Schweizerische Eidgenossenschaft
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Federal Department of the Environment, Transport, Energy and Communications DETEC

Swiss Federal Office of Energy SFOE
Energy Research and Cleantech

SWEET Call 1-2020: SWEET EDGE

Deliverable report

Deliverable n°	5.5
Deliverable name	Report on PV and public event
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Delivery date	November 2024

The research published in this report was carried out with the support of the Swiss Federal Office of Energy SFOE as part of the SWEET EDGE project. The authors bear sole responsibility for the conclusions and the results.

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Summary

This report shows the progress and outcomes of a photovoltaic (PV) development initiative conducted in the municipality of Wittenbach, Switzerland, as part of the SWEET EDGE project from 2022 to 2026. The initiative aimed to substantially accelerate the progress towards a local energy system with the highest possible share of renewable energy with PV as the cornerstone technology due to its substantial electricity generation potential and good public acceptance. The report provides an analysis of methods, results, and insights, highlighting both the achievements and the challenges encountered.

Leveraging geospatial data, a comprehensive PV potential analysis was conducted. Combining three independent datasets, roof potentials were aggregated at the building level, and undeveloped, high potential buildings identified. The analysis revealed that nearly half of Wittenbach's PV potential could be achieved by targeting just these high-potential buildings, which presents an opportunity for strategic resource allocation that we made use of. The owners of the top 10 % of buildings in undeveloped PV potential were actively contacted and offered support. Detailed feasibility studies, including technical and economic assessments, were prepared for those buildings with the necessary data being provided by the building owners.

This report further explores the development of PV systems on infrastructure and agricultural land. Infrastructure projects, such as a planned PV system above a parking lot with integrated electric vehicle charging stations and water collection systems, illustrate the potential of multifunctional applications. Agrivoltaics also emerged as a promising avenue, with several project ideas both on municipal and private land.

The results indicate that Wittenbach has seen notable progress in PV adoption, with an 84 % increase in installed capacity from 2022 to 2024. However, significant unutilized potential remains, particularly among high-potential buildings. Public engagement efforts, including surveys and information events, revealed strong interest in PV systems but also highlighted barriers such as structural constraints, funding gaps, and decision-making delays. Importantly, many negative decisions were linked to factors that could potentially be mitigated, such as planned renovations or lack of information.

The report underscores critical challenges to achieving rapid PV expansion, including limited incentives for grid enhancements, the fragmented nature of small distribution system operators (DSOs), and societal inertia toward adopting existing technologies. Despite these challenges, the initiative demonstrated effective strategies, including proactive engagement with building owners, targeting high-potential buildings, and targeted interventions, to accelerate PV deployment.

In conclusion, some learnings can be extracted from the Wittenbach project which are applicable to other municipalities aiming to expand their renewable energy generation capacity. While progress has been commendable, the realization of PV's full potential will require sustained efforts and enhanced collaboration between municipalities, DSOs, and policymakers. Recommendations for future work include exploring agrivoltaics, promoting decentralized energy systems, and addressing systemic barriers to PV adoption. Continued monitoring in the coming years will be essential to evaluate the long-term impact of these strategies and their contribution to Switzerland's renewable energy goals.

1 Introduction

As part of the EDGE project, from 2022 to 2026, Wittenbach was chosen as an exemplary municipality for the Swiss Midlands (Mohr et al., 2019) to establish an energy supply system with the highest possible share of renewable energy. This initiative aims to achieve an electricity supply dominated by renewable sourcesin Wittenbach within the coming years, a milestone currently expected to be realized across the rest of Switzerland only several years later.

Through a model municipality, this effort seeks to demonstrate concretely how the integration of significant renewable energy capacities can be optimized in the Midlands region and how Switzerland can achieve its energy and climate targets.

Since the project's inception, there has been close collaboration between the project team and the municipal administration of Wittenbach. Among renewable energy sources, photovoltaics holds the highest potential for local electricity generation in the municipality. While wind turbines could also contribute significantly, their development is hindered by land-use conflicts and public resistance.

The overarching goal of the PV expansion subproject was to stress-test the local electricity distribution grid and identify opportunities for integrating grid-supporting technologies such as neighborhood battery storage and smart grid solutions. A detailed analysis of Wittenbach's energy system highlighted PV as the cornerstone for achieving national renewable energy expansion targets. The analysis showed that a significant increase in PV capacity can be achieved before substantial grid challenges emerge. Moreover, even in a decarbonized scenario, local electricity generation aligns well with monthly consumption patterns, reducing the necessity for seasonal storage solutions.

Apart from PV on roofs and facades, Wittenbach as a municipality in the Midlands is expected to exhibit substantial potential mainly with agrivoltaics and to a lesser degree in infrastructure PV (Anderegg et al., 2024).

2 Methods

2.1 PV Potential Analysis

The Solar Roof Dataset, available on the Opendata 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 roof area and type, orientation, tilt angle, and annual solar irradiance. With these input variables and applying a methodology to reduce the potential of each roof by statistically determined reduction factors for different roof categories (size, inclination, irradtion) accounting for building specific challenges like obstacles or windows on roofs, the potential yearly energy yield from PV systems was estimated for each rooftop in Switzerland (Anderegg et al., 2022).

The open-access dataset named “Electricity Production Plants” (Swiss Federal Office of Energy SFOE, 2024) contains georeferenced information on Swiss electricity production plants above a nominal capacity of 2 kVA including their commissioning date. Even though systems below 30 kVA are only included if they are registered for certificates of origin or if they benefit from specific financial support schemes such as feed-in tariffs, one-time remuneration, or investment contributions, only a negligible number of PV systems are not part of the dataset[2]. It takes a variable time for built PV systems to be included in the dataset. Some might be included rather directly after being realized, while it could take other systems more than a year to become part of the dataset. A large PV system (rated power of 1326 kWp) at Grüntalstrasse 23 in Wittenbach, which was built and connected in October 2024 was not yet part of the dataset as of December 2024. Because of its importance for Wittenbach’s PV expansion, we decided to add this system to the dataset that our analysis is based on (the PV system is expected to become part of the dataset within short time in any case). For consistency reasons with the PV potential, which is given in energy per year and municipality, we calculated annual energy yields per system based on the official mean generation in 2022 of 970 kWh/kWp per year and using the nominal capacity as input (Hostettler & Hekler, 2023). As with the PV potential by municipality, we overlaid the existing PV systems with the Swiss municipal boundaries of 2022 to compute an absolute PV realization time series for Wittenbach, which becomes a relative PV realization by dividing by the municipality’s PV potential.

2.2 Aggregation of Roof Areas to Buildings

The dataset on PV potential is comprised of data on roof areas. However, decisions about installing PV systems are usually made on the building level by the owners. A building might consist of an arbitrary number of roof areas and the cost of installing a PV system on several roof areas usually decreases the specific costs due to synergy effects. The effect that the specific costs decrease with the size of a PV system is backed by statistical analyses about prices of realized systems in Switzerland (Bloch & Sauter, 2024). We therefore grouped roof areas in Wittenbach to the building level.

To this end, roof areas in Wittenbach, after being processed as described in section 2.1, were allocated to the known locations of buildings (Swiss Federal Office of Energy SFOE, n.d., 2017). In some instances, the allocation is directly possible by using the federal building identifier (EGID) as common ID to connect the two datasets. Unfortunately, a considerable share of buildings was missing the EGID at the time of conducting this analysis. In these cases, a geolocated anaysis of distances between roof areas and locations of buildings was carried out to allocate each roof to an official building location. The potential of all roof areas was then aggregated on the building level so that a list of all buildings in Wittenbach with their roof PV potential could be calculated (see Figure 1 for an illustration of the result of the hereby described methodology).

[1] https://opendata.swiss

[2] According to a statement by the dataset’s issuing body Pronovo AG via email from 22. November 2022.

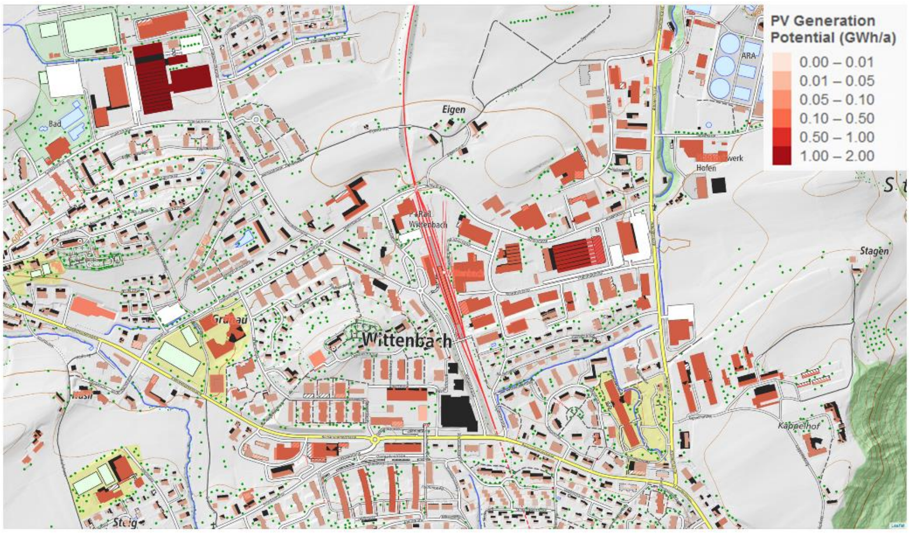

Figure 1. Illustration of results of geolocated analysis of PV potential on roofs of buildings in Wittenbach. A building consists of an arbitrary number of individual roof areas, which were grouped together for this analysis. Reduction factors were previously applied to the individual roof areas as described in section 2.1.

Buildings that are already equipped with a PV system were identified with a geolocated analysis using the previously mentioned dataset named "Electricity Production Plants"(Swiss Federal Office of Energy SFOE, 2024). This made it possible to identify buildings with existing systems and account for their potential accordingly. Buildings with existing PV systems were excluded from the identification of buildings with the largest open PV potential. It was assumed that their owners had already maximized installations based on their financial resources, the space available, and other restrictions.

