THE POTENTIAL OF PLUG&PLAY PV SYSTEMS IN SWITZERLAND

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ABSTRACT: Plug-in photovoltaic systems for balconies are becoming increasingly popular. This paper analyses the energy potential for such systems in Switzerland. Based on the known potential for facade PV systems, a randomized sample of different building categories is used to investigate whether balconies are present and what their photovoltaic potential is. The potential is then extrapolated to Switzerland's building stock.

In this project, supported by the Swiss Federal Office of Energy, the authors propose to clarify the relevant issues regarding Plug & Play PV systems in Switzerland. Part of this project is the calculation of the energy potential of such systems in Switzerland. The basis of the work is the solar cadastral data (www.sonnenfassade.ch) of Switzerland.

In total 950 facades of the Sonnenfassade.ch dataset were used to assess the suitability for a Plug & Play PV system and determine the potential. This test dataset is representative in terms of house types, sizes and regions. To reach the 950 test examples, 1300 facades were randomly chosen and analyzed by humans regarding the presence and size of balconies with help of publicly available images and maps. 27% of the 1300 facades couldn't be analyzed due to insufficient imagery. The analysis showed, that 60% of the chosen facades don't have any balconies. The example dataset has been extrapolated to all facades of Switzerland.

The areas usable for Plug & Play PV systems on balconies have been defined based on the typical size of such installations (P_{DC_STC}: 400 W on a balcony with approx. 1x2 m and a module efficiency of 20%). Three options were considered: 1. P_{DC_STC}: 800 W with limitation to 600 W AC inverter nominal power; 2. P_{DC_STC}: 1200 W with limitation to 600 W AC inverter nominal power; 3. P_{DC_STC}: 1200 W DC with no AC limitation. The potential is 894 GWh, 1004 GWh and 1040 GWh respectively.

Keywords: Solar Radiation, Satellite Data, PV Potential, Plug & Play PV Systems, Mini PV, Balcony PV

1 INTRODUCTION

Plug-in photovoltaic systems for balconies, also known as Plug & Play PV systems are becoming increasingly popular in Europe. Especially in Germany [1] the growth accelerated lately mainly by lowering bureaucratic thresholds to install such systems. Due to this boom recognizable in Switzerland also, the question arises, how big the potential for such systems might be.

In this project, supported by the Swiss Federal Office of Energy, a group with representatives from the scientific community, the PV and grid industries, and regulatory bodies propose to clarify the relevant issues regarding Plug & Play PV systems for Switzerland.

In a first part of this project the potential of such systems in Switzerland has been calculated.

In Switzerland the solar potentials of all facades and roofs of all existing buildings are well known. They have been calculated and published (www.sonnendach.ch, www.sonnenfassade.ch) by the Swiss Federal Office of Energy. They are updated every 6-7 years.

The total theoretical potential energy production of all facades is 50 TWh (the yearly electricity consumption in Switzerland is about 60 TWh) [2, 3]. But this also includes doors, windows, balconies, and other areas, which are hardly usable for PV. Based on a short analysis the realizable potential was reduced by a factor of 3 to 17 TWh [4].

To our knowledge a detailed analysis of Plug & Play PV systems hasn't yet been done anywhere, although knowing the potential would be crucial regarding future regulations. In 2024 a short analysis of the share of advertised rental apartments in combination with global horizontal irradiance has been made in Germany [5]. However, this does neither show the share of the buildings with balconies nor show the potential irradiance or PV production within the facades.

2 METHOD

2.1 Sample dataset

Based on the known potential for facade PV systems, a randomized sample for different building categories is used to investigate whether balconies are present and how large their photovoltaic potential is. The potential is then extrapolated to Switzerland's building stock.

The existing exceptional database of Sonnenfassade.ch was used as the basis for this evaluation. Initially, a sample dataset of 1000 randomized facades was defined by an automatic algorithm as a starting point. First, a subset of facades was selected according to the following factors: irradiation (above 600 kWh/m^{2}y), usage (residential buildings), area (above 50 m^2) and number of floors (more than 1 floor) (Figure 4).Within this selection, the sample is representative of all facades in Switzerland regarding the usage (residential only, mainly residential, and mixed), number of floors, year of construction, facade area, irradiation, region (Canton) and population density.

