



Final report from 18 February 2026

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# Alience

## Platform Alpine PV Competence

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Source: <https://alpine-pv.ch/>



**Applied Photovoltaic Research  
Swiss Solar Competence**

**Publisher:**

Swiss Federal Office of Energy SFOE  
Energy Research and Cleantech  
CH-3003 Berne  
[www.energy-research.ch](http://www.energy-research.ch)

**Subsidy recipients:**

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**SFOE contract number:** SI/502711-01

**The authors bear the entire responsibility for the content of this report and for the conclusions drawn therefrom.**



## Summary

In 2022, the Swiss Parliament introduced a temporary amendment to the Energy Act, allowing for a one-time subsidy of up to 60% of the investment costs for large photovoltaic systems. Subsidies are subject to technical requirements such as a minimum power yield of 500 kWh/kWp in the winter season (October to March), a level typically only achieved by PV systems in the Alpine region of Switzerland. The amendments to the Energy Act were limited until 2025.

The introduction of the new subsidy scheme initiated a lot of alpine photovoltaic projects. However, the realization of alpine PV plants faces a special challenge compared to plants on the Swiss Plateau. In the Alps, wind loads are higher, snow drifts occur, temperature cycles are faster, temperature amplitudes are larger, and at the same time, the irradiation of energy-rich UV light is increased. This results in additional requirements for the module design, the supporting structure, the system technology, the maintenance and the operational management of such systems.

Due to the lack of knowledge and the time pressure for realizing the alpine projects, the objective of this project was to support implementation partners by collecting all available data, bringing together the information, making the information available at one point and answering open emerging research questions.

In the project numerous discussions with implementation partners took place, for instance about the best suited modules, possible new degradation effects, about the requirements for the sub-constructions, and the effect of high irradiance levels on the safety and longevity of the system. It has been found that the successful realization and operation of alpine PV systems depend not only on the correct selection of PV components, but above all on the way the project is carried out and organised. Close collaboration and information exchange between different implementation partners, authorities, and research partners is of high importance.

High upfront costs (e.g. mounting systems, logistics, grid connection, and evolving documentation requirements) often must be incurred before a construction decision is made, creating financial risk and leading to potential project cancellations. Ongoing uncertainty about whether projects will proceed has weakened cross-project collaboration, shifting the focus from cooperation toward minimizing planning costs.

In this project, a webpage (<https://alpine-pv.ch/>) was created for a fast dissemination of knowledge around alpine PV systems featuring a map section showing all alpine PV plants in Switzerland, including those in the planning stage, under construction, or discarded [1]. The most important technical data and photos were collected from various public sources, such as press releases.

This webpage allows statistical analyses of project status and costs and provides a comprehensive collection of knowledge on alpine PV systems, including results generated within the project.

As part of the project, workshops were organised with implementation partners, which contributed to an exchange of information and were well received by the participants.

The realization of alpine PV systems seems feasible, when high investment costs are accepted. However, some technical challenges and questions remain. The high UV radiance in the alps is expected to result in a higher degradation rate compared to systems in the Swiss Plateau, and short-term high irradiation values that exceed the usual values by far may lead to inverter failures or possible safety risks under certain circumstances.



## Zusammenfassung

Im Jahr 2022 hat das Schweizer Parlament eine befristete Änderung des Energiegesetzes eingeführt, die eine einmalige Förderung von bis zu 60 % der Investitionskosten für große Photovoltaikanlagen ermöglicht. Die Subventionen unterliegen technischen Anforderungen wie einer Mindestleistung von 500 kWh/kWp in der Wintersaison (Oktober bis März), die in der Regel nur von PV-Anlagen in der Alpenregion der Schweiz erreicht wird. Die Änderungen des Energiegesetzes waren bis 2025 befristet.

Die Einführung der neuen Förderregelung löste eine Vielzahl von Photovoltaikprojekten in den Alpen aus. Die Realisierung von PV-Anlagen in den Alpen stellt jedoch im Vergleich zu Anlagen im Schweizer Mittelland eine besondere Herausforderung dar. In den Alpen sind die Windlasten höher, es kommt zu Schneeverwehungen, die Temperaturzyklen sind schneller, die Temperaturschwankungen größer und gleichzeitig ist die Einstrahlung energiereicher UV-Strahlung erhöht. Dies führt zu zusätzlichen Anforderungen an die Modulkonstruktion, die Tragkonstruktion, die Systemtechnik, die Wartung und den Betrieb solcher Anlagen.

Aufgrund des Mangels an Wissen und des Zeitdrucks bei der Umsetzung der alpinen Projekte war es das Ziel dieses Projekts, die Umsetzungspartner zu unterstützen, indem alle verfügbaren Daten gesammelt, die Informationen zusammengetragen, an einem Ort verfügbar gemacht und offene Forschungsfragen beantwortet werden sollten.

Im Rahmen des Projekts fanden zahlreiche Gespräche mit den Umsetzungspartnern statt, beispielsweise über die am besten geeigneten Module, mögliche neue Degradationseffekte, die Anforderungen an die Unterkonstruktionen und die Auswirkungen hoher Einstrahlungswerte auf die Sicherheit und Langlebigkeit der Anlage. Es hat sich gezeigt, dass die erfolgreiche Realisierung und der Betrieb von PV-Anlagen in den Alpen nicht nur von der richtigen Auswahl der PV-Komponenten abhängen, sondern vor allem von der Art und Weise, wie das Projekt durchgeführt und organisiert wird. Eine enge Zusammenarbeit und ein intensiver Informationsaustausch zwischen den verschiedenen Umsetzungspartnern, Behörden und Forschungspartnern sind von großer Bedeutung.