We then selected the 10 % of buildings in Wittenbach with the largest absolute roof PV potential without already existing PV system according to our calculation. In collaboration with the administration of Wittenbach building owners of these most suitable buildings were contacted personally and offered neutral advice, feasibility studies for PV systems, including technical and economic assessments. People were initially contacted with a letter to their official adress. Afterwards, communication was also carried out via phone and email. To improve the quality of the feasibility studies, building owners were asked for data relevant for the analysis. Such data include for example roof type and age, structural information about the roof, other installation relevant information, electricity consumption profiles, and financial parameters such as the type of financing, expectations for return on investment, etc.

2.3 Approach to Calculate PV System Size and Economic Feasibility

Based on the collected data (electricity bills, load profiles, images, or plans of the house/roof), individualized plans were developed. The level of detail in these plans varied depending on the data quality and level of interest of building owners. For highly motivated owners, detailed plans, including 3D models generated in a PV planning and simulation software[3], were created. In other cases, the initial focus was on providing economic feasibility assessments and general explanations to enhance motivation. Calculations of economic feasibility were normally carried out redudantly with two approaches to generate more robust results. One calculation was carried out with said PV planning software. The second one was carried out with a dynamic economic feasibility calculation according to Swissolar. Cost for the PV systems were taken from real quotes for the specific system if enough data were available. Otherwise, statistics of historical data for PV system costs in Switzerland were used (Bloch et al., 2022). The first wave during which every identified owner of the high-potential buildings

[3] PV*SOL premium by Valentin Software GmbH

was contacted took place from summer 2022 to spring 2023. Afterwards, support for ongoing projects went on and calls for support were answered.

In fall 2024, the whole list of owners of the 10 % buildings with highest potentials were contacted a second time. This time, focus was placed on receiving feedback on their decision process. To this end, letters with a QR-code to a short survey were sent to each building owner. Building owners with known email adresses or telephone numbers were also contacted via these means of contact to complete our statistics. In case owners expressed open questions or the desire for calculations and planning of a PV system, we also supported them in this way.

2.4 Detailed Planning of Selected PV Systems

Two significant sites — a retirement home and an indoor swimming pool — were identified due to their large roof areas and high energy consumption (Figure 2). These sites were deemed highly economical based on detailed assessments. Renovation plans for these buildings provided an opportunity to integrate PV systems, combining roof and façade installations to maximize energy generation.

Both buildings feature big roof areas in combination with a high consumption of electric energy. This combination is predestined to be highly economic which was shown in a detailed report including a technical analysis, economic assessments, ecological impacts, and aesthetic considerations (Isler et al., 2024). The PV systems are expected to be realized soon. The façade of the old people's home is going to be renovated soon and a façade and rooftop PV system might directly be installed to use synergies. The rooftop of the indoor swimming pool is expected to be due for renovation very soon. Such renovations will be combined with building a PV system. The analysis has shown that it is more promising to build a PV system instead of solar thermal systems even for the indoor swimming pool with its big use of warm water.

Figure 2. Visualization and aerial footage of a retirement home and the indoor swimming pool in Wittenbach (Isler et al., 2024). Several variants for each building were designed and analyzed with power ratings between 99 and 111 kWp on the retirement home and between 147 and 198 kWp on the indoor swimming pool.

2.5 Infrastructure PV

Together with the representatives of the administration of Wittenbach, we evaluated promising potential PV projects apart from building related PV. This initated Wittenbach's plans to develop a PV system above a parking lot, which will include EV charging stations and a water collection system for irrigation of public green spaces. A detailed feasibility study including several realization options was carried out for this potential project at ZHAW (Pröschel et al., 2023). This project exemplifies the potential of integrating multiple functionalities into PV infrastructure to maximize benefits. Figure 3 includes a visualization of how such a PV system could look like in the specific location in Wittenbach.

Figure 3. Visualization of one project scenario of a photovoltaic system above a car parking in Wittenbach (Pröschel et al., 2023). The rated power of the variant of PV system depicted here amounts to 449 kWp.

2.6 Agrivoltaics

Municipal agricultural lease land was identified as promising for agrivoltaic systems. A preliminary project is underway to assess suitable allotments, conduct economic evaluations, and address challenges. The focus is on vertical PV installations on grazing land, which balance energy generation with agricultural use.

Another initiative lead by the project team focuses on privately owned allotments. After analysing all parcels of Wittenbach in terms of suitability, landowners of promising locations were contacted directly to discuss projects (Figure 4). A detailed multi-criteria analysis was conducted for three agricultural land parcels with different owners to explore feasibility and potential synergies.

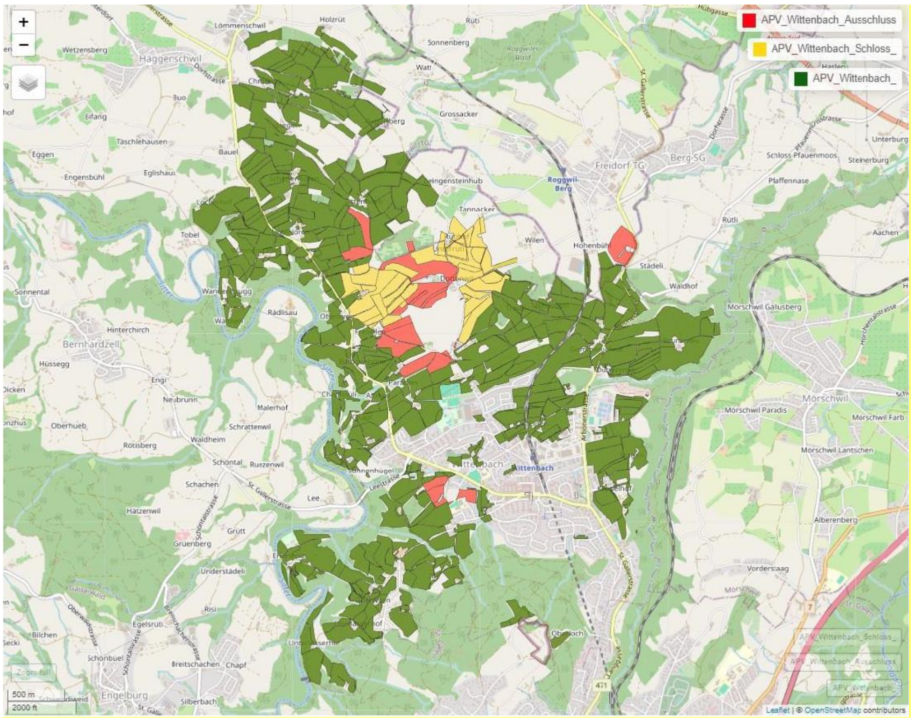

Figure 4. Agrivoltaics analysis of potential on agricultural land in Wittenbach. (Bassal et al., 2024). The red areas are excluded due to exclusion criteria from a national agrivoltaic analysis (Anderegg et al., 2024), while the yellow areas are excluded due to their proximity to the historic landmark of “Schloss Dottenwil”. Three locations each with several project variants were developed and analyzed. In total, PV systems with cumulated rated powers of about 2.6 MWp were suggested in this project report.

2.7 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.

3 Results and Discussion

Figure 5 shows the total aggregated PV production potentials for Wittenbach (rooftop- and façade-PV) as calculated both in 2022 and 2024 in comparison to the installed capacity at that time. While the installed capacity increased by 84% from 4.3 to 7.9 GWh/a, the total potential increased as well, from 56.4 to 66.7 GWh/a. This increase is to a major part caused by an updated module efficiency (increased from 17 % to 20 %) and to a much smaller degree by increases in available building roofs and façades because of new buildings. While the increase in installed capacity is substantial, the unutilized potential nevertheless remains significant. Section 3.1 details the distribution of building potentials, whereas section 3.2 gives insight into the process and timeline of converting this potential into actual installations. Section 3.3 presents the results of a survey conducted among owners of the buildings with highest potentials, covering the stated reasons for positive, undecided, and negative installation decisions. Finally, section 3.4 documents some of the public outreach activities undertaken by the project team, namely including the public PV event in Wittenbach.

While the potential on façades makes up a significant share of the total building related PV potential, all potential values and categorization within the rest of this report only include roof PV system. Reasons for this decision are the superior cost-efficiency of systems on roof, the observation that roof-mounted dominate among installed PV systems, and the observation that the open potential on roofs is still tremendous.

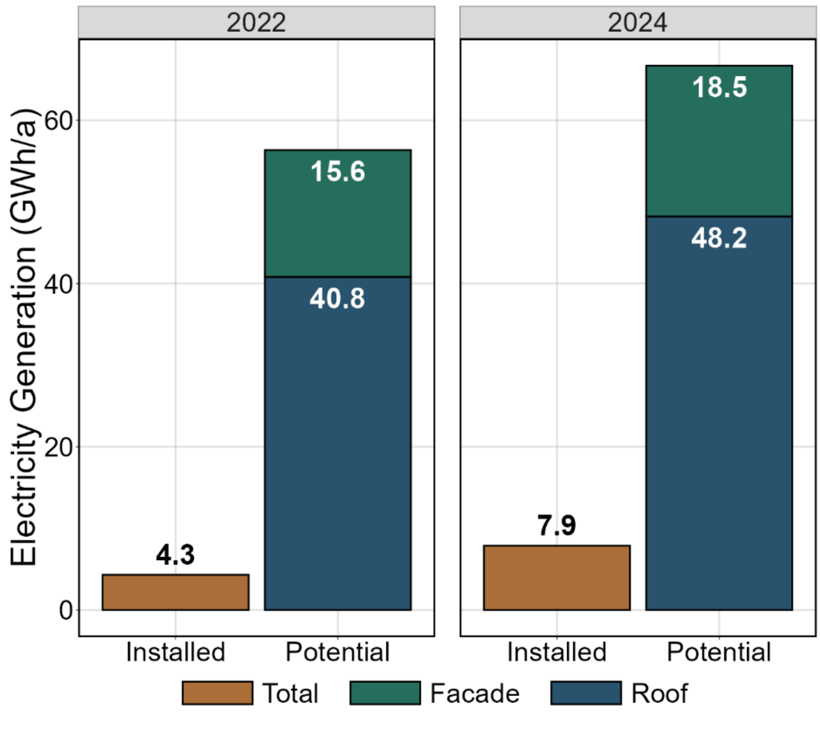

Figure 5. Comparison of calculated PV potentials and installed capacity on buildings in Wittenbach in 2022 and 2024. The installed capacity grew by 84% from 4.3 to 7.9 GWh/a during this timeframe. The share of installed PV systems on façades is still practically negligible. The rise in potential is due to a combination of factors, namely increased module efficiency (from 17 % to 20 %) and an increase in viable roof areas (additional buildings). The potential values represent total potential and thus include roofs and façades, where PV systems are already installed. The potential on roofs without a PV system amounted to 35.1 GWh/a in 2022 (meaning the utilization of calculated potential on equipped roofs was only 75 %).
As a comparison, the total electric energy consumption of Wittenbach in 2017 was 44.2 GWh/a (Wittenwiler, 2020).

