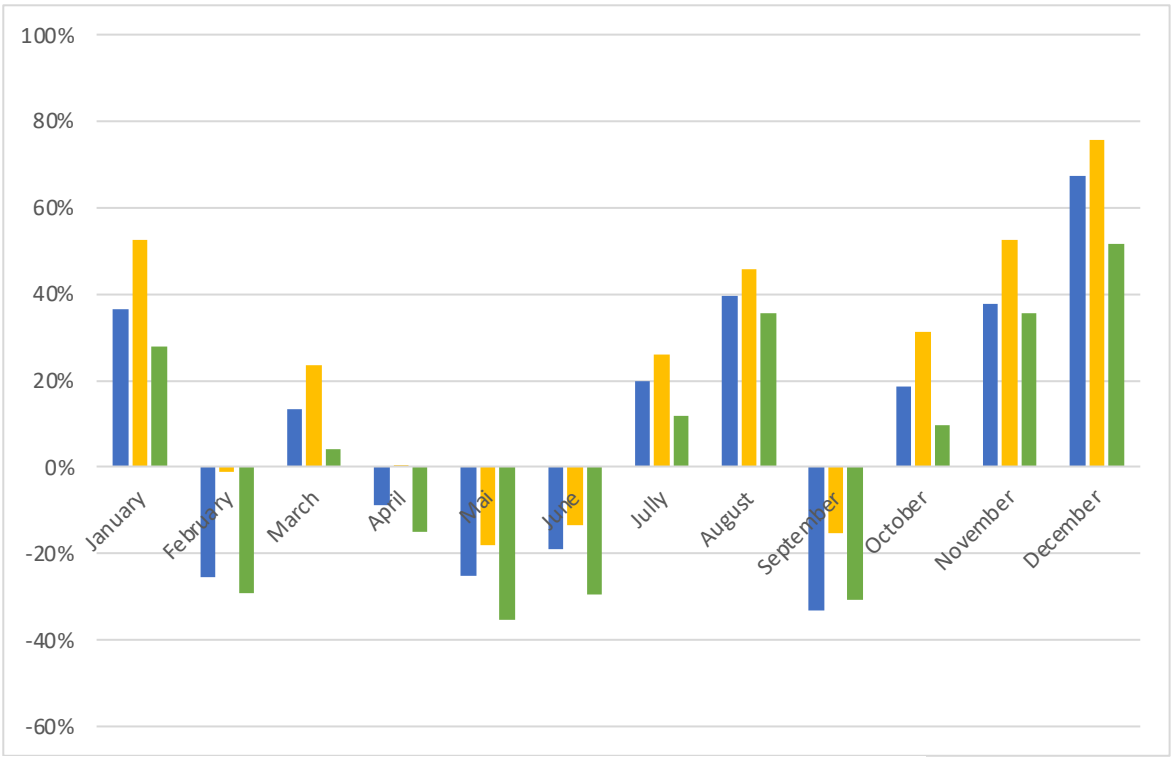


Figure 9: Differences energy captured between SolarLab and PGVIS - Chart

We do the same with energy not captured.

	Simulation 1	Simulation 2	Simulation 3
January	0%	0%	0%
February	100%	100%	100%
March	-35%	47%	34%
April	-25%	40%	31%
Mai	-147%	-11%	-27%
June	5%	56%	50%
Jully	-170%	-15%	-37%
August	36%	79%	74%
September	-72%	36%	28%
October	100%	100%	100%
November	100%	100%	100%
December	0%	0%	0%

Figure 10: Differences energy not captured between SolarLab and PGVIS

Respectively in this order: Simulation 1, Simulation 2, and Simulation 3 in Blue, Yellow, and Green.

