100% RENEWABLE ENERGIES - MANAGEMENT OF ABOUT 50% PV ELECTRICITY FOR SWITZERLAND

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ABSTRACT: The Swiss Energy Strategy 2050 aims to **phase out the five nuclear power plants in Switzerland by 2050** and plans to **replace 20 TWh** (of the total 60 TWh needed) with renewable energy and energy efficiency. If Switzerland aims to also replace all combustion engine cars running in Switzerland and all fossil fuel heating systems, another 20 TWh are needed. This totals to a 40 TWh of electricity that need replacing, which is more than 50% of the current electricity needs in Switzerland. Here, it is elaborated on how this massif amount of power from renewable energy into the grid can be managed with photovoltaics (PV) and in a cost-effective way in Switzerland.
Keywords: Swiss Energy Strategy 2050, PV Market, PV Curtailment, Hydropower, Storage, Decarbonization

1 INTRODUCTION

The Swiss Energy Strategy 2050 aims to phase out the five nuclear power plants in Switzerland by 2050 and to **replace 20 TWh** (of the total 60 TWh consumed in Switzerland) by renewable energy and energy efficiency (Fig. 1). An estimated 12 TWh (of the 20 TWh) are expected to stem from solar energy (photovoltaics, PV). Contributions from geothermal (4 TWh) and wind energy (4 TWh) are planned but likely not realistic. Given this, additional **PV electricity of 6-8 TWh is needed.**

No replacement of fossil energy in cars is foreseen in the Swiss Energy Strategy 2050, but the Swiss Government also aims to phase out combustion engines by 2050 [1]. Technology offers a high efficiency potential here and possible avenues. When the Swiss car fleet (about 5 million cars in Switzerland) is to be fully replaced by electric vehicles (EVs), **another 10 – 12 TWh electricity** per year is needed. This results in a total installed PV power of about ca. 32 TWh and hence 30 GWp [2]. If the heating systems currently operated with fossil energy (oil and gas) also will be replaced, about **6 -10 TWh** are needed for the heat pumps. All these electricity needs will result **in 40-50 GWp PV power**, which must be coordinated with the different types of hydro energy power plants in Switzerland (40 TWh). As the maximum consumption in the Swiss grid is about 6 - 12 GWp, there are active management measures needed.

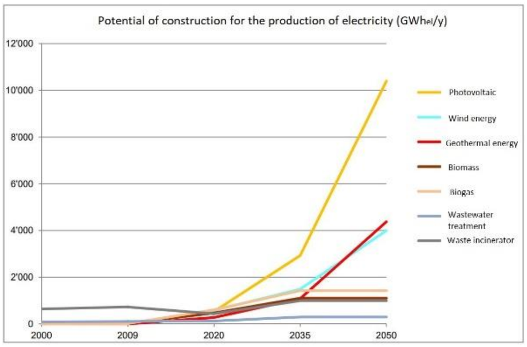

Figure 1: Production goals of new renewable energy systems in the Swiss Energy Strategy 2050. PV is predominant [3]

2 RESULTS - HIGH EFFICIENCY POTENTIAL WITH TECHNOLOGY

The goals of the Swiss Energy Strategy 2050 are less demanding than many people think. Instead of reducing the comfort of living or changing the behavior (what people don't like), using and fully implementing the technical progress of the last 40 years is the promising avenue. Nevertheless, the economic sectors (oil heating and fossil energy providers / gasoline car producers, etc.) facing disruption are likely reluctant to this change [4]. Therefore, this change will need a lot of time as many policy makers in Switzerland have mandates of the fossil energy industry (e.g., the president of the biggest political party (SVP) in Switzerland, Dr. Rösti, is the President of Swissoil).

The energy saving potential of the new technologies is tremendous (Fig. 2). Especially, if we replace the combustion processes in motors and heating systems [5].