3.1 Buildings with highest Potentials

The stated goal of the subproject in Wittenbach is to increase PV production as quickly as possible (nicknamed “PV-Boom”). This necessitates efficient use of the available resources. The cost of any given PV installation is comprised of multiple factors, dependent on the project itself and scaling variedly with the installation size. While material costs for panels and subframe scale more or less proportionally with installation size, planning and organisation, scaffolding, permitting etc. usually do not. This in general leads to larger installations being more cost-competitive and thus having a higher chance of success. Similarily, the effort required to initiate and later support a single project within the scope of the PV-Boom is not directly tied to the size of the installation. There are large differences in how much effort is needed to convince people and companies of the benefits of a PV installation, and due to the aforementioned cost-size-relation, economic arguments usually become weaker the smaller a potential installation gets.

The approach taken during this project therefore aimed to maximize the utilization of high-potential roofs, which represent a significant share of the total PV capacity in the municipality. The PV production potential of all roofs in Wittenbach was therefore preliminarily analyzed. Specifically, the analysis revealed that 46 % of the total potential could be realized by developing only the top 10 % of buildings, corresponding to 16.3 GWh/year from 134 buildings (Figure 6 and Figure 7).

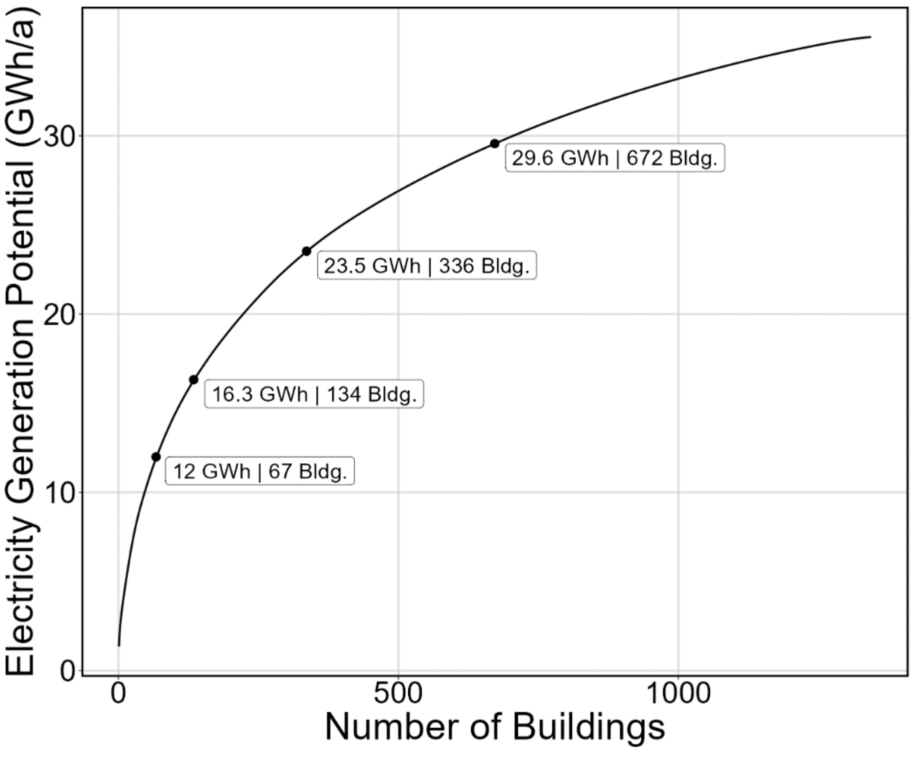

Figure 6. Absolute-value cumulative rank-size distribution of buildings and annual PV electricity production potential of buildings without a PV installation in Wittenbach in March 2022. The x-axis shows all buildings within the municipality ordered by potential, while the y-axis shows the cumulative potential. In total, 1346 buildings without any PV system were present in Wittenbach, with a cumulative potential of 35.1 GWh/a of PV production in 2022. The average potential is 26 MWh/a. 134 highest-potential buildings are sufficient to achieve nearly half of the potential (16.3 GWh/a), with an average potential of 122 MWh/a.

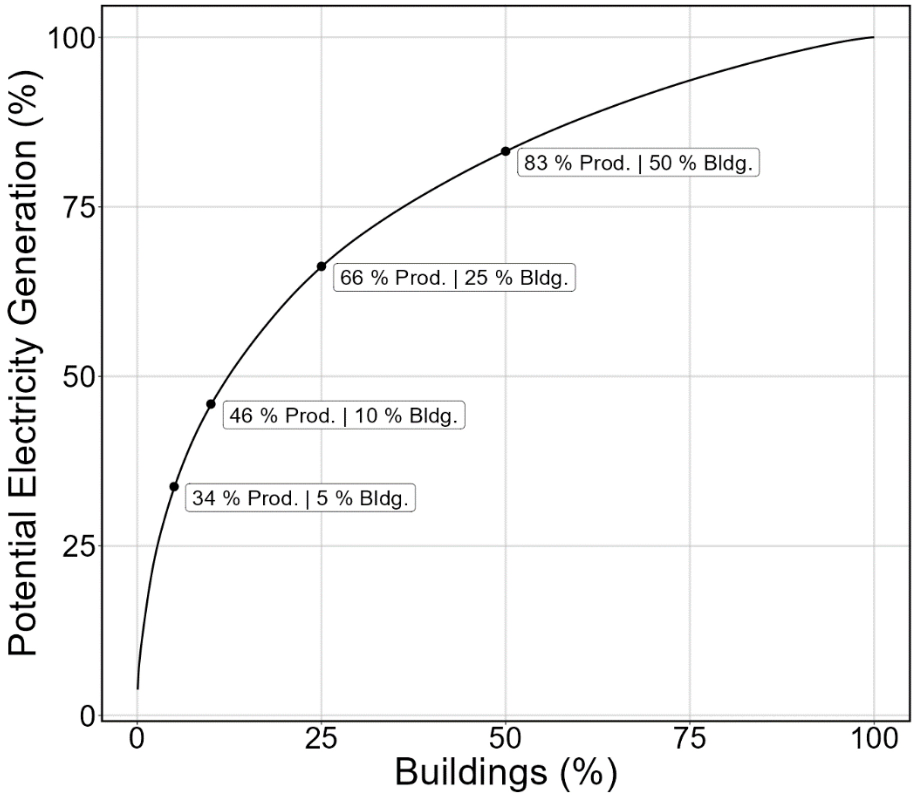

Figure 7. Relative-value cumulative rank-size distribution of buildings and annual PV electricity production potential of buildings without a PV installation in Wittenbach in March 2022. The x-axis shows fractions of all buildings within the municipality ordered by potential, while the y-axis shows fractions of the cumulative potential. In total, there is a cumulative unutilized potential of 35.1 GWh/a of annual PV production. Only the 5 % highest-potential buildings are necessary to reach almost a third of the whole potential and with 10 % of the highest-potential buildings nearly half of the available potential could be reached.

The rank-size plot of potential PV generation reveals as a key finding that the PV systems installed to date have not consistently been placed on buildings with the highest PV potential (Figure 8). Many of the buildings with the greatest potential remain undeveloped. While the rooftops that are already equipped with PV systems reduce the remaining available potential, the data suggest that not all "low-hanging fruit" in the form of high-potential buildings have yet been utilized.

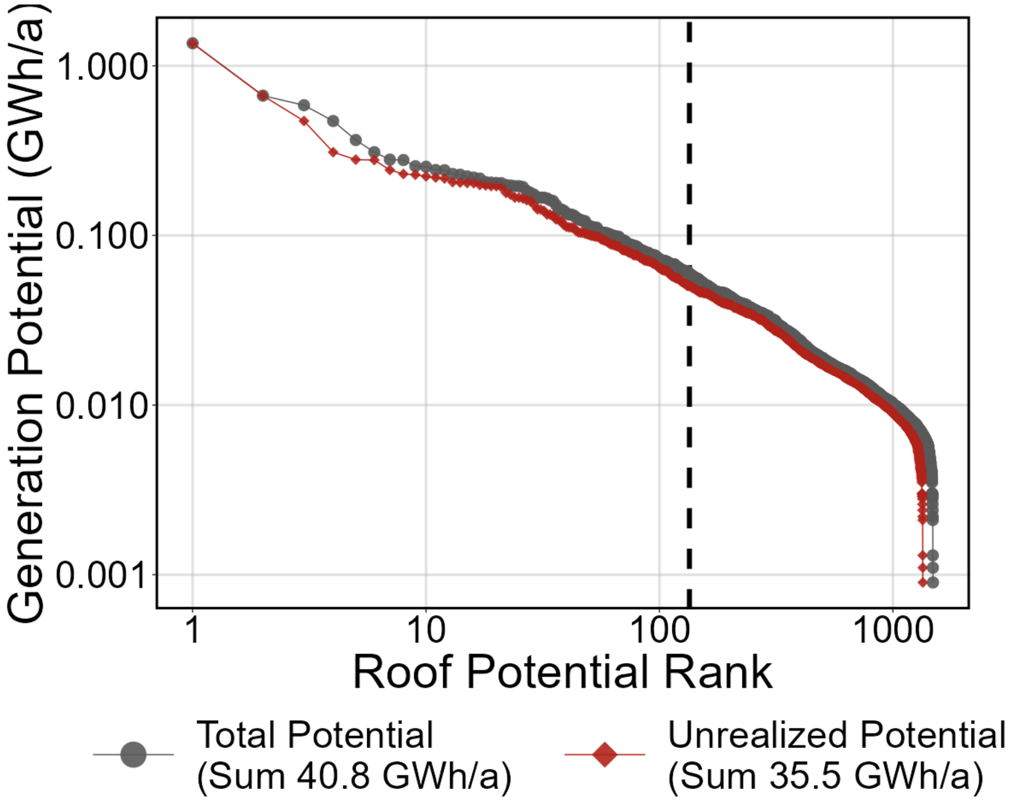

Figure 8. Absolute-value rank-size distribution of PV potentials per building in Wittenbach in March 2022, shown on a logarithmic scale. The distribution very closely follows a frequency law (such as the Zipf-Mandelbrot law), illustrative of phenomenons where the number of occurrences is inversely proportional to the size of the occurrence. In this case, there are only a handful of buildings with very large potentials, but a large number of buildings with small to very small potentials. The graph shows both the unrealized potential as well as the total potential (including already built PV systems). Of the five largest potentials, only the third- and fifth-highest had actually been utilized in 2022. In the meantime, the building with the highest potential was equipped with a 1326 kWp system.

