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A collaborative journal publication with the Institute of Political Science, University of Bern (collaboration within SWEET EDGE consortium) presenting an extensive analysis of reasons for differences in PV utilization of Swiss municipalities is in an advanced stage of preparation (Stadelmann-Steffen et al., 2025).

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Summary

Photovoltaic (PV) expansion plays a critical role in achieving Switzerland’s net-zero climate targets. This report evaluates the utilization of photovoltaic potential across Swiss municipalities. Using geolocated datasets, both absolute PV expansion and the relative measure of PV potential utilization of municipalities are assessed across temporal and spatial dimensions.

Key findings include the Midlands region's superior relative potential utilization compared to the Cities and Alps regions (regions according to EDGE project definitions). Municipalities with the highest absolute potential, particularly in urban areas, often underperform in relative utilization. This underperformance is likely because of structural and demographic factors, such as building ownership complexities and urban density that seem to negatively overcompensate for the favorable conditions to integrate decentralized renewables found in urban regions. Spatial disparities are pronounced; for example, the canton of Ticino exhibits stark heterogeneity, while regions such as northeastern Switzerland, Lucerne, and Lake Neuchâtel achieve higher potential utilization. These observations suggest that targeted policy interventions could yield highly favorable effort-result ratios.

Temporal analysis reveals notable trends: an early increase in PV installations from 2010 to 2015, relative stagnation until about 2020, and a still ongoing second surge reaching promising growth speed. However, recent growth coincided with exceptional external factors, such as the COVID-19 pandemic and the Russian war against Ukraine, which heightened energy security concerns. The sustainability of this momentum remains uncertain.

While Switzerland's PV deployment has made progress, achieving the ambitious target of 35 TWh/year by 2035 requires intensified efforts. Real-time, spatially resolved tracking of PV expansion, knowledge exchange, and adaptive policies are essential to address regional challenges, sustain growth, and react timely in case of insufficient progress to achieve the official targets. Understanding high-performing municipalities' strategies could offer valuable insights to accelerate PV adoption nationwide.

1 Introduction

The expansion of photovoltaic systems is a key component of Switzerland's strategy to achieve net zero emissions. Net zero entails a significant increase in electricity consumption due to the electrification and decarbonization of heating systems and transportation. Compounding this challenge, Switzerland has committed to phasing out nuclear energy, necessitating the rapid development of renewable energy sources to meet future electricity demand.

While national-level subsidies support PV expansion, many critical factors are determined at the cantonal or municipal levels. These factors include additional financial incentives, building regulations, permitting processes, public awareness campaigns, and grid connection costs. In combination with Switzerland's decentralized energy system consisting of a large number of distribution system operators (DSOs), this leads to a highly fragmented and heterogeneous approach to PV deployment. This decentralization creates disparities in the speed and scale of PV expansion across regions, complicating efforts to achieve uniform progress but creating opportunities to learn from positive examples. The country could potentially profit from the fragmented nature of its energy system in that many strategies are tried, and the best implemented on a wider scale.

In Swiss politics, the use of binding mandates to enforce target achievement is generally unpopular. Instead, incentives play a central role across all three levels of government—national, cantonal, and municipal. These incentives are tailored to encourage adoption while maintaining flexibility in governance. However, this reliance on incentives also places greater responsibility on local authorities to implement effective measures.

Given the central role of PV expansion in Switzerland's energy transition, it is crucial to track progress at the municipal level. Monitoring local developments allows for the identification and dissemination of best practices while highlighting challenges that require targeted solutions. Although Switzerland has made substantial progress in PV deployment, the scale of expansion required to meet its ambitious targets raises concerns about whether current efforts are sufficient.

The official goal of generating 35 TWh/year from new renewable sources by 2035 (Swiss Parliament, 2023) places significant reliance on PV. Renewable, locally-sourced biomass offers limited potential (Thees et al., 2017), while wind energy faces substantial public acceptance challenges, leaving PV as the primary contributor. To meet the stated target, Switzerland must realize a significant portion of its rooftop PV potential within the next decade.

One critical issue is the lack of a national mechanism to enforce these targets. While the goals are legally binding, their achievement depends heavily on local and regional initiatives. This decentralization risks leaving gaps in progress unaddressed. Close temporal tracking of PV expansion is therefore essential. Continuous monitoring will enable the identification of shortfalls and allow for the timely implementation of additional measures to ensure the targets are met.

This report analyzes officially published data on electricity generation systems from an official federal source (Pronovo, responsible for federal PV subsidies), focusing exclusively on photovoltaic systems. The dataset is geolocated and includes the commissioning date of each installation, enabling detailed analyses across both temporal and spatial dimensions. By leveraging this data, we provide insights into the current state of PV expansion in Switzerland, highlighting its development over time and at the municipal level.