Hohe Vorlaufkosten (z. B. für Montagesysteme, Logistik, Netzanschluss und sich ständig ändernde Dokumentationsanforderungen) müssen oft schon vor einer Bauentscheidung getragen werden, was ein finanzielles Risiko darstellt und zu möglichen Projektstornierungen führen kann. Die anhaltende Unsicherheit darüber, ob Projekte tatsächlich realisiert werden, hat die projektübergreifende Zusammenarbeit geschwächt und den Fokus von der Kooperation auf die Minimierung der Planungskosten verlagert.

Im Rahmen dieses Projekts wurde eine Webseite (<https://alpine-pv.ch/>) für die schnelle Verbreitung von Wissen über alpine PV-Anlagen erstellt, die einen Kartenbereich mit allen alpinen PV-Anlagen in der Schweiz enthält, einschließlich derjenigen, die sich in der Planungsphase befinden, im Bau sind oder verworfen wurden [1]. Die wichtigsten technischen Daten und Fotos wurden aus verschiedenen öffentlichen Quellen, wie z. B. Pressemitteilungen, zusammengetragen.

Diese Webseite ermöglicht statistische Analysen zum Projektstatus und zu den Kosten und bietet eine umfassende Sammlung von Wissen über alpine PV-Anlagen, einschließlich der im Rahmen des Projekts erzielten Ergebnisse.

Im Rahmen des Projekts wurden Workshops mit Umsetzungspartnern organisiert, die zum Informationsaustausch beitrugen und von den Teilnehmern gut angenommen wurden.

Die Realisierung von PV-Anlagen in den Alpen scheint machbar, wenn hohe Investitionskosten in Kauf genommen werden. Allerdings bleiben einige technische Herausforderungen und Fragen offen. Die hohe UV-Strahlung in den Alpen dürfte zu einer höheren Degradationsrate im Vergleich zu Anlagen im Schweizer Mittelland führen, und kurzfristige hohe Einstrahlungswerte, die weit über den üblichen Werten liegen, können unter bestimmten Umständen zu Wechselrichter ausfällen oder möglichen Sicherheitsrisiken führen.



## Résumé

Le 30 septembre 2022, le Parlement suisse a approuvé le soutien à l'installation de grandes centrales photovoltaïques et a mis en place une subvention pour celles-ci, avec une rétribution unique pouvant atteindre 60 % des coûts d'investissement. Les subventions sont liées à des exigences relatives aux systèmes, telles qu'un rendement électrique spécifique de 500 kWh/kWc durant le semestre hivernal (octobre-mars). En Suisse, ceci peut être atteint uniquement par des systèmes photovoltaïques situés dans la région alpine. Ces modifications de la loi sur l'énergie étaient limitées à fin 2025.

L'introduction de ces nouvelles subventions a initiée de nombreux projets photovoltaïques alpins. Cependant, leur réalisation pose des défis particuliers comparés aux centrales situées sur le Plateau suisse. Dans les Alpes, les charges de vent sont plus élevées, des congères se forment, les cycles de température sont plus rapides et leurs amplitudes plus importantes. En même temps, le rayonnement UV, riche en énergie, est plus intense. Il en résulte des exigences supplémentaires quant à la conception des modules et de la sous-construction, à l'ingénierie des systèmes, à la maintenance et à la gestion opérationnelle de ces installations.

En raison du manque de connaissances et de la pression temporelle pour la réalisation des projets alpins, l'objectif de ce projet était de soutenir les partenaires de mise en œuvre en collectant toutes les données disponibles, et en les rassemblant et les rendant disponibles en un seul endroit, ainsi qu'en répondant aux questions de recherche ouvertes qui se posaient.

Dans le cadre du projet, de nombreuses discussions ont eu lieu avec les partenaires chargés de la mise en œuvre, notamment sur les modules les mieux adaptés, les nouveaux effets de dégradation possibles, les exigences relatives aux sous-constructions ainsi que sur l'effet des niveaux d'irradiance élevés sur la sécurité et la longévité du système. Il a été constaté que la réussite de la réalisation et de l'exploitation des systèmes photovoltaïques alpins dépend non seulement du choix correct des composants photovoltaïques, mais en grande partie aussi de la manière dont le projet est mené et organisé. Par exemple, une collaboration étroite et un échange d'informations entre les gestionnaires des projets, les autorités et les partenaires de recherche sont de grande importance.

Des coûts initiaux élevés (dus, par exemple, aux systèmes de montage, à la logistique, au raccordement au réseau et à l'évolution des exigences en matière de documentation) doivent souvent être engagés avant qu'une décision de construction ne soit prise, ce qui crée un risque financier et peut entraîner l'annulation du projet. L'incertitude persistante quant à la poursuite des projets a affaibli la collaboration entre les projets, déplaçant l'accent mis sur la coopération vers la minimisation des coûts de planification.