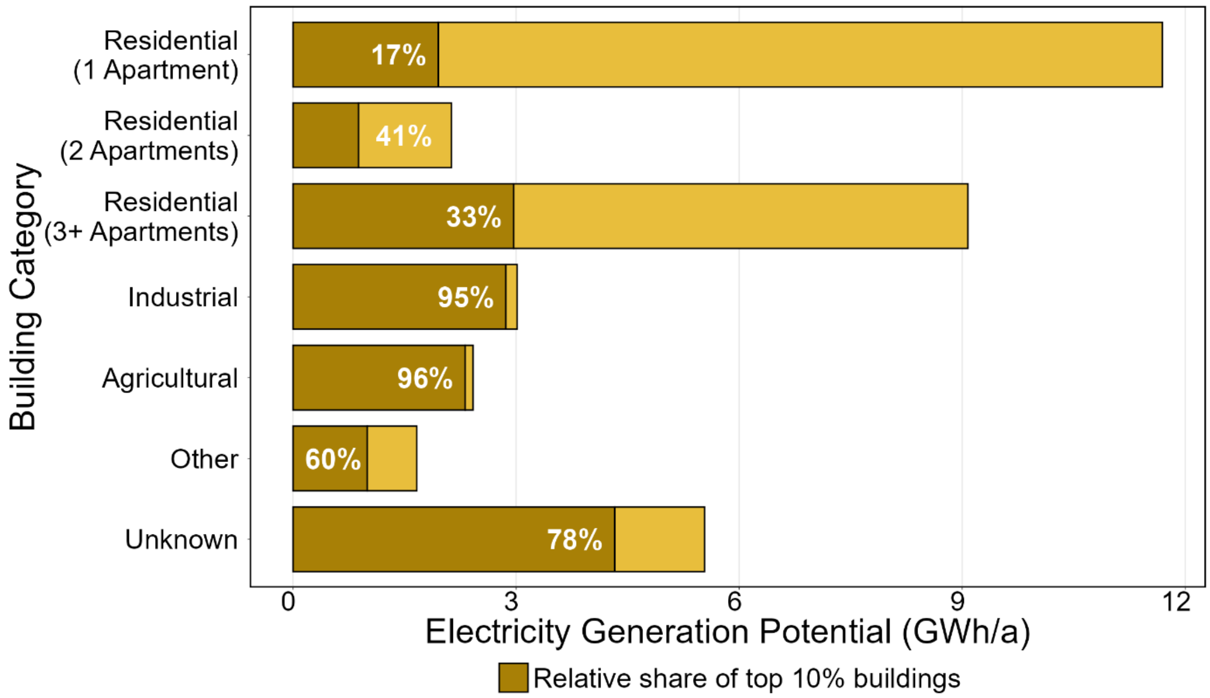

Figure 9. PV Electricity generation potential in Wittenbach disaggregated by building category, with categorization according to the federal building registry (Swiss Federal Office of Energy SFOE, 2017). The inner bars show the fraction of potential of the top 10 % buildings with largest potentials within each category. While residential buildings with one apartment are in general of similar size throughout (and thus all exhibit comparable potentials), industrial and agricultural buildings can vary greatly in size. As a consequence, the largest industrial potentials constitute a much larger fraction of the total industrial potential. Category “Unknown” is made up of buildings with a missing classifier for building type. Category “Other” is an aggregation of the following official categories with little potential: Other High-rise Structures, Cultural and Recreational Buildings, Silos and Storage Buildings, Museums and Libraries, Residential Communities, Transportation and Communication, Sports Halls, Schools and Universities, Churches, Hotel Buildings, Garage Buildings, and Office Buildings.

Figure 9 illustrates how the PV potential is distributed across different building types with an indication for the share of buildings with the highest potentials. Purely residential buildings constitute by far the largest category. However, buildings in the industrial and agricultural sectors exhibit substantial potential and represent a significant share of the buildings with the highest potential in Wittenbach, in contrast to residential buildings. Of these two, industrial buildings appear more promising because of the elevated electricity consumption that is present in many industrial buildings. Additionally, the category of residential buildings with three or more apartments appears particularly promising, as it not only has a large overall potential but also includes a significant number of individual properties with very high potential.

3.2 Overall PV Expansion

3.2.1 General Development

A part of the EDGE project in Wittenbach is the initiative to establish a local energy system with the highest possible share of renewable energy. To achieve this goal, efforts were primarily focused on expanding photovoltaic systems through active information campaigns. It is therefore of interest to analyze how the relative PV potential utilization in Wittenbach has developed since the project start, in comparison to other regions.

Figure 10 shows that PV utilization in Wittenbach initially developed very similarly to the aggregated municipalities of the Midland region and the rest of Switzerland. Between 2014 and approximately 2017, PV deployment in Wittenbach increased significantly. However, this period was followed by about four years of near stagnation. In 2020, PV expansion in Wittenbach gained momentum again, which can be attributed to a local subsidy program for PV systems introduced by the municipality. However, this program ended shortly thereafter.

Subsequently, and possibly as a rebound effect for the previous speed up, the expansion rate flattened again toward the end of 2021 before accelerating significantly from 2023 onward. Aside from a substantial increase due to the realization of a large PV installation in autumn 2024, the PV expansion in Wittenbach is roughly comparable to that in the comparison regions. The trend illustrates how significantly individual large-scale installations can influence the relative potential utilization in small and medium-sized municipalities.

The desired PV boom initiated through our efforts is not yet prominently visible in these data. However, there are early signs of an accelerated expansion. Since we expect the effects of the communication campaigns to become evident with considerable delay, it will be crucial to monitor the further expansion of PV systems in the coming years.

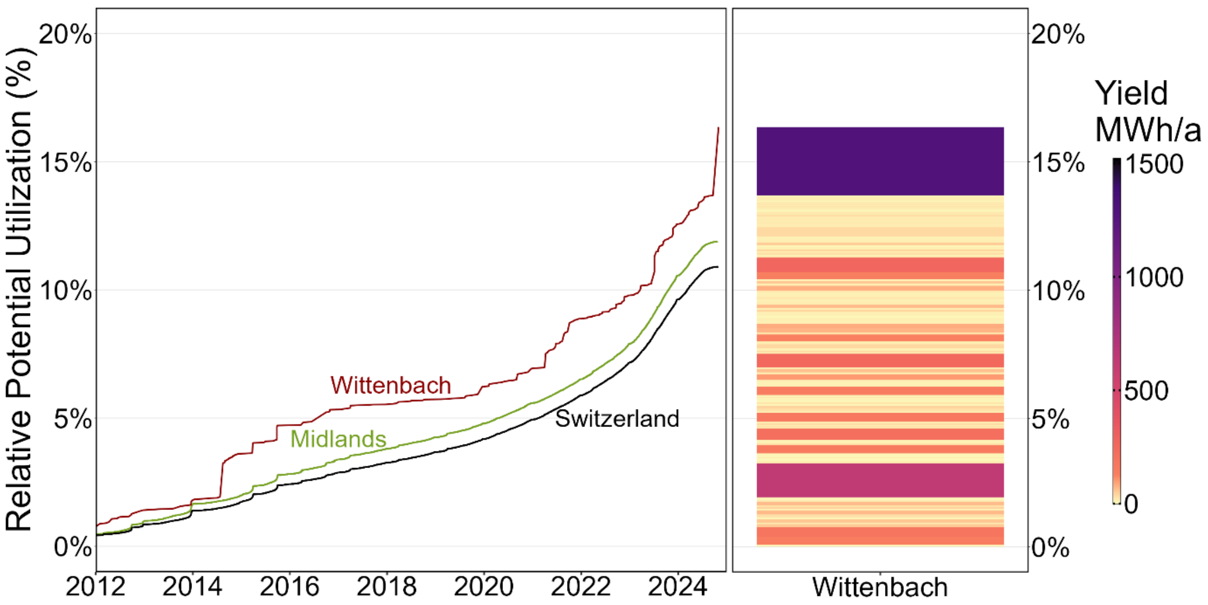

Figure 10. Temporal development of PV systems in Wittenbach in comparison to the Midlands region and all of Switzerland. The progression of the cumulative relative photovoltaic potential realized from 2012 to 2024 by area is shown in the left panel. To calculate relative potential utilization, the sum of the potential energy generation of all PV systems is divided by the calculated energy generation potential in 2024 of the area in question. Data on built PV systems show up in the official dataset with considerable delay meaning that data on late 2023 and all of 2024 is incomplete. This causes the apparent slow down in the growth in 2024. In the right panel, each individual PV system is represented by a colored segment of the bar. The segments are ordered by date of completion with the newest systems being at the top. The height of each segment represents its contribution to Wittenbachs relative PV potential. The colorbar indicates the absolute yield of the PV systems.

3.2.2 Buildings with high Potential

The best 10 % of buildings in terms of roof PV potential were identified and owners/administrators provided with specific information on PV systems on their building, including an economic feasibility assessment of a potential PV system. Tracking the progress over several years is important due to the long duration of such decision processes. In 2022, even after ordering a PV system, waiting times until installation were in many cases more than half a year, with peak waiting times up to a full year due to large backlogs. To our knowledge, this situation has eased in the meantime.