In addition, we evaluate regional differences in progress by applying the EDGE Project's definitions of Switzerland's three main regions, cities, midlands, and alps (Mohr et al., 2019). This approach allows for a nuanced understanding of how PV deployment varies across different parts of the country with their specific local energy system characteristics, offering valuable context for assessing the overall progress of Switzerland's energy transition. The findings presented in this report aim to contribute to a deeper understanding of PV system development and support targeted strategies for accelerating renewable energy adoption at regional and municipal levels.

A collaborative journal publication with the Institute of Political Science, University of Bern (collaboration within SWEET EDGE consortium) presenting an extensive analysis of reasons for differences in PV utilization of Swiss municipalities is in an advanced stage of preparation (Stadelmann-Steffen et al., 2025). The analysis is comprised of an extensive statistical analysis to identify the impact of municipality characteristics on their PV expansion and of case studies in which several municipalities' PV expansion history, municipal measures, and their current situation are closer examined.

2 Methods

2.1 PV Potential by Municipality

The Solar Roof Dataset, available on a federal Swiss open data platform[1], provides critical parameters for determining the solar energy potential of building rooftops across Switzerland (Swiss Federal Office of Energy SFOE, n.d.). This dataset contains geolocated information on e.g. electricity generation potential, roof area and type, orientation, tilt angle, and annual solar irradiance. Using these input variables and applying the methodology proposed by (Anderegg et al., 2022), the potential yearly energy yield from PV systems was estimated for each rooftop in Switzerland. Reduction factors were statistically determined for different roof categories (size, inclination, and irradiation) by Anderegg et al. to account for building-specific challenges such as obstacles or windows on roofs. A constant module efficiency of 20 % and a system performance ratio of 80 % were applied in the calculations.

To aggregate individual rooftop PV potentials to the municipality level, the dataset was overlaid with the official Swiss municipal boundaries as of January 2022. The sum of individual rooftop potentials within each municipality provided the overall PV potential on a per-municipality basis. Potential PV applications on building façades were not considered in this analysis.

2.2 PV Expansion by Municipality

The open dataset named "Electricity Production Plants" (Swiss Federal Office of Energy SFOE, 2024) contains georeferenced information on Swiss electricity production plants with a nominal capacity above 2 kVA, including their commissioning date. Although systems below 30 kVA are only included if registered for certificates of origin or if they benefit from specific financial support schemes (e.g., feed-in tariffs, one-time remuneration, or investment contributions), only a negligible number of PV systems are excluded from the dataset according to the data's issuer, Pronovo. However, there is variability in the time it takes for newly built PV systems to be included. While some systems are added shortly after being realized, others may take over a year to appear in the dataset.

For consistency with the PV potential, which is expressed in energy per year and municipality, annual energy yields per system were calculated using the official mean generation in 2022 of 970 kWh/kWp per year and the nominal capacity as input (Hostettler & Hekler, 2023). Existing PV systems were also overlaid with Swiss municipal boundaries from 2022 to compute an absolute PV realization time series per municipality. This time series was then normalized by dividing by the municipality's PV potential to derive a relative PV realization metric.

The combined use of the Solar Roof Dataset and the Electricity Production Plants dataset enabled a refined, detailed analysis of the temporal and spatial dimensions of PV deployment. This approach provides valuable insights into the state of PV expansion at both municipal and national levels, supporting efforts to track progress and identify opportunities for targeted interventions.

2.3 Software Tools for Report

Data analysis and creation of figures for this report were conducted using R and RStudio. The tidyverse package suite (Wickham et al., 2019) was employed for data manipulation, structuring, and graphical representation. Geospatial analyses were performed using the sf package (Pebesma, 2018).

This report includes translated, restructured, and stylistically refined text with assistance from OpenAI's ChatGPT language model (*ChatGPT [Language Model]*, 2024). ChatGPT was utilized for translating sections of the text from German to English, generating text suggestions, and improving the structure and coherence of written content. All outputs were carefully reviewed, validated, and only treated as suggestions by the authors.

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[1] https://opendata.swiss

3 Results and Discussion

The relative potential utilization of photovoltaic systems across Swiss municipalities currently exhibits a wide range, spanning from nearly 0 % to over 60 % (Figure 1). This significant variation underscores the heterogeneity in the extent to which municipalities have harnessed their available PV potential.