Dans le cadre de ce projet, une page web (<https://alpine-pv.ch/>) a été créée afin de diffuser rapidement les connaissances acquises. Elle comprend une carte indiquant toutes les centrales photovoltaïques alpines en Suisse, y compris celles en phase de planification, en construction ou abandonnées [1]. Les données techniques les plus importantes et des photos ont été recueillies à partir de diverses sources publiques, telles que des communiqués de presse. La page web permet aussi d'effectuer des analyses statistiques sur l'état d'avancement des projets et leurs coûts, et comprend une vaste collection d'informations sur les systèmes photovoltaïques alpins, y compris les résultats obtenus au cours du projet.

Dans le cadre du projet, des ateliers ont été organisés avec les partenaires de mise en œuvre, ce qui a contribué à l'échange d'informations et a été apprécié par les participants.

D'après ces résultats, la réalisation de systèmes photovoltaïques alpins est faisable, à condition d'accepter des coûts d'investissement élevés. Cependant, certains défis techniques et certaines questions demeurent. Le rayonnement UV élevé dans les Alpes semble entraîner un taux de dégradation plus important que celui des systèmes installés dans le Plateau suisse, et des valeurs d'irradiation ponctuellement élevées, dépassant de loin les valeurs habituelles, pourraient entraîner des pannes d'onduleurs ou présenter des risques pour la sécurité dans certaines circonstances.



## Main findings/results («Take-Home Messages»)

- The key point of the project is that a broad variety of information concerning alpine PV-Systems is provided at one single point with the webpage <https://alpine-pv.ch/>. Moreover, the implementation of alpine PV systems was supported by technical discussions bringing in the joint expertise in photovoltaics of the four involved Universities of Applied Sciences and all the actors contacted during this project. Even though the focus was not on technical research, new technical findings have been accomplished within the framework of this project, for instance concerning module requirements for alpine systems.
- In principle, the technical challenges posed by alpine facilities can be overcome; however, in some cases at very high cost. Typical costs for the alpine systems are in the range of 2500 to 5000 CHF/kWp. It remains to be seen whether the facilities will be durable under alpine conditions and how high the maintenance costs will be.
- Due to the high costs and the resulting low returns, uncertainties in project development are particularly critical. There are reports of certain projects, particularly during the planning phase, where changing and growing requirements on the part of the authorities have led to projects being abandoned for risk reasons.
- The increased irradiation and UV levels in the Alps, compared to the Swiss Plateau, highlight the importance of UV resistance of PV modules and their materials. UV ageing tests conducted in this project reveal that current alpine-related modules exhibit significant UV-induced degradation of solar cells. While an outdoor observation supports these results, additional outdoor performance studies are necessary to strengthen the laboratory outcomes.
- Bifacial irradiation reaches up to 2.4 kW/m<sup>2</sup>. None of the plant operators contacted take this into account in their inverter design. This systematically violates installation and safety standards. At this point in time, it is not yet possible to say whether the standards are too strict or the plant design is incorrect. The issue has been raised in the relevant standards committee (IEC TC 82) and will be discussed in the future.



# Content

<b>Summary</b> .....	<b>3</b>
<b>Zusammenfassung</b> .....	<b>4</b>
<b>Résumé</b> .....	<b>5</b>
<b>Main findings/results («Take-Home Messages»)</b> .....	<b>6</b>
<b>Content</b> .....	<b>7</b>
<b>List of abbreviations</b> .....	<b>8</b>
<b>1 Introduction</b> .....	<b>9</b>
1.1 Context and motivation .....	9
1.2 Project objectives .....	9
<b>2 Approach and method</b> .....	<b>10</b>
<b>3 Results and discussion</b> .....	<b>10</b>
3.1 Wiki page .....	10
3.1.1. Map .....	11
3.1.2. Statistics.....	11
3.1.3. Knowledge .....	12
3.2 Module evaluation .....	12
3.2.1. Outdoor Exposure.....	12
3.2.2. Indoor Module Testing .....	13
3.2.3. Summary of the module evaluation: .....	15
3.3 Collaborations, interviews and workshops .....	16
<b>4 Conclusions and outlook</b> .....	<b>17</b>
<b>5 Publications and other communications</b> .....	<b>18</b>
<b>6 References</b> .....	<b>18</b>



## List of abbreviations

DC	Direct Current
DSO	Distribution System Operator
EL	Electroluminescence
FF	Fill factor
GCR	Ground Cover Ratio
IEA	International Energy Agency
IEC	International Electrotechnical Commission
Isc	Short circuit current
I-V	Current-voltage
MEL	Mechanical load test
MPP	Maximum Power Point
P <sub>m</sub>	Maximum power
PV	Photovoltaic
PVPS	Photovoltaic Power Systems
SFOE	Swiss Federal Office of Energy
STC	Standard Test Conditions
TC	Thermal cycling
UV	Ultraviolet
UVID	Ultraviolet induced degradation
Voc	Open circuit voltage



# 1 Introduction

## 1.1 Context and motivation

With the amendments to the Energy Act adopted on 30 September 2022 (urgent measures for the short-term provision of a secure electricity supply in winter, “solar offensive”), the Swiss Parliament facilitated the approval of large-scale photovoltaic plants and established a subsidy for these with a non-recurrent remuneration of up to 60% of the investment costs. These facilitations apply until these new large-scale photovoltaic plants permit a total annual production of a maximum of 2 TWh throughout Switzerland. The amendments to the Energy Act were limited until 2025.