The facades have been analyzed by humans with the help of Swiss Topographic maps, Google Street View, Google Earth and Apple maps in order to assess their suitability for the potential study.

In the end the sample was enlarged to 1300 facades. The reason to use more than the initial 1000 facades selected in the beginning was that not all of them could be analyzed due to the lack of imagery of the facade available. To determine the parameters of the facades, an image must be available online. Finally, 950 out of 1300 facades (73%) could be examined. It is not known whether the non-inspected buildings differ systematically from the inspected buildings in terms of the characteristics analysed. Approximately 60% of these facades did not have any balconies – a higher percentage than assumed.

The following parameters have been evaluated for each of the 950 sample facades:

Number of balconies, sum of length of balconies (assuming that a balcony is always high enough to place a

PV module (1x2 m area)), number of flats (min and max estimation), potential number of modules on all balconies (min. and max. estimation). The latter two have been evaluated for the three options calculated (see chapter 2.2).

For each facade the production per area [kWh/m^2 y] (PV_{rel}) was available based on Sonnenfassade.ch. This potential included the shading of the surrounding environment (trees, buildings, and topography) as well as the shading of the building itself. Figure 1 shows an example of a facade with many balconies.

Figure 1: Example building facade with 20 balconies, a summed balcony length of 100 m and a maximum of 40 modules (for max. 2 or 3 modules per apartment). Source: Google Maps.

2.2 Calculation of potential production on each sample facade

Based on the aforementioned figures the potential PV production of the modules situated on the balconies have been estimated. In this process, the areas usable for Plug & Play PV systems on balconies have been defined based on the current regulations and typical size of such installations. For the modules a nominal DC power of 400 W at STC was assumed with a module efficiency of 20% and a needed area of 1x2 m. Apart from the limit of 600 W per meter circuit, no other requirements for the electrical installation and spatial planning aspects were taken into account in this analysis.

Only modules in landscape orientation with 90° tilt angle applied to the outer side of balconies have been considered. This was done due to the upscaling method based on the known potential of the underlying facades dataset.

The following **three options have been modelled**:

1. 800 W P_{DC_STC} system (2 modules) with limitation to 600 W AC inverter nominal power
2. 1200 W P_{DC_STC} system (3 modules) with limitation to 600 W AC inverter nominal power
3. 1200 W P_{DC_STC} (3 modules) with no AC limitation

The PV production of the Plug & Play modules (PV_{pp}) was calculated as follows:

$$PV_{pp} = PV_{rel} \circ Area_{pp}$$

Where

$$Area_{pp} = 2 \circ \frac{Max.nr + Min.nr\ modules}{2}$$

The average number of potentially mountable modules was applied.

Figure 2 shows the facade of a typical small house in Switzerland where the potential for installations of Plug & Play PV systems has been analyzed for.

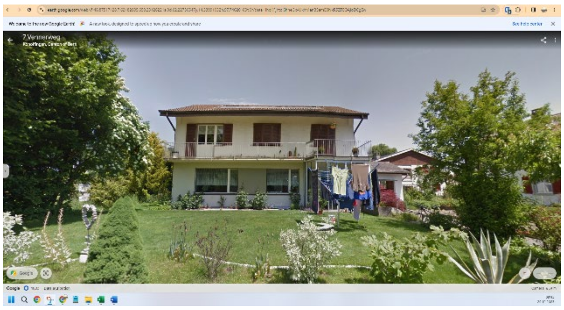

Figure 2: Example building facade with 1 balcony, a summed balcony length of 7 m and a maximum of 2 resp. 3 modules. Source: Google Maps. The potential production calculated for option 1 was 605 kWh/year, 794 kWh/year for option 2 and 908 kWh/year for option 3. Source: Google Street View.