Figure 11 and Figure 12 visualize the achievements of the first wave of contacting owners in 2022 and the additional progress until late 2024. It is important to note that the allocation of projects to the shown categories is fluid and constantly changing. Decisions and intentions can change due to changes in the private life of owners, changes in building ownership, and the general evolution of the economic and social attractiveness of PV systems.

It is dissatisfactory that even after two years and several attempts to get in contact, no contact could be established with 35 building owners representing 2.8 GWh/a of potential. The potential of buildings whose owners did not yet decide whether they are going to install a PV system remains nearly unchanged and represents a considerable share of 3.4 GWh/a. To accelerate the renewable transition, it would be worthwile to specifically target this group because of the open potential.

In the case of positive decisions, the cumulative potential has not increased significantly. However, it is crucial to emphasize that the number of installed PV systems has grown substantially. Additionally, there have been some new positive decisions. These were partially offset by buildings initially categorized as having a positive decision without being ordered, which in the meantime had to be reclassified as undecided.

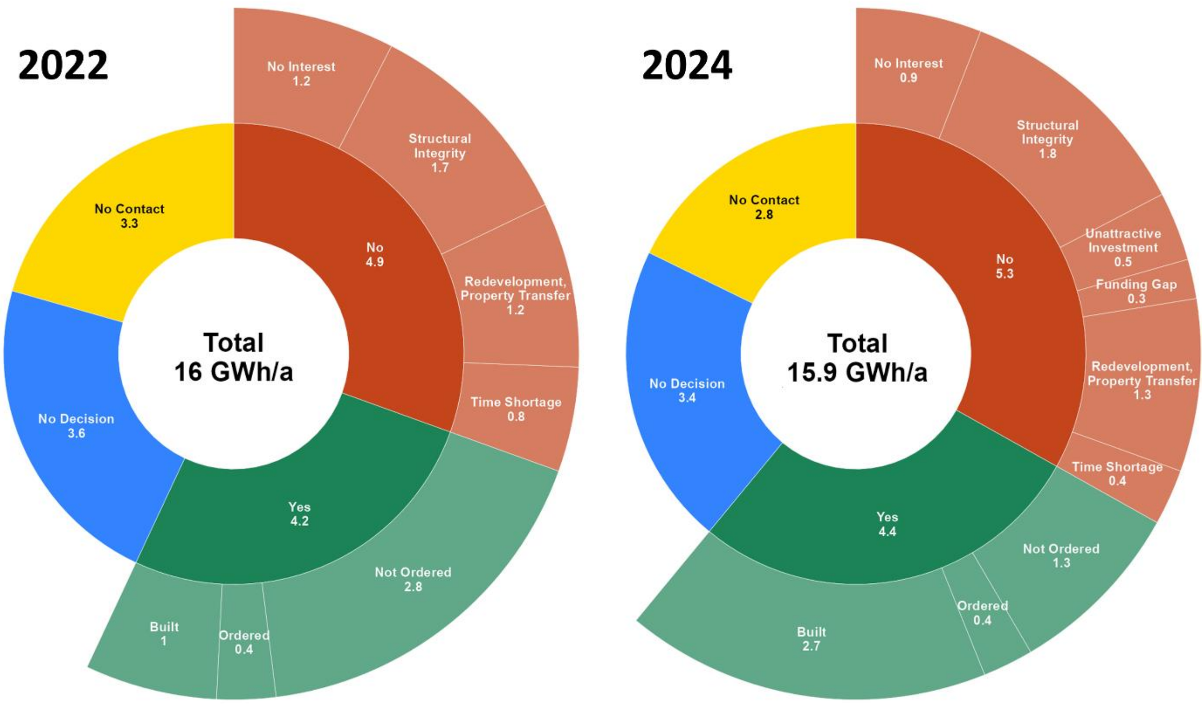

Figure 11. PV expansion progress among the 10 % of buildings with the largest roof PV potential. All values are given in GWh/a. Ring segments represent a more detailed allocation of the inner ring segment that they are adjacent to and sum up to the same total. The start of our efforts to trigger a PV-boom in Wittenbach was in summer 2022. After trying to contact every owner, statistics of the progress of PV expansion were collected towards the end of 2022 (left plot). In fall of 2024 the statistics were updated. The update in 2024 involved more options for reasons not to build a PV system (unattractive investement and funding gap). The total potential is slightly lower in 2024 because some PV systems realized between 2022 and 2024 were built slightly smaller than their calculated potential.

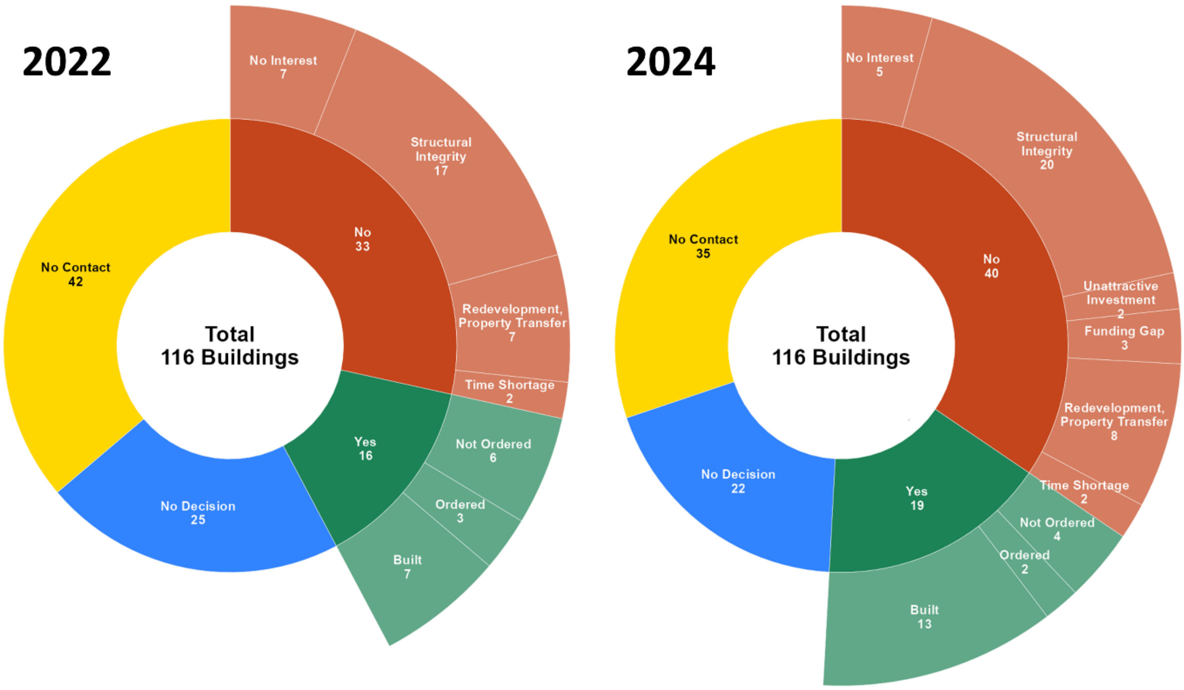

Figure 12. PV expansion progress among the 10 % of buildings with the largest roof PV potential. All values are given in number of buildings. Ring segments represent a more detailed allocation of the inner ring segment that they are adjacent to and sum up to the same total. The start of our efforts to trigger a PV-boom in Wittenbach was in summer 2022. After trying to contact every owner, statistics of the progress of PV expansion were collected towards the end of 2022 (left plot). In fall of 2024 the statistics were updated. The update in 2024 involved more options for reasons not to build a PV system (unattractive investement and funding gap).

While the progress in positive decisions and constructed systems is remarkable and contributes to an increase in PV electricity generation in Wittenbach, the share of negative decisions, when looking solely at the raw numbers, is concerning in light of Switzerland's expansion goals. Comparing the current estimated rooftop potential of 53.6 TWh/a (Anderegg et al., 2022) with the official expansion target of 35 TWh/a of new renewables by 2035 (Schweizer Parlament, 2023), it becomes clear that approximately half of Switzerland's rooftop potential must be realized by 2035 (biomass has significantly smaller potential and wind energy faces major acceptance challenges). In light of these figures, the share of negative decisions amounting to 5.3 GWh/a (33 %) among this group of buildings with the highest potentials is a bad sign. It should be noted that high-potential buildings typically achieve significantly lower generation costs when implemented, leading to better economic feasibility.

However, a closer look at the detailed categories, combined with responses from the survey and oral discussions during the PV event in Wittenbach, shows that a substantial portion of the currently negative decisions could be converted into positive decisions within a few years. The detailed categories "Structural Integrity," "Redevelopment, Property Transfer," and "Time Shortage" are all reasons that could be quickly reversed. Together, these categories account for 3.5 GWh/a of PV potential. Additionally, it is noteworthy that only a small share of the negative decisions are primarily due to financial or ideological reasons (i.e., "No Interest").

3.3 Survey Results

The ca. 110 building owners with the highest PV potential in Wittenbach were contacted to give feedback on their decision about building a PV system. Apart from the decision about building a PV system, the survey covered the reasoning behind the decision including a free text option for feedback. 36 people filled in the survey with an even distribution between positive and negative decision and a majority that is still undecided (see Figure 13).