Based on that, a lot of projects started under high time pressure, although there were and still are open research questions.

The motivation of the ALIEN project was to support implementation partners of alpine PV systems by collecting available information, interpret available data, make it available fast to implementation partners and to address the open research questions to enhance the quality of the alpine PV systems to be installed. As alpine PV is still in a pioneering phase, this survey included all forms of alpine installations, ranging from projects under development according to the “solar offensive”, as well as already existing smaller alpine PV systems (on dam walls for example) and alpine test rigs, such as to gather as much know-how as possible.

To do so, the four Universities of Applied Sciences BFH, OST, SUPSI and ZHAW joined forces and worked together in this project: Open questions and challenges in alpine PV systems were collected and answered together, making use of the knowledge and experience from all four PV laboratories. This collaboration has proven fruitful: as all groups are limited in size and personnel, the consortium allowed to cover a significantly broader range of topics with expertise, while remaining small enough for efficient coordination. This also had positive impact beyond the scope of this project, such as the teaching, for example, helping to provide the students holistic competences in photovoltaics.

## 1.2 Project objectives

The project had the following objectives:

- Compiling a collection of relevant information on the topic, which is as complete as possible. The information should also be structured and evaluated in order to provide stakeholders and interested parties with the best possible source
- Provide a web-platform for fast dissemination of information and results, including an overview of all the alpine PV-plants
- Provide and collect best practices for the design of alpine PV plants: Design, modules, sub-construction, cables, inverters
- Networking with implementation partners
- Address specific research questions for alpine PV-systems such as specific degradation mechanism of modules under alpine weather conditions



## 2 Approach and method

The ALIENCE project is a container project consisting of a variety of individual activities. However, the basic methodology is based on the following approach:

1. Stakeholder dialogue: Discuss with stakeholders of Alpine PV systems to find out which topics are relevant to them.
2. Use this information to formulate research questions and distribute them to the project partners.
3. Find answers to the questions, either through our own analyses and simulations or through research and interviews with relevant individuals.

Another pillar of the methodology is the dissemination platform '[alpine-pv.ch](http://alpine-pv.ch)'. The declared goal of the ALIENCE project was to publish information much faster than in traditional research projects. This was achieved by setting up a dedicated platform instead of using the usual publication channels and processes. Reports are published on this platform, some of which have a much narrower scope than is usually the case with conventional publications. In return, they were created, published, and distributed in a timely manner and tailored to specific target groups.

## 3 Results and discussion

As described previously, the outcomes of this project are of various nature. Some results are findings from experiments, simulations or literature research performed by the universities of applied sciences within the framework of this project. Others are insights gathered from various actors in the field during interviews, workshops and bilateral discussions. Most information was published on the wiki page described in sub-section 3.1. The articles cover a broad range of topics relevant to various [actors](#) in the field; ranging from considerations about site selection for alpine PV installations, choice of modules, ongoing related research projects in Switzerland and beyond, as well as field experience from existing plants and first insights from the planning and construction of large alpine PV plants in the framework of the "solar offensive".

In addition, this project contributed to the network of alpine PV. The workshops, discussions and co-edited articles strengthened the collaboration between the actors and provided new contacts on several occasions.

The global structure of the website created during this project, as well as a selection of results published there, is presented in sub-section 3.1 below. Sub-section 3.2 contains not yet published results from the ongoing accelerated aging tests on alpine PV modules. Finally, sub-section 3.3 lists the collaborations, interviews and workshops that took place in the framework of this project.

### 3.1 Wiki page

In order to disseminate information quickly and efficiently, a website was set up at the beginning of the project and updated throughout the project with articles and information. The homepage can be accessed via [alpine-pv.ch](http://alpine-pv.ch), providing an overview and links to the three main sections '[Map](#)', '[Statistics](#)', and '[Knowledge](#)' and is completed by an '[About](#)' page. There have been around 2,350 clicks in the last 16 months.



### 3.1.1. Map

The [Map](#) section shows all alpine PV plants in Switzerland, including those in the planning stage, under construction, or discarded (Figure 1). The most important technical data and photos were collected from various public sources, such as press releases. Furthermore, all known project managers were asked to correct and add missing data, and many responded with additional information. Various filter options allow users to find the most relevant plants out of the 66 currently mapped projects. In addition, 17 test facilities are visible.