Since 2020, a marked increase in PV deployment has been observed, contributing to a further widening of the range of potential utilization across municipalities. This growth indicates that while many municipalities have successfully scaled up their PV installations, others remain in the early stages of development, resulting in pronounced disparities.

The observed increase since 2020 can be attributed to various factors, including favorable policy measures, improved economic feasibility, heightened public awareness of renewable energy's importance, and external pressures such as energy security concerns. However, this divergence highlights the need for targeted interventions to support municipalities with lower utilization levels, ensuring a more balanced and equitable progression towards Switzerland's renewable energy goals.

Photovoltaic expansion in Switzerland first began to show notable growth around 2010, with significant increases in installed capacity during the initial years (Figure 2). This rapid growth was likely driven by generous subsidies and the availability of the most suitable rooftop spaces for installations (with great economic feasibility). However, starting around 2016, the pace of expansion slowed, entering a period of stagnation. This phase persisted until approximately 2020, when a very strong resurgence in PV deployment was observed.

The quarterly analysis of PV expansion reveals unexpected fluctuations before 2016, including sharp increases and decreases in installation rates from one quarter to the next (Figure 3). These irregularities (most likely artefacts originating from the reporting process) diminished after 2016, resulting in a more stable growth pattern. Beginning in 2020, PV deployment accelerated significantly, culminating in an unprecedented surge in 2023, when installation rates effectively exploded.

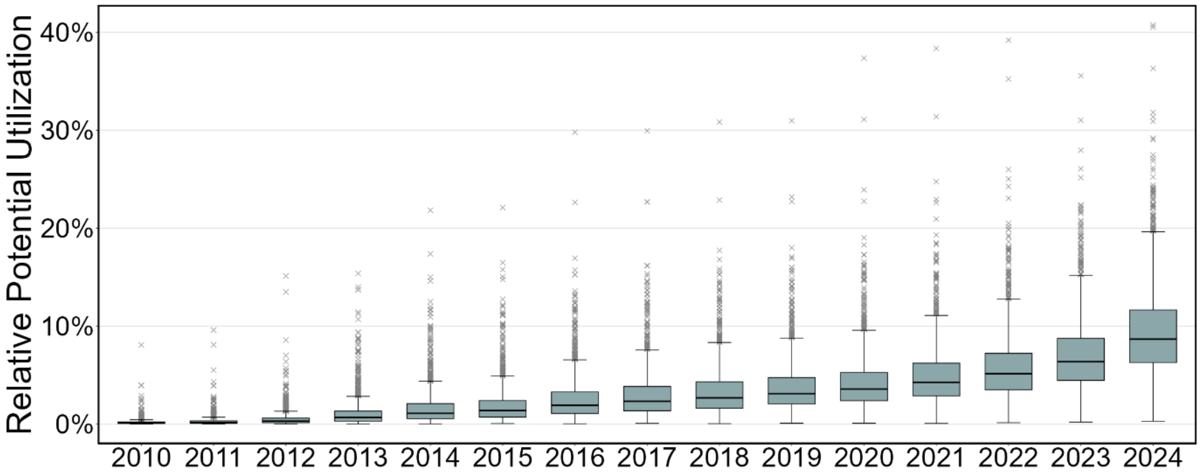

Figure 1. Evolution of the relative potential utilization per municipality in Switzerland from 2010 to present. The center of the bar represents the median municipal potential utilization in Switzerland. Note that this specifically does not represent the relative potential utilization for all of Switzerland combined. For improved readability, the municipality of Onnens (VD) is excluded. It features a single large logistics building, bringing the potential utilization to well above 60 %.

The developments observed in recent years underscore the dynamic nature of PV deployment in Switzerland. The rapid acceleration since 2020, particularly the record-breaking growth in 2023, raises intriguing questions about future trends. Observing how PV expansion evolves beyond 2023 will be crucial in understanding whether this momentum can be sustained and what factors will shape the trajectory of Switzerland's transition to renewable energy.