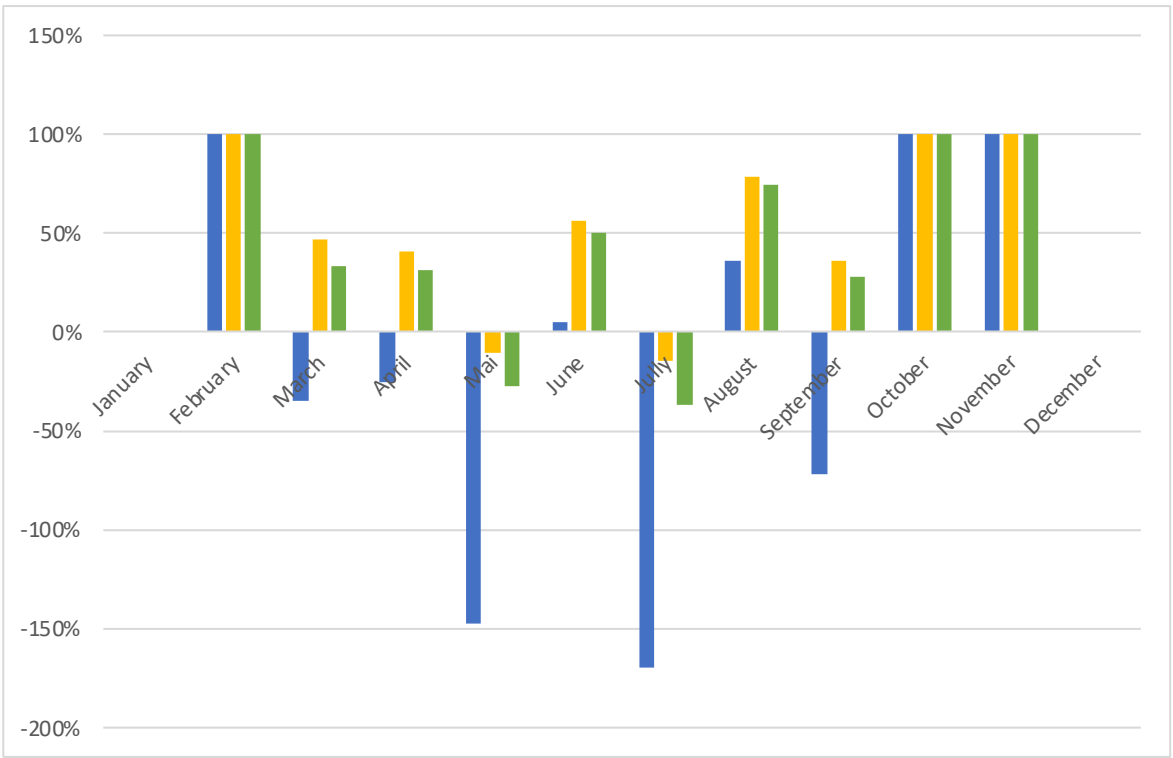


Figure 11: Differences energy not captured between SolarLab and PGVIS - Chart

Conclusion

This report aimed to compare the solar production measured at the Solar Lab in Bergen with the simulations from the PVGIS tool, testing three approaches (raw data, annual efficiency of 80%, and monthly efficiencies). We calculated the daily averages of energy output and energy not captured, as well as the losses, but the results show significant discrepancies: an average of 21% over the year and up to 76% in December. These differences prevent us from confirming the reliability of PVGIS for accurate predictions in Bergen.

The issue likely stems from the Solar Lab. With only one year of data and occasional missing or inconsistent measurements due to testing or malfunctions, the results are too fragile to serve as a solid reference. PVGIS, based on long-term climate data, appears more stable, but its assumptions (such as clean panels) don't always align with the local reality, especially in winter with snow or clouds.

This work shows that a single year of measurements is not enough to validate a tool like PVGIS in a northern climate. Moving forward, it would be necessary to collect data over several years, regularly clean the panels, and verify the calibration of the instruments. These improvements would help better assess whether PVGIS can be used to size solar installations for off-grid Norwegian cabins.

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2019

REPORT

ECOLOGY AND SELF-SUFFICIENT HOUSE

Solar Lab



What are we talking about ?

THE **SOLARLAB** PASSIVE HOUSE, LOCATED AT THE WESTERN NORWAY UNIVERSITY OF APPLIED SCIENCES (HVL) IN BERGEN, IS A PROTOTYPE OF AN **OFF-GRID** HABITAT DESIGNED TO RUN ENTIRELY ON SOLAR **ENERGY**. ITS MAIN GOAL IS TO TEST, OPTIMIZE, AND DEVELOP SUSTAINABLE ENERGY SOLUTIONS FOR THE BUILDINGS OF THE FUTURE.