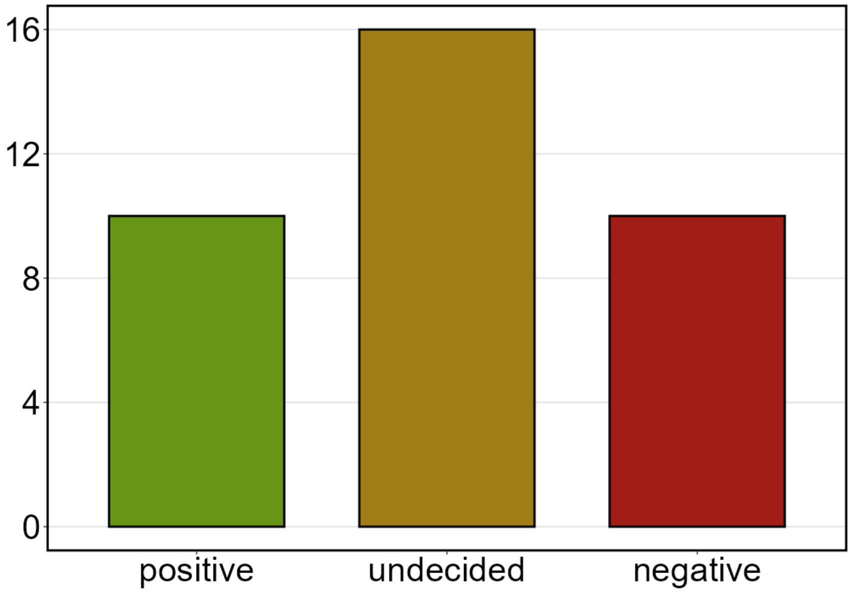

Figure 13. Overview of survey responses whether a PV system was built or is going to be built ("positive"), whether there is not a final decision ("undecided"), or whether no PV system is going to be build on the building ("negative"). Of ca. 110 contacted building owners 36 responses were registered, which results in a response rate of 33 %.

Figure 14 shows the detailed survey results of people that decided to build a PV system. Among them, an increase in self-sufficiency was the main cause for the positive decision. Closely following is sustainability. Public funding also seemed to be a trigger for some, while contributions to Swiss climate targets played a role as well. Financial reasons like building valorization and investement opportunities were at least a factor for a considerable share of respondents. Social influences of friends or the social circle did not seem to be strong factors among our survey participants.

The details of building owners that did not yet make a final decision whether or not to build a PV system on their building are shown in Figure 15. A planned building renovation or conversion is an often-cited reason to postpone the decision about building a PV system. Missing information and a lack of time were similarily reasons that caused several people to remain undecided. Other provided reasons do not seem to be a significant factor in decision-making.

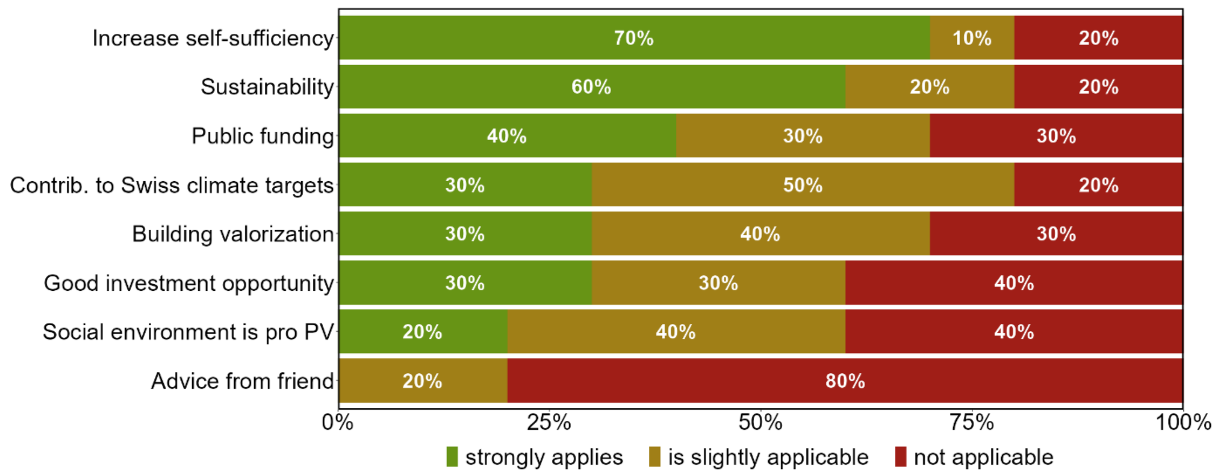

Figure 14. Detailed survey responses of building owners with positive decision to build a PV system. 10 people filled in this section of the survey.

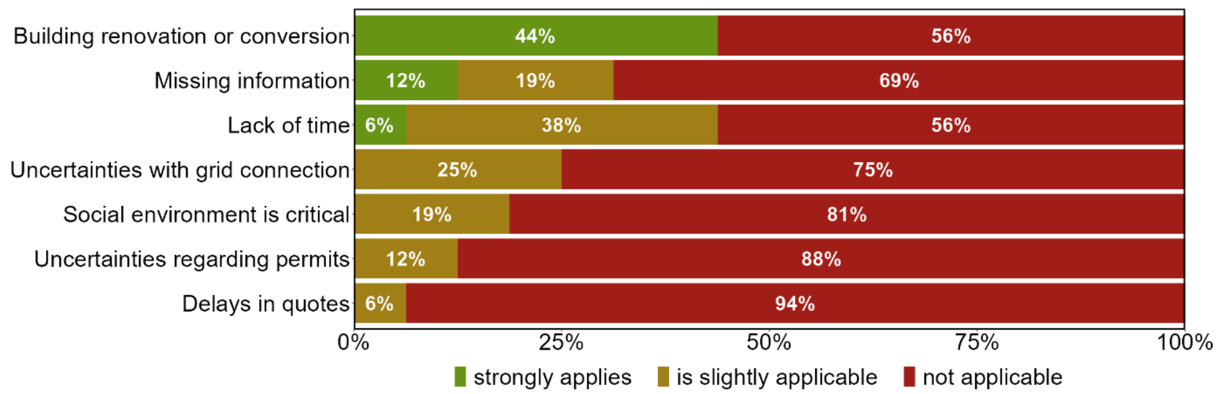

Figure 15. Detailed survey responses of undecided building owners regarding building a PV system. 16 people filled in this section of the survey.

Figure 16 shows the detailed survey results of building owners that decided against building a PV system. Like people who are still undecided, structural building reasons were the main reason to decide against building a PV system. Another often stated problem was a lack of funds. While problems with grid connection should be mentioned as sometimes being an issue, it is worth pointing out that the option “Not interested” was not an often-cited reason. This option was expected to be chosen by people who are opposed to PV as a technology because of their settled conviction. We therefore deduce that general resistance to roof PV is low among owners of buildings with large PV potential in Wittenbach.

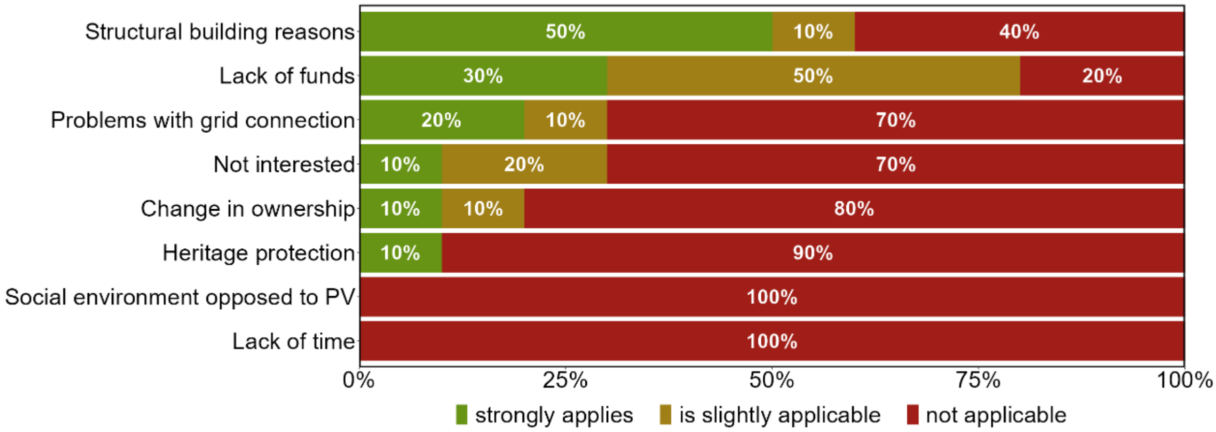

Figure 16. Detailed survey responses of building owners with negative decision to build a PV system. 10 people filled in this section of the survey.

In addition to the above-mentioned findings, the survey delivered more detailed answers via a free text field for additional reasons for people's decision. Among people who chose against building a PV system, several respondents mentioned alternative investments that are more profitable, while a similar amount of people described structural reasons as the barrier for a positive decision. Both these types of respondents could quickly change their opinion because the underlying reason for the negative decision can easily change. Notably, only one detailed response was recorded with a negative decision based on general scepticism towards the technology.

A major share of undecided respondents answered with details about a building renovation planned in the next few years. This result is positive for the medium-term success of a strong PV expansion because it shows that even among the undecided ones, many are probably going to install PV systems within the coming years. Right now, they are simply waiting because it is not economically viable to build a PV system that needs to be dismantled for a renovation, but once the renovation is carried out there are usually even synergies that make building a PV system economically more attractive.

In summary, among undecided people or people with a negative decision, frequently the stated causes are building-related challenges, which are often expected to be solved within the coming years, thus these decisions could turn positive quickly. In addition, there were also cases such as condominium ownership where the decision process naturally takes a lot of time. Challenges with the cost or temporal requirements for grid connection have also been mentioned as problems, albeit to a lesser degree.

Among respondents with positive decision to build a PV system, several people wrote details about an increase of self-sufficiency as a major reason. They mentioned the goal in correspondence with the costs of electricity in Wittenbach, which were described as high in these answers.

3.4 Public Photovoltaic Event

After giving two presentations at public events (named "Bürgerinfo") in the year 2022 on Mai 9 and November 7, a third public event with information about photovoltaics in Wittenbach took place on 11 (anouncement text in Appendix A, Figure 17). November 2024. Besides a presentation, we discussed findings and future potentials at a booth with two posters (posters in Appendix B and C, Figure 18 and Figure 19). At the end of the event, we presented a summary about discussion points and answered final questions. Discussion topics were mainly grid connection challenges, system economics, and energy storage solutions. Attendees showed strong interest in PV adoption, highlighting the importance of continued public engagement.

4 Conclusion

PV is the technology with the highest potential in Wittenbach which can likely be realized. The same will be true for many other municipalities in Switzerland.