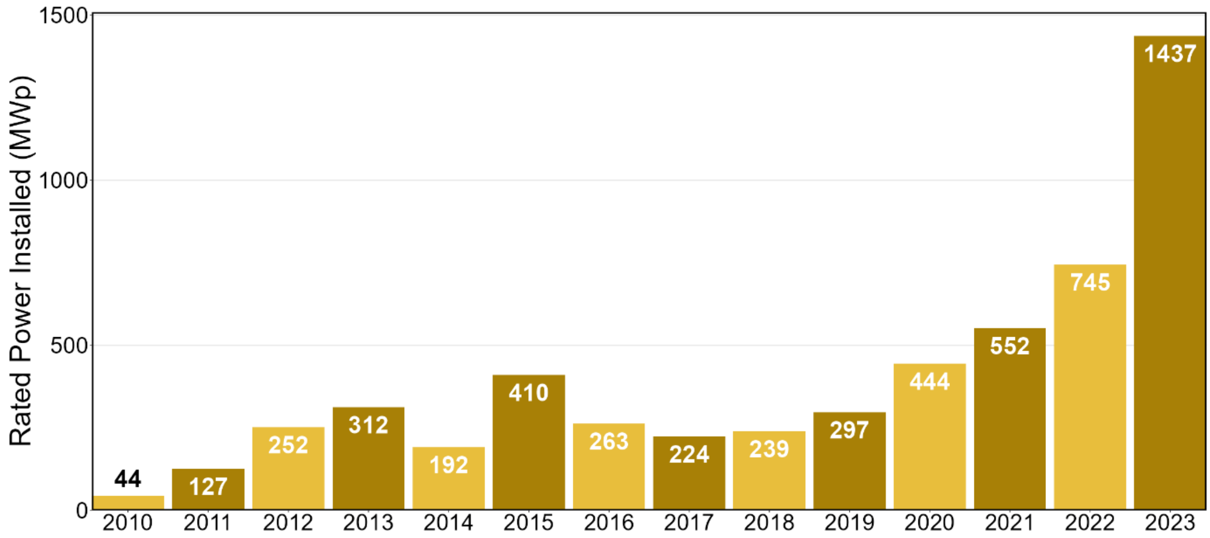

Figure 2. Yearly installed PV generation capacity (rated power) in Switzerland from 2010 to 2023. The same data is shown in quarterly intervals in Figure 3. Because of previously observed delays in reporting, it is expected that data for 2023 are not yet complete but the share of missing data should be minor.

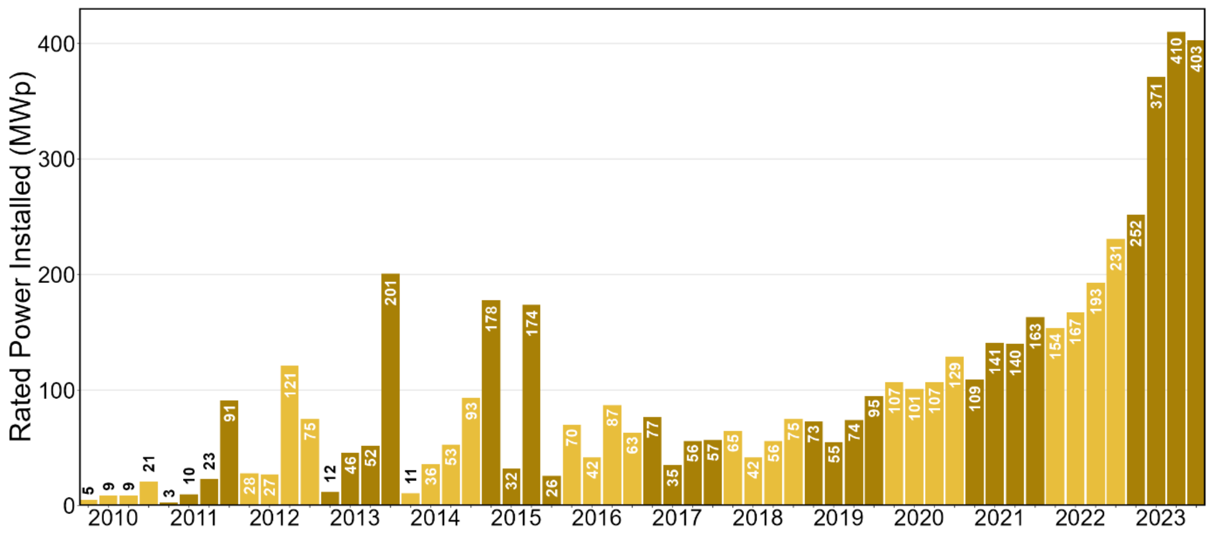

Figure 3. Quarterly installed PV generation capacity (rated power) in Switzerland since 2010. The same data is shown in yearly intervals in Figure 2. Note that the significant outliers in the earlier years are most likely reporting artefacts or due to certain deadlines for subsidies. Because of previously observed delays in reporting, it is expected that data for 2023 are not yet complete but the share of missing data should be minor.