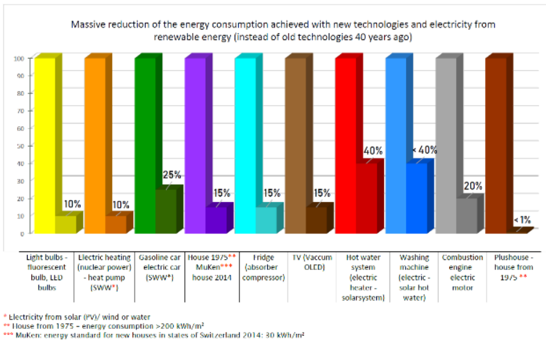

Figure 2: Massive reduction of the energy consumption is achieved with the new technologies and electricity from solar (PV), wind or water (SWW) (instead of the old technologies from 40 years ago)

3 THE NEED OF NEW RENEWABLE ENERGY SOURCES FOR THE DECARBONISATION OF THE SWISS ENERGY SUPPLY

3.1 Swiss Energy Strategy 2050

The Swiss Energy Strategy 2050 primarily seeks to phase out the five old nuclear power plants and replace nuclear energy by renewable energy sources. In this strategy, oil and gas heating systems and all combustion engine cars, however, still operate on fossil energy. Yet, since Switzerland has launched the Swiss Energy Strategy 2050 after the Fukushima accident in 2011, the world has a strong interest to move a step further. In the context of global warming, the reduction of the CO_2 emission is an important avenue. Switzerland has very good conditions for this. We have no oil / gas and no car industry. The hydro plants produce 55% of the electricity of Switzerland and offer more than 8 TWh storage capacity and several GWp pump storage capacity, too.

The electrification of the public transport started early in the first world war because of the shortage of coal. After the 2nd world war, the Swiss electricity industry fostered the use of electricity for cooking, heating and hot water preparation. If we pursue this avenue and completely **switch our fossil heating systems and cars to electric**, we need [6]:

- 20 TWh for the replacement of the nuclear power plants.
- 17 TWh (with the same old car technology but turned into electric cars), therefore could be 5 TWh lower, i.e., about 12 TWh.
- 6 TWh to heat the buildings (with heat pumps) - thermal solar collector could further help to reduce this number.

This gives a **total of 38 – 43 TWh**. Aviation is excluded in this number and is yet another challenge; a way towards electrification is to bring more electric drive trains into this application. The Institute for Energy and Mobility Research (IEM) at Bern University of Applied Sciences BFH in Burgdorf and Biel has supported several projects in this regard. One of our spin-offs runs the company "Evolaris" for electric planes.

3.2 Installed renewable energies since 2011

Since 2011, Switzerland has installed 5,9 TWh through funded projects on new renewable energies, which get a positive decision for the support by the feed-in-tariff [7]. Additionally, PV installed in Switzerland in total reaches 1,4 TWh. This gives a subtotal of 7,3 TWh.

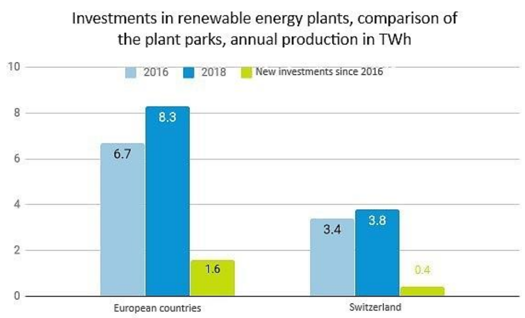

Figure 3: Existing capacities owned by the Swiss utilities (Source: Suisse Eole)

In addition, up to 2018, Swiss utilities installed another 8,3 TWh of new renewable energies, mainly wind farms all over Europe. Together with the installed capacity we have still 16 TWh production capacities since 2011. If we consider these production capacities, we have to produce not more than 30 TWh by PV to decarbonize the energy system of Switzerland. These new production capacities of new renewable energies with 16 TWh are a big success of the policy makers. Policy makers in Switzerland don't communicate this as a success of the "Swiss Energy Strategy 2050", however.