There are different applications of PV like roofs, facades, agrivoltaics, on infrastructure, or alpine pv. The survey and discussions with residents of Wittenbach demonstrated that PV on roofs has very good acceptance. There is a multitude of factors that influence the decision to build a PV system. The combination with long decision processes creates a complex situation. In this project we offered neutral counseling and actively contacted owners of buildings with high potentials, showing them the economic feasibility of a PV system on their roof. These are only a few measures out of many, so it would be surprising if the PV expansion in Wittenbach was exceptionally high. We expect that more and diverse measures would be needed for that to occur.

The PV project in Wittenbach serves as an insightful case study, demonstrating both the potential and challenges of accelerating renewable energy adoption at the municipal level. Over the two years since the project's inception, significant progress has been made, albeit not at the scale required to fundamentally stress the local grid or necessitate the immediate implementation of innovative smart grid technologies. Nonetheless, the observed PV expansion in Wittenbach has outpaced the average progress in other Swiss municipalities, a promising sign for the region's renewable energy goals.

The project highlighted several critical barriers to rapid PV expansion, including limited incentives for proactive grid upgrades, the small scale of local energy providers, and the broader societal preference for more "innovative" projects over widespread PV adoption. Many people place their hopes for the energy transition on yet to be developed technologies, even though Switzerland with its strong electric grids, central location in the European power grid, and high share of hydropower is in an excellent position to master the energy transition with currently available technological solutions. Local decision makers and residents often rate the level of innovation of a system by the innovation grade of singular components instead of the entire system. As a result, a highly decarbonized local energy system is undervalued if it is comprised of market-ready technologies. In reality, the system is more than just a sum of its components. Therefore, a fully decarbonized local energy system should be recognized as highly innovative.

Distribution system operators (DSOs) play a pivotal role in the deployment of PV systems, influencing the process through grid connection costs, grid enhancement planning, coordination and timelines, and communication with stakeholders. Addressing these barriers will require coordinated efforts between municipalities, DSOs, and policymakers to streamline processes and incentivize forward-looking grid planning. Expansion of the distribution grid primarily happens only when grid bottlenecks arise. The current compensation of costs via Elcom (proof of demand) does little to promote forward-looking grid expansion. Some DSOs do not have an intrinsic interest to quickly expand PV within their grids because that makes their core task of grid reliability more challenging. The size of distribution system operators also plays a role. Small operators, of which there are many in Switzerland, usually do not have the ressources in-house for a proactive development of their grids or project collaborations outside of the minimally required core tasks.

Looking forward, it is crucial to prepare for a future with a significantly higher share of PV in the energy mix. This includes developing strategies to manage high generation peaks and preparing measures such as dynamic feed-in tariffs and flexible curtailment of PV systems. Priority should still be a quick expansion of PV, but it will be more cost effective to start with preparations for a future with a dominant share of PV locally now. The integration of energy storage solutions, supported by anticipated extreme cost reductions, will also play a vital role in enhancing grid stability and accommodating increased renewable energy generation.

Despite these challenges, the project reaffirmed the high potential of PV technology in Wittenbach, particularly through applications on rooftops, infrastructure, and agricultural land. In our analysis we see the strong impact of relatively big PV systems around 1 MWp on PV potential utilization of municipalities like Wittenbach. It proved that our strategy to target the owners of buildings with the highest potentials is a good approach to speed up the expansion of PV. However, for electric distribution grid integration, expansion with more decentralized systems would be beneficial because of a more even generation to load ratio within buildings with PV systems.

Agrivoltaics and infrastructure-based PV systems emerged as promising areas for future exploration, offering the potential for large-scale deployment and cost-competitive energy generation. Agrivoltaics, in particular, should be explored further due to its tremendous theoretical potential and the prospect of big project sizes that help bring down costs.

The public engagement efforts in Wittenbach demonstrated strong interest in PV systems, with many residents expressing support for continued expansion. However, a widespread sense of complacency—stemming from the perception that current progress is sufficient—remains a challenge. To achieve Switzerland’s energy and climate targets, it is imperative to instill a greater sense of urgency among both citizens and policymakers.

In conclusion, while the project has made commendable strides, realizing the full potential of PV in Wittenbach and beyond will require sustained efforts, innovative approaches, and robust collaboration across all levels of the energy ecosystem. Revisiting the outcomes in two years will provide further insights into the long-term impacts and effectiveness of the strategies implemented.

5 Acknowledgement

We would like to express our gratitude to the following individuals for their valuable contributions to this project:

Daniel Worni, *Leiter Infrastruktur / Liegenschaften / Tiefbau* municipality of Wittenbach: For providing local information, facilitating public events in Wittenbach, and assisting in establishing connections with local property owners.

Lukas Bernhard and Ramon Hauser: For contacting building owners, planning PV systems, and conducting economic feasibility studies.

Dionis Anderegg and Sven Strebel: For their contributions to PV planning projects, agrivoltaics, and discussion and analysis of survey results.

Their efforts and expertise were instrumental in the success of this project.

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7 Appendix

Appendix A

AUS DER GEMEINDE

Wittenbach: Vorreiterrolle in der Energiewende

Bei der Integration dezentraler erneuerbarer Energien will Wittenbach eine führende Rolle spielen. Anlässlich der Bürgerinfo vom 11. November wird die «Sweet Edge»-Projektleitung, Prof. Jürg Rohrer und Nicolas Stocker, über den Stand der Projekte in der Modellgemeinde Wittenbach berichten.

Das Förderprogramm Sweet des Bundesamtes für Energie unterstützt innovative Projekte zur Umsetzung der Energiestrategie 2050 und zur Erreichung der Klimaziele der Schweiz. Im Jahr 2021 gewann das Edge-Konsortium, bestehend aus 14 Hochschulen, Universitäten und zahlreichen Industriepartnern, die Ausschreibung zum Thema «Integration dezentraler erneuerbarer Energien». Zwischen 2021 und 2027 entwickelt das Edge-Projekt regionale Szenarien und Strategien, um die Energieversorgung der Schweiz bis 2050 nahezu vollständig auf erneuerbare Energien umzustellen. Dabei liegt der Fokus auf dezentralen Energiequellen wie Photovoltaik (PV), Wind und Biomasse. Diese sollen durch bestehende Wasserkraft und moderne Speichermöglichkeiten ergänzt werden. Der Fokus liegt nicht nur auf der Technologie, sondern auch auf der Förderung von Investitionen, neuen Geschäftsmodellen und der gesellschaftlichen Akzeptanz der Energiewende.

Wittenbach als Modellgemeinde

Gemäss Projektleiter Nicolas Stocker unterscheiden sich die Herausforderungen und Möglichkeiten zur Transformation zu einem nachhaltigen Energiesystem je nach Region deutlich. Von 2022 bis 2027 dient Wittenbach als Modellgemeinde im Mittelland für das Edge-Pilotprojekt. Hier soll gezeigt werden, wie eine Energieversorgung mit einem hohen Anteil an erneuerbaren Energien in der Praxis funktionieren kann. Wittenbach kann damit eine Vorreiterrolle einnehmen, um die Energiewende voranzutreiben und bereits heute Lösungen zu erproben, die in der Schweiz erst in den kommenden Jahren flächendeckend umgesetzt werden sollen.

Fokus auf Photovoltaik – hervorragendes Potenzial

Nicolas Stocker: «Wegen des herausragenden techno-ökonomischen Potenzials ist Photovoltaik ein Fokusthema. Neben weiteren Teilprojekten mit anderem Fokus arbeiten wir daher darauf hin, in Wittenbach einen starken Ausbau der Photovoltaik auszulösen. Dies soll erreicht werden, indem die grössten Potenziale identifiziert, analysiert und transparent präsentiert werden, inklusive einer gezielten Informationsverbreitung. Die kontinuierlichen Fortschritte in der Photovoltaik ermöglichen einerseits neue Anwendungen und verbessern andererseits stetig die Wirtschaftlichkeit geplanter Projekte. Neben der Ausarbeitung von Planungsvarianten und Wirtschaftlichkeitsrechnungen für grosse PV-Anlagen auf Gemeindeobjekten kommen auch innovative Anwendungen der Photovoltaik zur Sprache, wie zum Beispiel über Parkplätzen oder als Agri-PV. Wir haben ermittelt, dass dies 10 Prozent der Gebäude mit der besten Eignung knapp 50 Prozent des vorhandenen PV-Dachflächenpotenzials vereinen.» Was wurde zur Förderung des Photovoltaik-Zubaus getan? Nicolas Stocker: «Wir haben massgeschneiderte Planungsvorschläge mit Wirtschaftlichkeitsrechnungen an die Gebäudebesitzer*innen verschickt und ihnen bei der Umsetzung Unterstützung angeboten.»

> «Auch PV-Anlagen über Parkplätzen und Agri-PV kommen zur Sprache.»

Wie weit ist Wittenbach?

Nicolas Stocker: «An der Bürgerinfo werden wir die wichtige Rolle der Photovoltaik für die Transformation des Schweizer Energiesystems erklären. Nach einer kurzen Zusammenfassung zum Stand des PV-Zubaus in der Schweiz und einer Einordnung, wie Wittenbach im Vergleich zu anderen Gemeinden dasteht, werden wir auf aktuelle Entwicklungen der Photovoltaik und Chancen für die Bürger*innen von Wittenbach eingehen. Der Fokus des Vortrags wird darauf liegen, den Zwischenstand des lokalen PV-Zubaus zu zeigen und die weiteren Aktivitäten zu präsentieren. Sehr gerne werden wir im Anschluss für Fragen, Anregungen und Diskussionen zur Verfügung stehen.»

Jürg Grau

Professor Jürg Rohrer, ZHAW, «Sweet Edge»-Leitungsteam.

Nicolas Stocker, ZHAW, «Sweet Edge»-Projektleiter Wittenbach.

Bilder: ZHAW

«Sweet Edge» für die schweiz

Das Edge-Konsortium zielt darauf ab, wissenschaftliche Erkenntnisse zu liefern, um den Einsatz erneuerbarer Energien lokal und dezentral in der Schweiz zu beschleunigen. Das Konsortium soll zeigen, dass das Schweizer Energiesystem bis 2035 und 2050, wenn erneuerbare Energien einen ambitionierten Anteil erreicht haben, technisch und wirtschaftlich optimal und sicher gestaltet und betrieben werden und auf den europäischen Märkten gut positioniert sein kann.