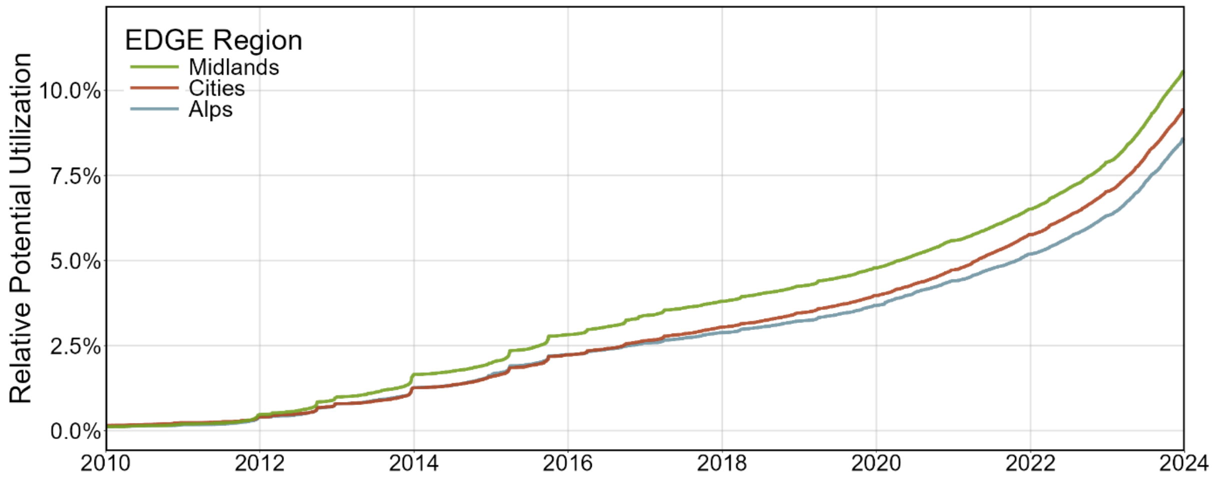

Figure 4. Relative PV potential utilization in Switzerland since 2010, summarized by EDGE regions (Midlands, Cities, Alps). The relative values are created by dividing the region-specific absolute energy generation installed by the roof PV generation potential (it corresponds thus to a weighted average of municipalities in each region).

The temporal evolution of photovoltaic deployment in Switzerland reveals significant regional variations among the three EDGE regions: Midlands, Cities, and Alps (Figure 4). Starting around 2012, the Midlands region began to demonstrate a noticeable acceleration in PV installation rates, surpassing the other regions. This early lead has remained consistent over time, highlighting the region's sustained progress in utilizing its PV potential.

A similar divergence emerged in 2017, when the Cities region began to outperform the Alps in terms of PV potential utilization. This shift left the Alpine region increasingly behind in the progress to increase PV potential utilization. In both cases—Midlands versus the other regions and Cities versus Alps—the regions that initially lagged have been unable to close the gap, even as deployment efforts continued.

These persistent disparities underscore the need to better understand the factors driving regional differences in PV deployment. Identifying the enabling conditions in high-performing regions and addressing the barriers in those falling behind will be essential to achieving a more balanced and equitable expansion of PV capacity across Switzerland.

The map shown in Figure 5 vividly highlights the significant spatial heterogeneity in photovoltaic potential utilization across Swiss municipalities. Neighboring municipalities can exhibit starkly contrasting levels of utilization, even though in many cases the physical conditions for PV installations are virtually identical. This phenomenon is particularly pronounced in the canton of Ticino, where the variation in potential utilization is striking.

In general, rural municipalities within the Alpine arc show low levels of PV potential utilization even though potential utilization is a relative metric that accounts for the lower absolute PV potential inherent to these regions. In contrast, areas with a notable concentration of municipalities achieving high potential utilization are evident in northeastern Switzerland, the canton of Lucerne, and the region around Lake Neuchâtel.

Interestingly, many of Switzerland's largest cities display relatively modest levels of PV potential utilization. This observation underscores a critical disparity between urban centers and high-performing regions, despite the often favorable financial, infrastructural, and political conditions in cities. These spatial patterns raise important questions about the underlying factors driving these differences and the opportunities to enhance PV deployment more uniformly across the country.