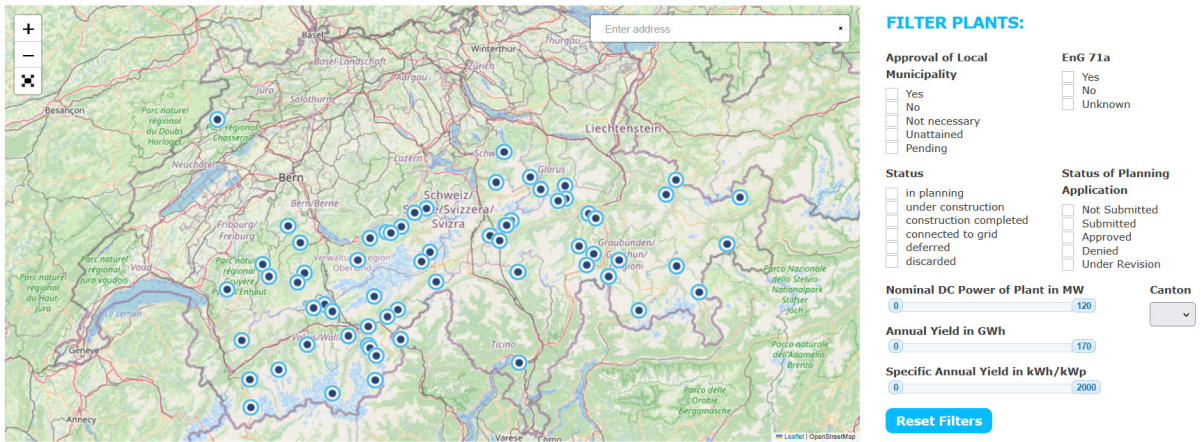


Figure 1: Screenshot of the interactive map of alpine PV power plants in Switzerland with filter options.

### 3.1.2. Statistics

Evaluations of the collected projects from different perspectives, such as project status, electrical properties and costs, were prepared and can be accessed via the ['Statistics'](#) tab. Several filter options allow for individual adaptations. Figure 2 provides an example.

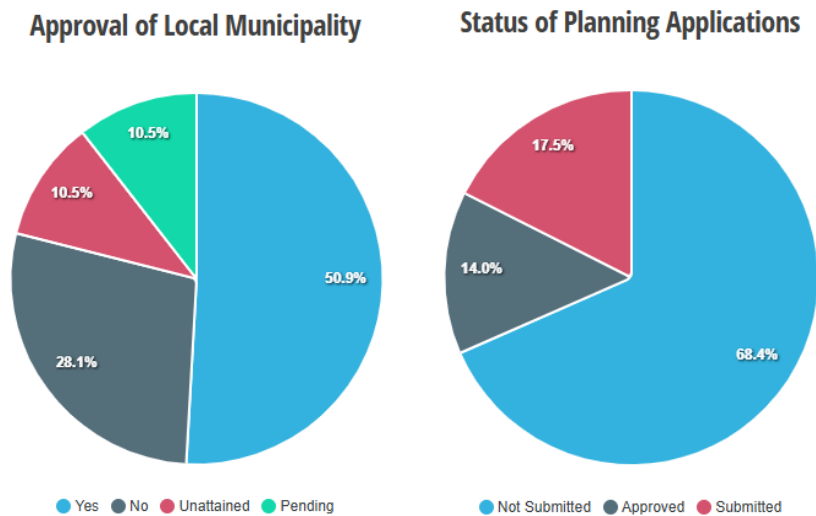


Figure 2: Example from a 'Statistics' subpage, showing the status of the 55 collected alpine PV systems according EnG71a at the 12.02.2026.



Based on the available data, alpine PV installation display, in average, yearly specific energy yields of 1435 kWh/kWp and winter electricity yields of around 640 kWh/kWp, highlighting the potential contribution of alpine PV to winter electricity supply. The costs of these power plants range from 1700 CHF/kWp to 25'000 CHF/kWp, with most projects being within 2500 to 5000 CHF/kWp. One example at lower cost segment with ~2000 CHF/kWp is the solar project “Morgeten” [2].

### 3.1.3. Knowledge

'[Knowledge](#)' is a wiki-like collection of relevant information on alpine PV plants. The 54 articles provide valuable information for the planning, product selection, operation and maintenance, as well as insights from research projects both within and outside Switzerland. Further information on actors, guides, or the slides of the workshop complete the website. The articles are based on interviews with stakeholders, literature research, as well as own measurements, data analyses, and simulations. Below are some examples of articles from different fields, based on different approaches:

- The article '[Irradiation at high altitudes for alpine photovoltaic systems](#)' presents the potentially high levels of bifacial irradiation for alpine systems, based on own measurements and data analyses. It also discusses the consequences for inverter sizing, based on conversations with inverter manufacturers.
- <https://alpine-pv.ch/wiki/energy-yield-winter-yield/parametric-study-on-a-swiss-location-for-alpine-pv-systems/> provides insights into the expected energy yield of alpine PV systems in relation to various parameters, as determined by energy yield simulations.
- The article '[Typical Degradation Rates in Alpine Climates](#)' is based on public literature combined with own research.
- '[Field experiences so far](#)' were gained through interviews with different stakeholders from already running systems.
- The article '[Insights from the first construction season](#)' provides an overview of the most relevant findings from the first plants that are now under construction under the “solar offensive” regulation, a summary of interviews with the persons in charge of each construction site.

## 3.2 Module evaluation

The results discussed in this section have not yet been published on our website. Therefore, this section provides more detail than others in the report.

### 3.2.1. Outdoor Exposure

During the project, we received modules that had been operated long term under alpine conditions (>1500 m). To preserve anonymity, we do not share images or provide specific information about the modules, installation sites, or exact operating conditions.

Identical module types were installed under differing conditions, resulting in lower temperature exposure and UV dose than standard alpine conditions for some modules. This allowed us to assess the impact of thermal and UV stress on module performance in Alpine conditions. Two main outcomes are:

- Modules exposed to higher UV doses (alpine representative) showed greater losses in Voc and FF, along with checkered electroluminescence (EL) patterns. These observations are consistent with UV-induced degradation (UVID) reported in the literature.
- Modules subjected to higher thermomechanical stress (alpine representative) exhibited more severe metallization damage (i.e. solder bond and finger damage). We believe these findings point to manufacturing quality issues, as similar defects (less severe) were also observed in modules exposed to lower thermal stress. Increased thermomechanical stress likely accelerated and amplified this mechanism.