THE SOLAR LAB IS AN ULTRA-ENERGY-EFFICIENT BUILDING THAT MINIMIZES HEATING AND ENERGY NEEDS THROUGH :

- *ENHANCED THERMAL INSULATION (WALLS, ROOF, WINDOWS).*
- *EFFICIENT CONTROLLED AIR CONDITIONNER*
- *THE USE OF RENEWABLE ENERGY, MAINLY PHOTOVOLTAIC SOLAR PANELS.*
- *ENERGY CONSUMPTION ANALYSIS AND MEASUREMENT TOOLS*
- *POWER MANAGEMENT DEVICE*

TECHNICAL COMPONENTS OF THE SOLARLAB

- *12 PHOTOVOLTAIC PANELS (6 MONOCRYSTALLINE AND 6 POLYCRYSTALLINE)*
- *SUNNY BOY INVERTERS TO CONVERT ELECTRICITY TO AC*
- *SUNNY ISLAND INVERTER-CHARGER FOR ENERGY STORAGE MANAGEMENT*
- *LI-ION BATTERY TESVOLT TS25 48V*
- *MONITORING SYSTEM WITH SUNNY HOME MANAGER 2.0 AND TIGO CLOUD CONNECT*
- *VENTILATION WITH HEAT RECOVERY*
- *PYRANOMETER TO ANALYZE REAL-TIME SOLAR IRRADIATION*



A Franco-Norwegian Collaboration



SINCE 2020, STUDENTS FROM ICAM (FRANCE) HAVE BEEN ACTIVELY INVOLVED IN THE DEVELOPMENT OF THE SOLARLAB PASSIVE HOUSE IN COLLABORATION WITH PROFESSORS AND RESEARCHERS AT THE WESTERN NORWAY UNIVERSITY OF APPLIED SCIENCES (HVL) IN BERGEN. UNDER THE SUPERVISION OF PROFESSOR RICHARD J. GRANT, EACH STUDENT HAS CONTRIBUTED TO THE CONTINUOUS IMPROVEMENT OF THE SYSTEM, WORKING ON ENERGY OPTIMIZATION, DATA MONITORING, AND SYSTEM AUTOMATION.

PROJECT EVOLUTION – TIMELINE

PHASE 1: *INSTALLATION OF BASIC EQUIPMENT*

PHASE 2: *INITIATING ENERGY MONITORING AND OPTIMIZATION*

PHASE 3: *DATA COLLECTION*

PHASE 4: *SITE STUDY AND SOLAR IRRADIATION ANALYSIS*

PHASE 5: *ENERGY MANAGEMENT AND BATTERY REPLACEMENT*

PHASE 6: *SYSTEM OPTIMIZATION AND GENERATOR MANAGEMENT*

PHASE 1: INITIAL INSTALLATION AND SETUP

- INSTALLATION OF 12 PHOTOVOLTAIC PANELS (MONOCRYSTALLINE AND POLYCRYSTALLINE).
- SETUP OF SUNNY BOY INVERTERS TO CONVERT SOLAR ENERGY.
- WIRING OF THE DC ELECTRICAL SYSTEM (CABLES ROUTED UNDER THE FLOOR).
- CREATION OF A POWER DISTRIBUTION PANEL (PATCHING BOARD).
- INSTALLATION OF POWER OAK ES5048 BATTERY (20 KWH) FOR ENERGY STORAGE.