4 RESULTS

4.1 Producing more renewable energy

Up to 2017, the estimated PV production potential was 30-50 TWh in Switzerland [8], if PV is mounted on all relevant roofs and façades (free-standing field PV installations on ground are not common in Switzerland). Programs (like sonnendach.ch) funded by the Swiss Federal Office of Energy (SFOE) evidence that the potential is much higher (see [9] and Table 1).

Table I: Potential exploitable power from PV surfaces

PV surface	Potential exploitable [TWh]	Potential exploitable in short and medium term [TWh]	Surface [km^2]
Roofs of buildings	49.1	23.2	153
Facades of buildings	17.2	8.2	107.4 (vertical)
Streets	24.7	2.5	16.2
Over parking spaces	4.9	3.9	25.7
Along highways	5.6	3.9	25.7
Free standing (mountains/ alps)	16.4	3.3	31.3
Total	117.9	**45.0**	251.9 (without facades)

SFOE now indicates a potential of 50 TWh only from roofs, 15 TWh for façades and 17 TWh from infrastructure [10]. The **82 TWh production capacity** is much higher than the entire current consumption of electricity in Switzerland. This PV production potential is currently not included in the "Swiss Energy Strategy 2050" but offers an interesting option for the generation of winter electricity [11]. In addition, it demonstrates that there is no need to cover all the roofs and façades with PV in Switzerland to use solar energy for electricity production.

The potential for wind energy in Switzerland is also highly relevant. In countries surrounding Switzerland (France and mainly southern Germany), hundreds of wind plants are installed in regions similar to the Swiss Jura mountain range. But the resistance from Swiss people against wind power installations is very high. It is, therefore, unlikely that the planned **4 TWh** wind power production will ever become reality in Switzerland. Wind energy is, nevertheless, contributing to the Swiss electricity portfolio, as the Swiss utility companies bought wind production capacities of more than 6 TWh [12] in Europe.

Geothermal electricity is also expected to contribute **4 TWh** to the "Swiss Energy Strategy 2050". However, the geothermal conditions are not quite favorable in Switzerland. This inadequacy was demonstrated on two drilling sites near Basel and St. Gallen, on which micro earthquakes were encountered. The political climate is hence not very favorable for this technology. No policy maker will suggest investing very high subsidize for the drilling of holes in the future, when the results are micro earthquakes damaging the infrastructure including houses of citizens.

Electricity production from waste combustion, sewage water plants and wood combustion plants amounted to nearly **3 TWh** [13] in July 2018, which is almost the foreseen potential.

In conclusion, the most realistic avenue and really big potential is offered by PV electricity production. In addition, PV is the cheapest new electricity source in Switzerland and high PV shares can be managed by the grid (see Sections 4.2 and 5).

4.2 PV is not expensive anymore - the PV price studies are wrong

At the end of 2018, over 2 TWh PV electricity were produced in Switzerland [14]. As compared with the potential, this is a surprisingly low number and may reflect the general public perception that PV is too expensive.

This misconception is supported by studies of renowned research institutes from Switzerland such as Paul Scherrer Institute (PSI) and the Eidgenössische Technische Hochschule Zürich (ETHZ). Both, PSI and ETHZ presented, in their studies of 2012 and 2017 [15] very high prices for PV electricity today and in the future. Even the prices estimated by PSI and ETHZ for 2050 (see Table 2) are above the actual PV electricity prices in 2018/2019, for a cost-effective 1,2 MWp PV plant built in 2018 in the Swiss city of Burgdorf. The costs of 920'000 sFr. for the 1,2 MWp PV plant leads to PV electricity prices of 5Rp/ kWh (in Table 2).

Table II: Published PV electricity prices

PV electricity price [Rp/ kWh]	2010	2017	2018/19	2020	2035	2050
ETHZ study (2012)	35-55			20-30	10-15	6-10
PSI study (2017)		18-31				8-19
PV plant Burgdorf 1,2 MWp (2018)			<5			
PV plant Burgdorf 100 kWp (2019)			7			

The comparatively high numbers for PV prices, published by established Swiss research institutes like PSI and ETHZ are misleading. As evidenced in an expertise published by four Swiss energy experts in fall 2018 [16]: "PV is the cheapest new electricity source in Switzerland"!