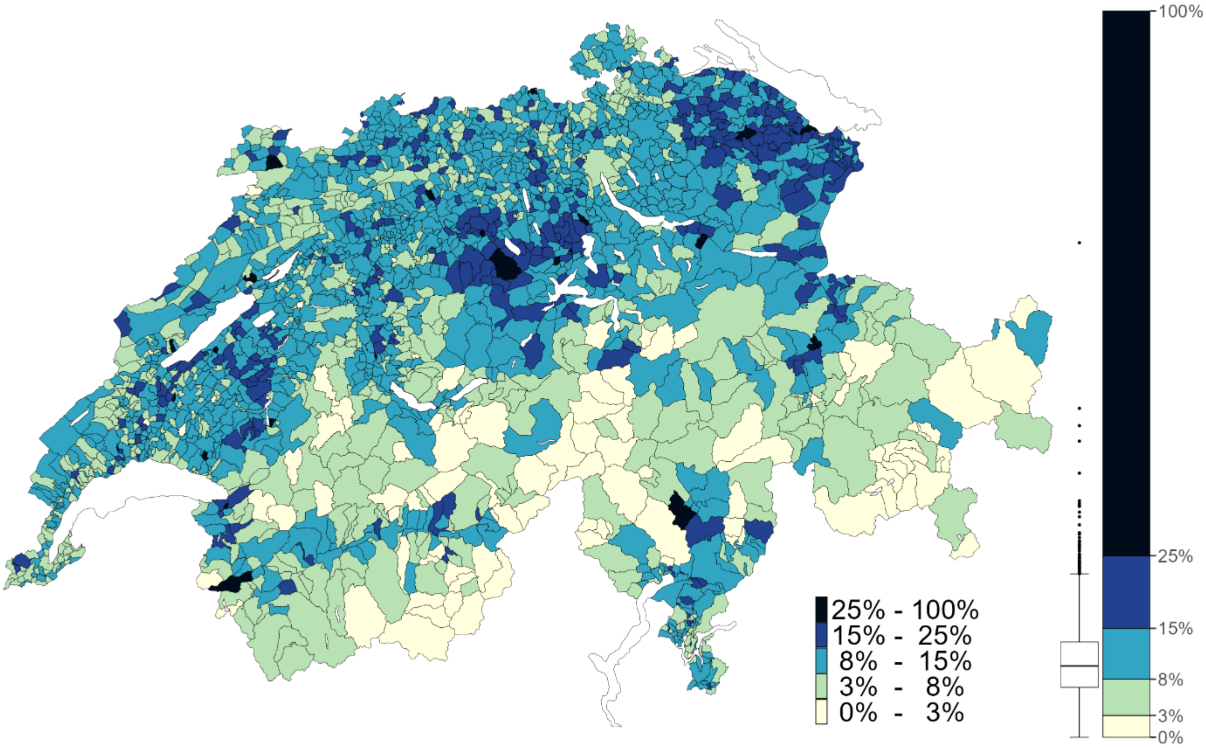

Figure 5. Relative rooftop PV potential utilization among municipalities in Switzerland as of 2024. The official set of municipalities as defined at the start of the year 2022 was used. The relative potential utilization is the ratio of effectively installed solar power capacity to the potential solar power capacity on the roof surfaces in each municipality. The boxplot shows the distribution of relative rooftop PV utilization of all municipalities. The color scale is identical to the coloring of bins used in the map section of the figure.

The analysis of absolute photovoltaic potential versus relative potential utilization across Swiss municipalities only reveals subtle patterns (Figure 6). While clear, overarching trends are not immediately apparent, the Midlands region consistently demonstrates the highest average relative potential utilization. In contrast, municipalities in the Cities region exhibit the highest average absolute potential, followed by the Midlands and the Alps. This ranking aligns directly with absolute population numbers, as larger municipalities naturally possess greater absolute PV potential.