### 3.2.2. Indoor Module Testing

The project involves static mechanical load (MEL) and UV tests, which have been identified as two of the most critical module-level tests for alpine conditions [3]. The UV test was not yet complete by the end of the project. The results of both tests will be published on our [website](#) within a couple of months after the end of the project.

#### 1. Static Mechanical Load test

- Thicker glass, reinforced frames, and optimized frame geometries significantly improve mechanical robustness. Three alpine-related modules withstood three cycles each of +5400 / -2400 Pa, +6400 / -2400 Pa, +7400 / -2400 Pa, and +8400 / -2400 Pa static mechanical loads after TC50 (to prestress metallization and solar cells) without visible damage or performance loss. In contrast, the standard module failed during the first +5400 Pa cycle due to glass breakage.
- Only two alpine-related modules showed finger damages starting at +7400 / -2400 Pa, without impact on electrical performance.
- One alpine-related module type showed pre-existing metallization damage (e.g. damaged soldering or fingers) already at the initial stage. All 4 out of 4 modules of this type exhibited such damage. Another alpine-related module and the standard module showed metallization damage (finger damage, small cell cracks, damaged wires) already after TC50 (Figure 3). The presence of initial or early-stage damages in 3 out of 4 module types raises concerns about overall module manufacturing quality.

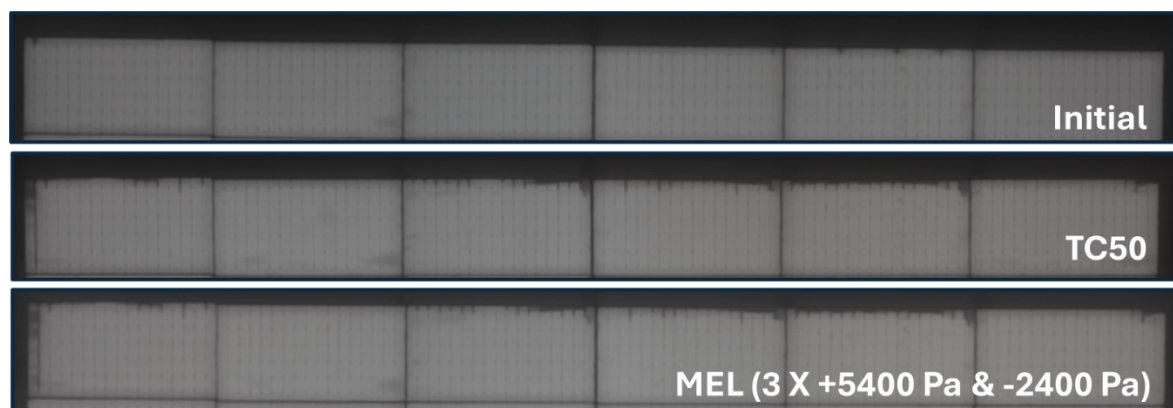


Figure 3: Detailed EL images of an alpine-related module at initial, post-TC50 and post-mechanical load (MEL) stages.

#### 2. UV Test Results – UV60-Front

- UV60-front testing shows that both the standard module and the three alpine-related modules are UV-sensitive, with varying severity.
- After UV60-front, modules exhibited 2–4% loss in maximum power ( $P_m$ ), mainly driven by  $V_{oc}$  reductions of 1–3% (Figure 4). No significant difference between standard and alpine-related modules was observed at this stage, except the standard module has much more significant UV-related instability than others. These electrical losses correlate with the checkered degradation patterns observed in EL images (not shown).
- A short light-soaking step ( $\approx 1\text{--}2 \text{ kWh/m}^2$ , 1–2 hours at  $1000 \text{ W/m}^2$ ) regenerates the reversible component of the performance loss due to UV stress. Since outdoor modules are continuously



exposed to sunlight and regeneration occurs rapidly each morning (within 1 hour), current-voltage (I-V) measurements after light soaking best represent real performance.

### 3. Ongoing Extended UV Testing – UV90-Front

- Extending UV exposure beyond UV60 is critical, as UV60 does not represent even one year of outdoor exposure in Burgdorf (533 m), Lugano (283 m), or Birg (2680 m), based on rough estimates.
- UV testing has advanced from UV60-front to additional UV90-front. Although UV90-front has been completed, not all modules have yet reached the light-soaking step. Two alpine-related modules that completed light soaking show additional degradation after UV60-front + UV90-front (Figure 4):
  - Module-3
    - -3.2% Pm after UV60 + UV90 (vs. -2.0% after UV60)
    - -2.2% Voc after UV60 + UV90 (vs. -1.3% after UV60)
  - Module-4
    - -5.3% Pm after UV60 + UV90 (vs. -2.8% after UV60)
    - -2.9% Voc after UV60 + UV90 (vs. -1.5% after UV60)