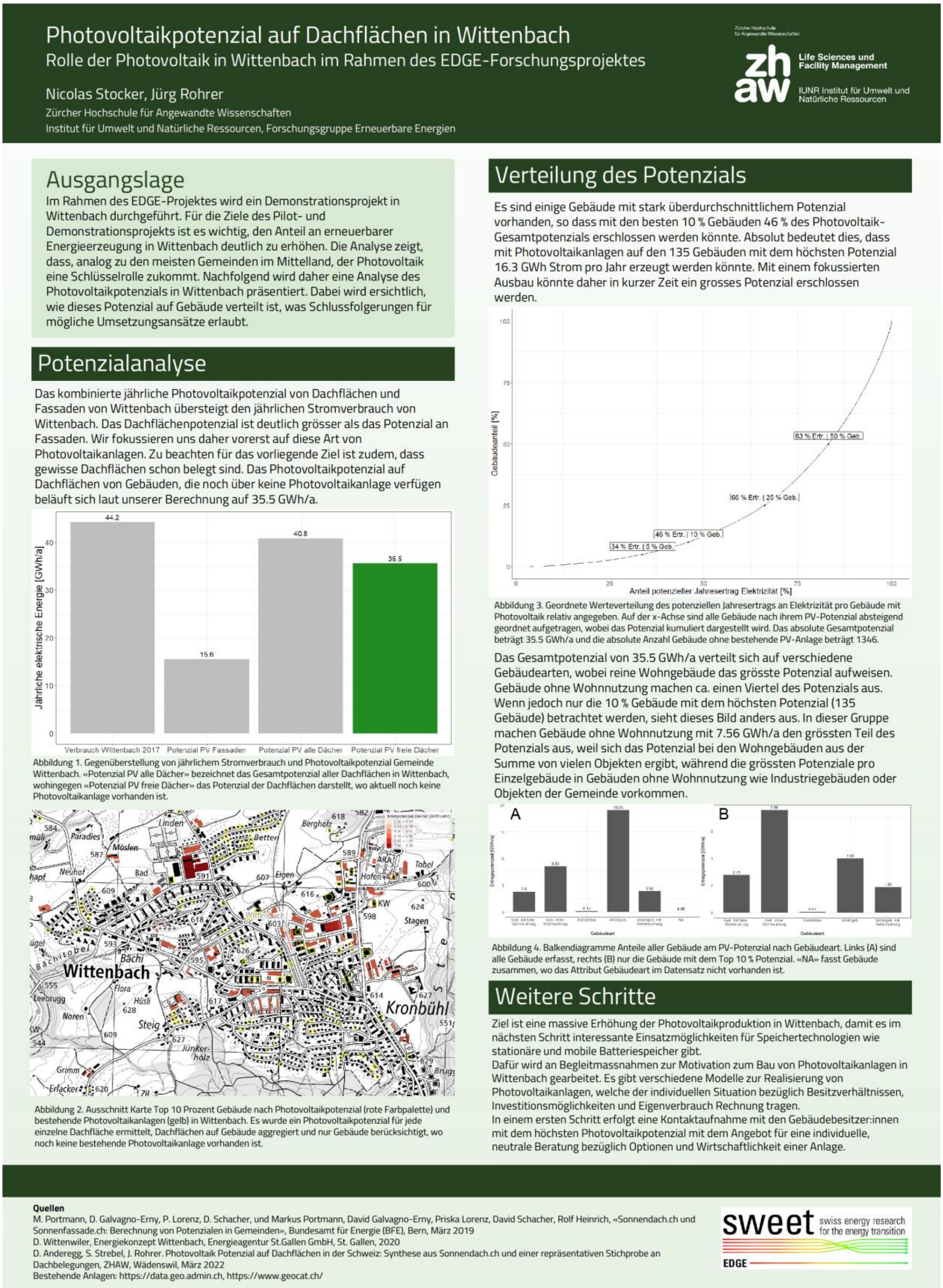
sweet swiss energy research for the energy transition

EDGE

2 am Puls | Nr. 41 vom 10. Oktober 2024

Figure 17. Announcement of PV presentation and discussion at public event ("Bürgerinfo") in Wittenbach (in German).

Appendix B



Photovoltaikpotenzial auf Dachflächen in Wittenbach
Rolle der Photovoltaik in Wittenbach im Rahmen des EDGE-Forschungsprojektes

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Zürcher Hochschule für Angewandte Wissenschaften
Institut für Umwelt und Natürliche Ressourcen, Forschungsgruppe Erneuerbare Energien

Ausgangslage

Im Rahmen des EDGE-Projektes wird ein Demonstrationsprojekt in Wittenbach durchgeführt. Für die Ziele des Pilot- und Demonstrationsprojekts ist es wichtig, den Anteil an erneuerbarer Energieerzeugung in Wittenbach deutlich zu erhöhen. Die Analyse zeigt, dass, analog zu den meisten Gemeinden im Mittelland, der Photovoltaik eine Schlüsselrolle zukommt. Nachfolgend wird daher eine Analyse des Photovoltaikpotenzials in Wittenbach präsentiert. Dabei wird ersichtlich, wie dieses Potenzial auf Gebäude verteilt ist, was Schlussfolgerungen für mögliche Umsetzungsansätze erlaubt.

Potenzialanalyse

Das kombinierte jährliche Photovoltaikpotenzial von Dachflächen und Fassaden von Wittenbach übersteigt den jährlichen Stromverbrauch von Wittenbach. Das Dachflächenpotenzial ist deutlich grösser als das Potenzial an Fassaden. Wir fokussieren uns daher vorerst auf diese Art von Photovoltaikanlagen. Zu beachten für das vorliegende Ziel ist zudem, dass gewisse Dachflächen schon belegt sind. Das Photovoltaikpotenzial auf Dachflächen von Gebäuden, die noch über keine Photovoltaikanlage verfügen beläuft sich laut unserer Berechnung auf 35.5 GWh/a.

Abbildung 1. Gegenüberstellung von jährlichem Stromverbrauch und Photovoltaikpotenzial Gemeinde Wittenbach. «Potenzial PV alle Dächer» bezeichnet das Gesamtpotenzial aller Dachflächen in Wittenbach, wohingegen «Potenzial PV freie Dächer» das Potenzial der Dachflächen darstellt, wo aktuell noch keine Photovoltaikanlage vorhanden ist.

Abbildung 2. Ausschnitt Karte Top 10 Prozent Gebäude nach Photovoltaikpotenzial (rote Farbpalette) und bestehende Photovoltaikanlagen (gelb) in Wittenbach. Es wurde ein Photovoltaikpotenzial für jede einzelne Dachfläche ermittelt, Dachflächen auf Gebäude aggregiert und nur Gebäude berücksichtigt, wo noch keine bestehende Photovoltaikanlage vorhanden ist.

Verteilung des Potenzials

Es sind einige Gebäude mit stark überdurchschnittlichem Potenzial vorhanden, so dass mit den besten 10 % Gebäuden 46 % des Photovoltaik-Gesamtpotenzials erschlossen werden könnte. Absolut bedeutet dies, dass mit Photovoltaikanlagen auf den 135 Gebäuden mit dem höchsten Potenzial 16.3 GWh Strom pro Jahr erzeugt werden könnte. Mit einem fokussierten Ausbau könnte daher in kurzer Zeit ein grosses Potenzial erschlossen werden.

Abbildung 3. Geordnete Werteverteilung des potenziellen Jahresertrags an Elektrizität pro Gebäude mit Photovoltaik relativ angegeben. Auf der x-Achse sind alle Gebäude nach ihrem PV-Potenzial absteigend geordnet aufgetragen, wobei das Potenzial kumuliert dargestellt wird. Das absolute Gesamtpotenzial beträgt 35.5 GWh/a und die absolute Anzahl Gebäude ohne bestehende PV-Anlage beträgt 1346.

Das Gesamtpotenzial von 35.5 GWh/a verteilt sich auf verschiedene Gebäudearten, wobei reine Wohngebäude das grösste Potenzial aufweisen. Gebäude ohne Wohnnutzung machen ca. einen Viertel des Potenzials aus. Wenn jedoch nur die 10 % Gebäude mit dem höchsten Potenzial (135 Gebäude) betrachtet werden, sieht dieses Bild anders aus. In dieser Gruppe machen Gebäude ohne Wohnnutzung mit 7.56 GWh/a den grössten Teil des Potenzials aus, weil sich das Potenzial bei den Wohngebäuden aus der Summe von vielen Objekten ergibt, während die grössten Potenziale pro Einzelgebäude in Gebäuden ohne Wohnnutzung wie Industriegebäuden oder Objekten der Gemeinde vorkommen.

Abbildung 4. Balkendiagramme Anteile aller Gebäude am PV-Potenzial nach Gebäudeart. Links (A) sind alle Gebäude erfasst, rechts (B) nur die Gebäude mit dem Top 10 % Potenzial. «NA» fasst Gebäude zusammen, wo das Attribut Gebäudeart im Datensatz nicht vorhanden ist.

Weitere Schritte

Ziel ist eine massive Erhöhung der Photovoltaikproduktion in Wittenbach, damit es im nächsten Schritt interessante Einsatzmöglichkeiten für Speichertechnologien wie stationäre und mobile Batteriespeicher gibt.
Dafür wird an Begleitmassnahmen zur Motivation zum Bau von Photovoltaikanlagen in Wittenbach gearbeitet. Es gibt verschiedene Modelle zur Realisierung von Photovoltaikanlagen, welche der individuellen Situation bezüglich Besitzverhältnissen, Investitionsmöglichkeiten und Eigenverbrauch Rechnung tragen.
In einem ersten Schritt erfolgt eine Kontaktaufnahme mit den Gebäudebesitzer:innen mit dem höchsten Photovoltaikpotenzial mit dem Angebot für eine individuelle, neutrale Beratung bezüglich Optionen und Wirtschaftlichkeit einer Anlage.

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Bestehende Anlagen: https://data.geo.admin.ch, https://www.geocat.ch/

Figure 18. PV potential poster for public event in Wittenbach.

Appendix C

Figure 19. Poster with general information about the EDGE project for public event in Wittenbach.