Additionally, the share of eventually curtailed energy was calculated for each of the three options. This was done based on a typical year for the irradiation in the city of Berne with one minute resolution based on Meteonorm software. Different azimuths of the facades have been applied based on the shares of azimuths found in an analysis over the filtered facade dataset as shown in Figure 3. The average of a south facade and a facade with an azimuth of 120° (60° deviation from the South) was applied as curtailment factor, as this average represents the found distribution well.

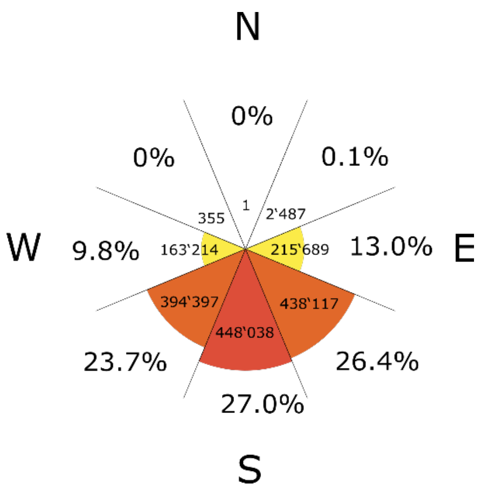

Figure 3: Found distribution of the azimuths of all facades.

This resulted in the following shares for the three options:

1. 800 W P_{DC_STC} / 600 W AC limit: 1.45% of the annual energy is curtailed.
2. 1200 W P_{DC_STC} / 600D W AC limit: 12.7% of the annual energy is curtailed.
3. 1200 W P_{DC_STC} / no AC limit: no curtailment

As the share in option 1 is close to zero and lower than the assumed uncertainties no curtailment was applied for the results of this option. The curtailment for option 2 is lowest in summertime and shows small peaks during spring and autumn. Average monthly curtailment shares have been applied to the original (not curtailed) data to model the final production.

To test the robustness of the approach different weightings to the extrapolation have been applied. A mixture on the buildings based on usage and year of building, number of floors, and usage as well as on usage, number of floors, and year of building and on Cantons alone have been applied. All four weighting options lead to comparable results. The weighting based on usage and year leads to results very close to the results based without weighting.

3 RESULTS

The potential of all the referencing facades in the subset selected initially by the factors irradiation, usage, area, and number of floors sums up on a national scale to 21.611 TWh / year (Figure 4).

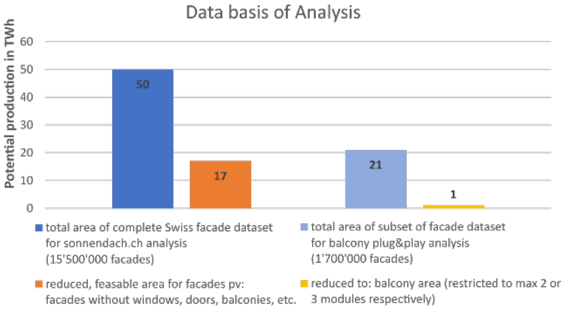

Figure 4: Overview of the data basis and the resulting potentials. For the Plug & Play analysis a subset of facades of the total Swiss facade dataset was used and applied to the percentage of balcony areas taking into account the restrictions of Plug & Play regulations.

The share of the summed production of the Plug & Play systems divided by the summed production of the whole facades subset is 4.1% for option 1. Applying this percentage to the Swiss facade potential, a total of 895 GWh is calculated (Table 1).

Table 1: Results of the estimation of the potential yearly production in Switzerland for the three options chosen.

	Option 1	Option 2	Option 3
Nr. modules	2	3	3
DC	800 W	1200 W	1200 W
Max. AC	600 W	600 W	no limit
Share of curtailed energy	0%	12.7%	0%
Potential production	895 GWh	1002 GWh	1048 GWh
Winter half year share	337 GWh (37.65 %)	379 GWh (37.82 %)	393 GWh (37.5 %)
Summer half year share	558 GWh (62.35 %)	623 GWh (62.18 %)	655 GWh (62.5 %)

In case of option 2 a total of 1002 GWh was calculated (4.6%). For option 3 a total of 1048 GWh resulted (4.9%).