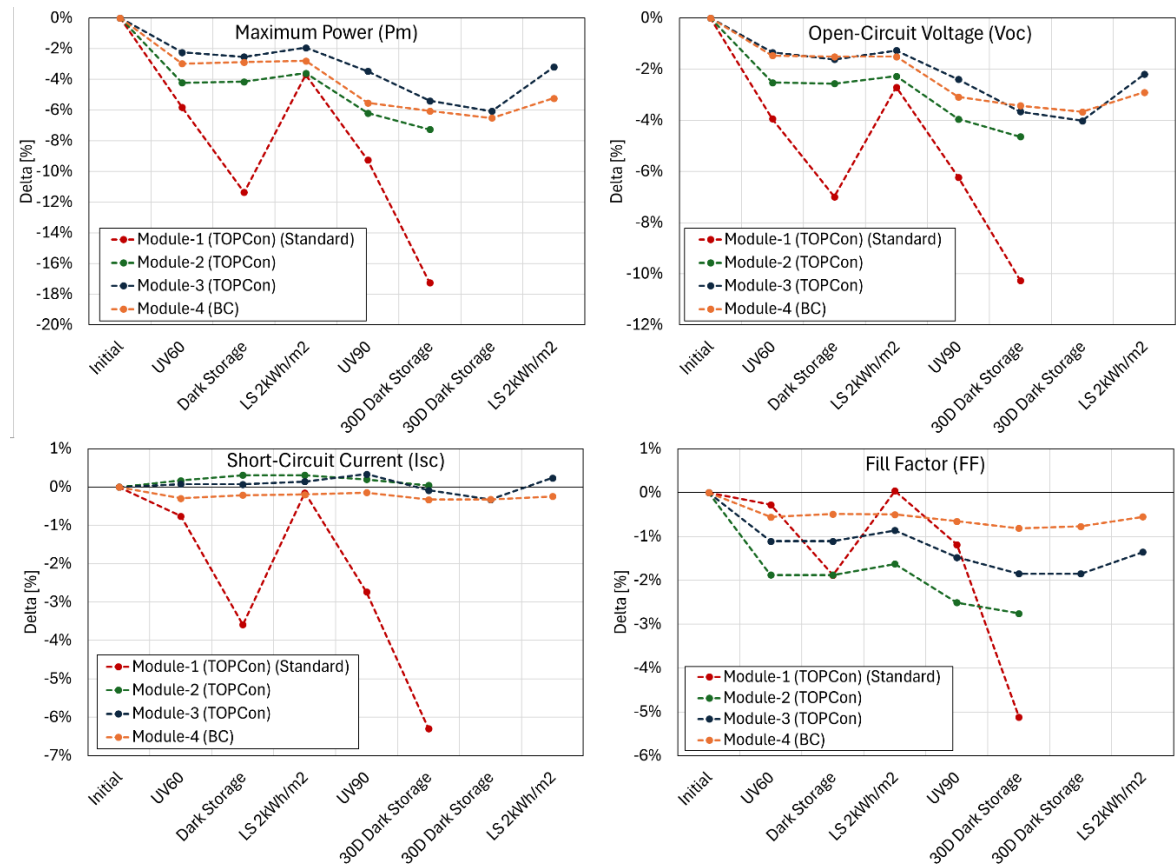


Figure 4: Change in (top-left) maximum power (Pm), (top-right) open-circuit voltage (Voc), (bottom-left) short circuit current (Isc), and (bottom-right) fill factor (FF) of the modules during UV test sequence.

### 3.2.3. Summary of the module evaluation:

- Static mechanical load tests reveal that alpine-related modules with thicker glass and reinforced frames can withstand much higher loads (+8400 Pa / -2400 Pa). Meanwhile, the standard module failed at +5400 Pa using the same mounting setup.
- Indoor UV tests indicate that all modules—three alpine-related and one standard—are sensitive to UV exposure. They experience a 2–4% power loss after UV60-front exposure, which is less than one year of outdoor exposure, primarily resulting from decreases in Voc and FF. Degradation persists with further losses at UV90-front.
- Metallization damage, such as solder bond or finger damage, was observed early (initial or after TC50) in 3 of 4 module types, suggesting manufacturing quality concerns despite the robust designs.
- Modules exposed to long-term outdoor conditions in alpine environments (>1500m) exhibited Voc and FF reductions, along with checkered electroluminescence patterns indicative of UV-induced degradation. Additionally, metallization issues such as damaged solder bonds and fingers were observed, likely resulting from larger or faster temperature fluctuations. However, further detailed operational data is required to verify this.



### 3.3 Collaborations, interviews and workshops

Several collaborations existed already between the Universities of Applied Sciences and actors in the field of alpine PV, mainly Distribution System Operators (DSO) implementing alpine PV projects, which contributed to the knowledge shared here.

Next to spontaneous discussions and exchanges, several rounds of interviews were organised. In a first one, stakeholders were contacted to inquire about the open questions in the field. Answers were collected from several DSOs, engineering companies, as well as project consortia.

Then, the owners of the censused alpine PV plants (existing or in planning) were contacted to complement the information gathered.

To address specific research questions, interviews were conducted with various actors, including module, inverter, battery and measurement equipment manufacturers, DSOs, research institutes and engineering companies. The information and know-how gathered this way was disseminated in the various articles published in the '[Knowledge](#)' section of the set up website.