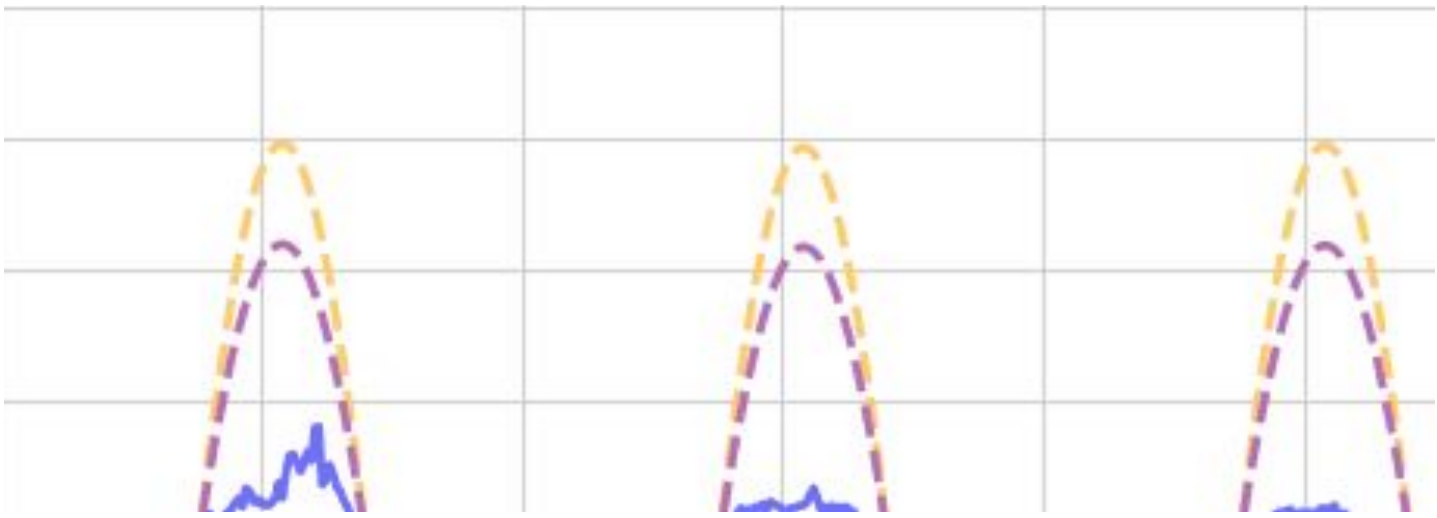


PHASE 2: ENERGY MONITORING AND OPTIMIZATION RESEARCH

- DEVELOPMENT OF A REAL-TIME SOLAR DATA DISPLAY SYSTEM USING RASPBERRY PI.
- IMPLEMENTATION OF MODBUS TCP PROTOCOL TO COMMUNICATE WITH INVERTERS.
- STUDY OF SUNNY ISLAND INTEGRATION FOR BETTER ENERGY MANAGEMENT.

PHASE 3: SOLAR IRRADIATION STUDY AND SITE ANALYSIS

- INSTALLATION OF TIGO OPTIMIZERS TO IMPROVE SOLAR TRACKING.
- PARTIAL SETUP OF SUNNY ISLAND INVERTER FOR BETTER BATTERY MANAGEMENT.
- SELECTION OF A NEW COMPATIBLE BATTERY TO REPLACE POWER OAK.



LINK : HTTPS://SOLARLAB.ONLINE/

PHASE 4: SOLAR IRRADIATION STUDY

- 3D SIMULATION OF SUNLIGHT EXPOSURE USING SKETCHUP AND SKELION.
- INSTALLATION OF PYRANOMETER TO MEASURE REAL-TIME SOLAR IRRADIATION.
- DEVELOPMENT OF PYTHON SCRIPT FOR SOLAR DATA COLLECTION AND VISUALIZATION.



PHASE 5: ENERGY MANAGEMENT AND BATTERY

- SELECTION AND VALIDATION OF THE NEW BATTERY MODEL (TESVOLT TS25).
- ENHANCEMENT OF SOLAR MONITORING SCRIPT TO IMPROVE ACCURACY.



PHASE 6: SYSTEM OPTIMIZATION AND GENERATOR MANAGEMENT

- OPTIMIZED BACKUP GENERATOR OPERATION VIA SUNNY ISLAND.
- CONFIGURED VENTILATION SYSTEM (FLEXIT CI 600) TO REDUCE HEAT LOSS.
- IMPROVED HARDWARE MANAGEMENT INTERFACE (FIXED IP ADDRESSES, EASIER ACCESS).