The production during the winter half-year summed up to 337, 379 and 393 GWh respectively

Option 2 and 3 with 3 modules resulted in higher production – but not as much as assumed based on the number of modules alone. The main reason is that for many balconies only 2 modules can be attached due to limited space. Like this the theoretical curtailment share of 12.7% has a relatively small impact on the potential.

Figure 5 shows the monthly distribution of the PV production for options 1- 3. In all three options the winter energy share is around 37 %.

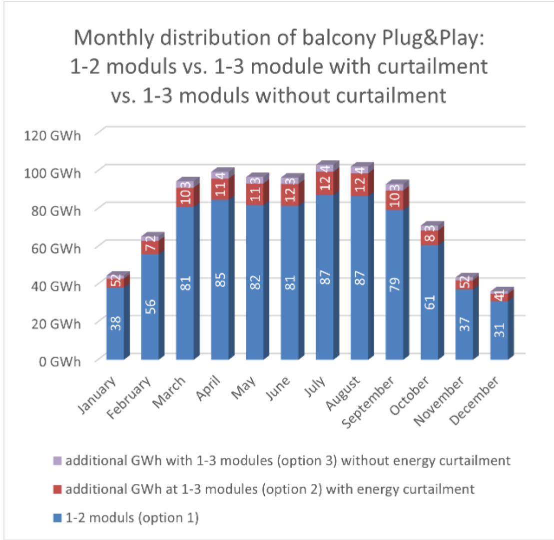

Figure 5: Monthly distribution of balcony PV Plug & Play Potential with all three options

4 CONCLUSIONS

The potential of Plug & Play PV systems in Switzerland was calculated to 900-1000 GWh. In comparison to the total roof potential of 50 TWh [4] on roofs and 17 TWh on facades respectively, this figure is rather small, but still significant. Adding a well distributed 1 TWh would nevertheless be useful, especially producing around 0.37 TWh electricity during winter half year. Additionally, the advantage of this potential is that these systems can be built by anyone. No trained specialists are required. They therefore contribute to a broader and more democratic support of the energy transition. In addition, they are not in direct competition with roof and facade systems, as they do not affect their potential.

The uncertainty of our approach is quite high even considering that the basis – the solar cadaster of Switzerland – is unique regarding accuracy and details. An analysis conducted by humans includes uncertainties as well. The visibility of many facades is limited. The needed balcony dimensions could only be partially measured. The facades are mostly only visible from the side facing the roads. This may induce bias in the extrapolation.

The focus of this paper is on the application of Plug & Play PV systems specifically on balconies. However, the possible use of such systems extends beyond the confines of balcony installations (Figure 6). Within the built environment, numerous surfaces are exposed to sunlight, presenting opportunities for PV system deployment.

Yet, the high costs associated with conventional electrical installations, including safety certifications, often render PV installations on these surfaces economically unviable. Nonetheless, the adoption of Plug & Play PV systems for a low-threshold feed-in, which circumvents the need for extensive electrical work, holds promise for substantial cost reductions at the end customer scale.

Figure 6: Examples of non balcony Plug & Play PV-Systems, whose potential is not included in the present potential study. Source: Solarblitz.ch

Potential additional surfaces for Plug & Play PV installations include bicycle shelters, carports, fences, playground shelters, sunshades, and weather protection. Applying simple scale analysis for such systems with 0.5 – 1 kW scaled up for 2 million buildings a total installed DC power P_{DC_STC} of 1-2 GW could be added. Yet, the energy potential so such non-balcony Plug & Play PV-Systems has not been analyzed in detail but is roughly estimated with additional about 0.7-1.5 TWh a year based on the average specific yield of 725 GWh/MW/a calculated out of the statistics for the year 2023 ($E_{2023, PVtot}$: 4624 GWh, $P_{DC\ STC\ tot}$: 6375 MW) [6].

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6 ACKNOWLEDGEMENTS

Our thanks go to Swiss Federal Office of Energy, which funded the work (contract nr. SI/502662-1).