Several partly confidential discussions were held with PV module and inverter manufacturers, installers as well as project managers of IEC TC82 standards. Standardisation gaps for modules and inverters were identified and fed into the pipeline for future standard revisions. For inverters, the occurrence of very high but short power peaks in particular represents a standardisation gap [4]. In PV module testing for high-altitude alpine environments, certain tests should be modified or extended to more accurately reflect actual operating conditions and avoid overstating module performance by relying solely on standard tests intended for conventional PV installations (see [Alpine PV Module Testing](#) for more details).

In fall 2025, a further series of interviews was conducted with the project managers of the large-scale alpine PV plants under construction, in order to gather insights from the first construction season. Additionally, the managers of a discarded project, as well as two projects still in planning were interviewed, complementing this [article](#) with lessons learned from challenging situations during the approval phase.

Finally, two workshops were organised during the course of this project. A first one during the “Schweizer Photovoltaik-Tagung”. The aim was to gather the various actors in the field of alpine PV, foster exchanges, and collect open questions to be addressed. Towards the end of the project, an online Workshop “[Technical Requirements of Components for Alpine PV Systems](#)” with 50 participants had been organised and pursued with the support of Swissolar and Solalpine.

#### 29.10.2025 Online Workshop

Created by M.H., BFH, on 19.09.2025

#### Workshop «Technical Requirements of Components for Alpine PV Systems»

The realisation of alpine PV plants faces specific challenges compared to plants on the Swiss Plateau. In the Alps, wind loads are higher, snow drifts occur, temperature cycles are faster and more extreme, and irradiation of energy-rich UV light is increased. These conditions result in additional requirements for module design, supporting structures, system technology, maintenance, and operational management.

This workshop will provide insights into the requirements for components of alpine photovoltaic systems and offer the opportunity to exchange views on technical topics. The main focus will be on modules, their connection to the substructure, and system technology.

The workshop is aimed at experts involved in the design and realisation of photovoltaic systems in the Alps.

Discover the unique technical challenges of alpine PV systems and learn how experts design solutions for extreme conditions. Join us for insights, best practices, and real-world experiences from pioneering projects above 1,500 metres.

Feedback from this second workshop:

“Herzlichen Dank für die Organisation dieses sehr spannenden Austausches!”

Translated to English; Feedback from a participant: “Many thanks for organizing this very exciting exchange!”



## 4 Conclusions and outlook

The project has demonstrated the value of consolidating comprehensive information on alpine photovoltaic (PV) systems within a single framework while actively supporting their implementation through targeted technical discussions. Although the project did not primarily focus on fundamental technical research, it nevertheless generated relevant new technical insights, particularly regarding module requirements for alpine environments. By leveraging broad expertise in photovoltaics, the project contributed to a clearer understanding of both the opportunities and limitations of alpine PV deployment.

From a technical perspective, the challenges associated with alpine PV systems can, in principle, be overcome. However, this often comes at a very high cost, with current investment levels typically ranging between 2500 and 5000 CHF/kWp. In addition, uncertainties remain regarding long-term durability under harsh alpine conditions and the associated maintenance requirements. Based on available data, average yearly specific energy yields of approximately 1435 kWh/kWp and winter electricity yields of around 640 kWh/kWp have been observed, highlighting the potential contribution of alpine PV to winter electricity supply.

Economic and regulatory uncertainties play a particularly critical role given the high costs and comparatively low returns of alpine PV projects. Several projects, especially during the planning phase, have reportedly been abandoned due to increasing and changing requirements imposed by authorities, which significantly raised project risks. These findings underline the importance of stable regulatory frameworks and transparent approval processes.

The project further identified several technical aspects requiring greater attention in future developments. Bifacial irradiation levels of up to 2.4 kW/m<sup>2</sup> were observed, exceeding the design assumptions of currently available inverters, yet this issue is not adequately addressed in current project planning practices. Moreover, static mechanical load tests have shown that alpine installations require PV modules with increased glass thickness and reinforced frame designs to withstand the exceptionally high mechanical loads encountered at high altitudes. Laboratory tests on alpine-related modules indicate they are susceptible to UV-induced degradation. Due to higher UV exposure at high altitudes, degradation is expected to be faster than installations in the Swiss midland. Further long-term outdoor performance data is necessary to verify these findings.

Finally, the success of alpine PV projects was found to depend strongly on non-technical factors. Close collaboration and information exchange with comparable projects and external experts, a bottom-up approach to build trust and acceptance among local authorities and the population, and robust logistics combined with agile project management emerged as key success factors. Addressing both the technical and organizational challenges identified in this review will be essential for the sustainable and economically viable deployment of alpine PV systems in the future.

Based on the experience and the visibility of project results, it is expected that the exchange in between the project and implementation partners will remain in the future. The website will be maintained and updated for at least one year after the end of the project, and at least one more article on the ageing of modules under alpine conditions will be published.



## 5 Publications and other communications

Poster “ALIENCE-Alpine PV competence” at the National PV Conference 2024

Poster at the EUPVSEC in Vienna 2024

Article in PV magazine (<https://www.pv-magazine.com/2024/07/29/switzerland-publishes-database-on-alpine-pv-systems/>)

Poster presentation at the Industry day 2025 at SUPSI

Article in Collage ([https://www.f-s-u.ch/wp-content/uploads/2025/03/Collage\\_1\\_25\\_Autoren\\_PDF.pdf](https://www.f-s-u.ch/wp-content/uploads/2025/03/Collage_1_25_Autoren_PDF.pdf))

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