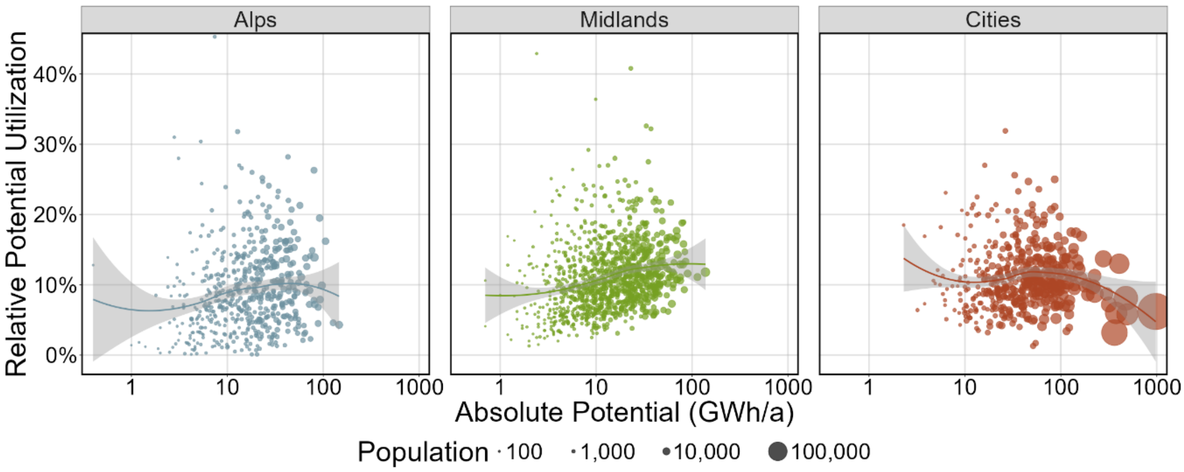

Figure 6. Relationship between absolute potential and relative PV potential utilization in all Swiss municipalities, categorized by EDGE regions. The size of the dots indicates the population size of each municipality. For improved readability, the municipality of Onnens (VD) is excluded. It features a single large logistics building, bringing the potential utilization to well above 60 %. Trend lines were created with the LOESS methodology.

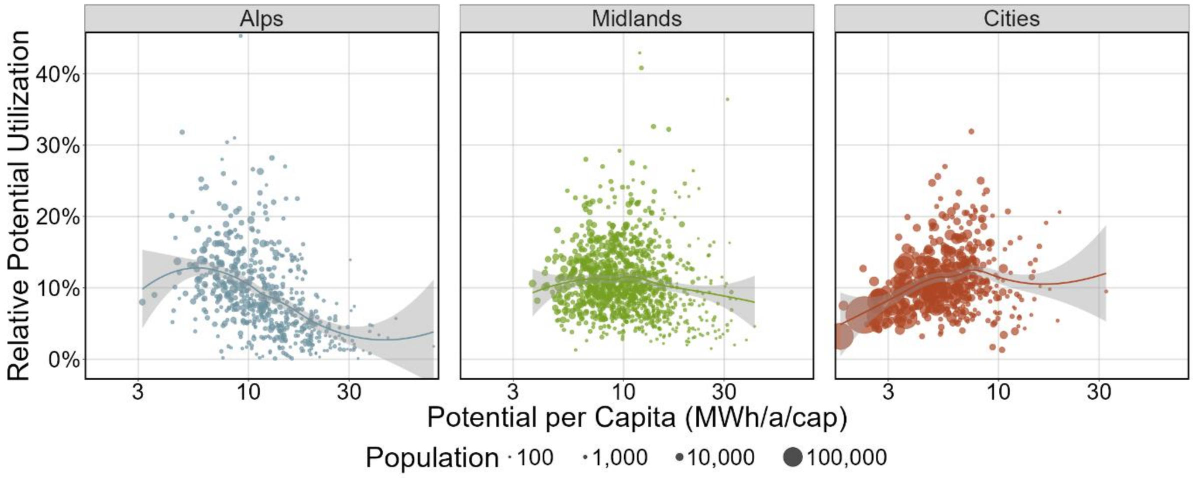

Figure 7. Relationship between potential per capita and relative PV potential utilization in all Swiss municipalities, categorized by EDGE regions. The size of the dots indicates the population size of each municipality. For improved readability, the municipality of Onnens (VD) is excluded. It features a single large logistics building, bringing the potential utilization to well above 60 %.

Within the Midlands, there is a noticeable correlation: municipalities with higher absolute PV potential tend to achieve higher relative potential utilization. This suggests that local conditions in the Midlands may support a more efficient deployment of solar energy infrastructure. However, the Cities region presents a contrasting picture. Here, municipalities with the highest absolute PV potential often show significantly lower relative utilization. A similar, though less pronounced, trend is observed in the Alps, where municipalities with very high absolute potential also demonstrate reduced utilization. These findings suggest that high absolute potential alone is insufficient to guarantee high utilization, particularly in regions facing structural or demographic barriers.

When PV potential is analyzed per capita, an inverse relationship emerges compared to absolute potential (Figure 7). Larger municipalities in the Cities region exhibit the lowest relative potential utilization values, while the Midlands and Alps regions show more comparable results. In urban areas with high population density, additional factors—such as the composition of building stock and complex property ownership structures—likely exacerbate these difficulties. This trend highlights challenges faced by larger municipalities in translating higher potential per capita into realized installations. Conversely, municipalities with high PV potential per capita also experience a reduced potential utilization, with this effect being particularly pronounced in the Alps region but also observed in the Midlands. This decline is to be expected at a certain ratio of potential to population because limited financial resources are available to realize the existing potential.

These observations emphasize the multifaceted nature of PV deployment, influenced by a combination of demographic, economic, and structural factors. The Midlands region offers a model for efficient utilization of solar resources, but the disparities observed in the Cities and Alps regions reveal persistent barriers. Urban areas, for instance, may benefit from targeted interventions to address challenges unique to high-density populations and diverse property ownership profiles.

4 Conclusions

Photovoltaic technology is a cornerstone of Switzerland's strategy to achieve its net-zero climate targets. Despite its critical importance, the expansion of PV systems shows considerable disparities across the country[2]. While some municipalities have scarcely tapped into their solar resources, others are nearing the levels of PV deployment necessary for the country to meet its ambitious goal of generating an additional 35 TWh/year from new renewable sources.

Switzerland’s largest cities are underperforming in PV development, a trend that is both concerning and surprising. These cities typically have several favorable attributes for PV deployment, including substantial financial resources, politically progressive orientations supportive of environmental initiatives, high electricity consumption, and strong distribution grids capable of handling increased generation. The reasons for their lagging performance might be attributed to significant differences in ownership of buildings and in building structures compared to the rest of Switzerland.

Interestingly, very small villages also face challenges in utilizing their PV potential, often trailing behind other municipalities. The Midland region, as defined in the EDGE project, demonstrates the highest average utilization of PV potential, followed by the Cities region and the Alps region. This variation is apparent in aggregated data from thousands of municipalities, with considerable differences between regions.

Certain areas in Switzerland stand out as hotspots for high PV potential utilization, notably the canton of St. Gallen, the canton of Lucerne, and the region around Lake Neuchâtel. While the specific factors driving these regional successes are beyond the scope of this analysis, further investigations have been carried out and are going to be published in a journal article in 2025.

A small number of municipalities have reached or are approaching PV potential utilization levels necessary for Switzerland to meet its net-zero target. These high-performing municipalities could provide valuable insights into overcoming challenges and implementing solutions, particularly regarding the integration of PV systems into local electricity grids. Understanding their strategies could help accelerate PV deployment nationwide. Large PV systems might have a distorting influence on the relative PV potential utilization rate.

The disparities in PV expansion across Switzerland highlight the need for targeted interventions to address regional and urban challenges. While the overall outlook for PV development is promising, with increasing deployment rates and notable regional successes, a more nuanced understanding of barriers and enablers is essential. By leveraging lessons from high-performing municipalities and addressing systemic obstacles, Switzerland can accelerate and optimize its transition to a renewable energy future.

Switzerland’s PV expansion trajectory has shown marked improvement in recent years. After a boom in installations from 2013 to 2015, most likely largely driven by the attractive feed-in tariff program (“Kostendeckende Einspeisevergütung, KEV”), the sector experienced a stagnation period until around 2020. Since then, annual PV additions have grown significantly, reflecting renewed momentum in the country’s PV expansion.

The temporal development of PV deployment reveals notable patterns across the three EDGE regions (Midlands, Cities, Alps). Around 2012, the Midlands began to outpace the other regions in PV installation rates, and this lead has persisted. Similarly, from approximately 2017 onward, the Cities-region began to surpass the Alps region in PV potential utilization, leaving the latter increasingly behind. In both instances, the regions that lagged failed to close the gap after the initial divergence.

[2] The analysis presented in this report provides an overview of the current status of PV expansion in Swiss municipalities, with a focus on identifying temporal and spatial trends and developments. For a detailed examination of the underlying factors contributing to the observed heterogeneity, we refer readers to a forthcoming journal publication, scheduled for release in 2025, which was developed in parallel with this report as an EDGE-collaboration (Stadelmann-Steffen et al., 2025).

Latest figures for PV expansion in Switzerland are promising, suggesting positive momentum in renewable energy deployment. However, the country remains at risk of falling short of its ambitious targets unless progress is closely monitored at both municipal and temporal levels. Continuous learning and exchange of best practices among municipalities will be essential, alongside timely and adaptive policy responses to address any stagnation or shortfalls.

It is risky to assume the recent acceleration in PV development is a stable trend. The past five years have been marked by exceptional circumstances, including the global COVID-19 pandemic and the ongoing Russian invasion of Ukraine. Especially the latter event has had profound implications for the European energy sector, driving heightened awareness and urgency around energy security and the diversification of energy sources. While these factors have contributed to increased investment and interest in PV systems, there is no guarantee that this momentum will persist under changing conditions.

To ensure Switzerland stays on track to meet its renewable energy goals, it is vital to institutionalize mechanisms for real-time tracking of progress, fostering knowledge-sharing networks among municipalities, and implementing flexible, proactive policies. It would therefore be important to create a tracking system that does not feature the delays in inclusion of PV systems observed today in the dataset used for this analysis. By doing so, Switzerland can maintain and build upon the recent progress while addressing potential challenges that could disrupt its pathway to a sustainable energy future.

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