5 MANAGEMENT OF HIGH PV CONTRIBUTION IN THE SWISS GRID

Years before the Swiss government presented the "Swiss Energy Strategy 2050", the former leader of the Photovoltaic Laboratory at Bern University of Applied Sciences (BFH), Prof. emer. Dr. Heinrich Häberlin, presented a simple solution that was finally published in his book in 2010 [17]. In one of the graphs, he demonstrates that about 16 GWp PV can be installed and fed into the grid without major problems (Fig. 4).

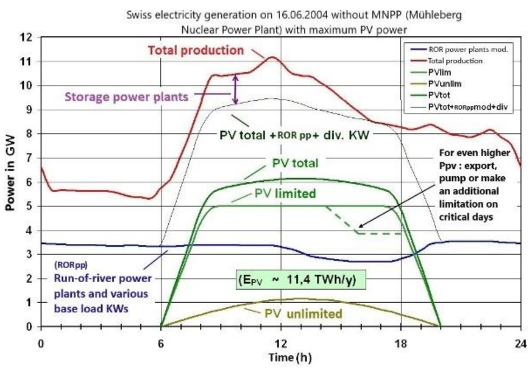

Figure 4: Simple management of about 16 GWp PV power in the Swiss grid - no pump storage plants are needed yet [17]

The only measure needed is a reduction of the peak power of the PV plants to 50% of the installed nominal power, the so-called "curtailment". It is only important that the electricity "band production" of the 5 nuclear power plants disappears. Consequently, it is imperative to stop this band production (what is the objective of the "Swiss Energy Strategy 2050").

If we have more PV power than the 16 GWp, we need to start with other measures in the construction of the PV plants (see Table 3). The simplest action is "PV curtailment" [18].

We therefore propose a more detailed measure to manage the peak power production of the PV power at noon. Together with the "**peak shaving**", we propose "smart users" such as EVs, heat pumps, industrial consumers etc. and "east-west" and vertical PV surfaces. With all these measures, **we can produce about 40 TWh** without big losses and costs. PV façades, a new and very interesting way to produce more electricity in winter and hence to avoid the production peak at noon from spring to fall, are not listed yet in Table 3. Although not really needed for the purpose of peak power management, local batteries (see Table 3) might yet be another option.

Table III: Solution for PV overproduction

Nr.	Actions to manage the PV overproduction	Power consumption	+ PV power	Cost of the action
1	Limit 30% of the PV power		+42%	3%
2	Regulated consumers (suggestion)	3 GW	+20%	< 5%
3	New consumers as EVs, heat pumps with storage etc.	>8 GW	+100%	5-50%
4	Limit 50% of the PV power		+100%	18%
5	50% East-west PV installations (90% yield)		+20%	ca. 50%
6	Vertical PV (8GWp/5TWh)		*+4GWp*	*10-50%**
7	Local batteries (50% of all PV plants)	2 GW	+50%	50% (goes down)
8	Pump storage plants		+50%	50%
9	Grid re-inforcement (high voltage)		about 20%	about 25%

*=assumption

The maximum load that can be absorbed is around 7 GWp (Fig. 4, red curve - blue curve). With "peak shave of 50%" and "east-west" PV installations, we get: 20 GW x 1,5 x 1,2 ➔ 36 GWp. With 50% peak-shaving and 8 GWp PV façade, we get an annual production of about 41 TWh.

The pump storage plants from Switzerland, which some utilities producer expanded, are also not needed for the peak power management of PV. These plants were planned before the "Swiss Energy Strategy 2050" was defined in 2011 and aimed at storing nuclear electricity from France for peak consumption in mainly Italy and Germany. The utility companies, unfortunately, did not realize that these countries installed more than 60 GWp PV power and there is now no need for expensive noon electricity anymore. Therefore, some of these plants like "Linth-Limmern [19]" and "Nant de Drance" [20] generate relevant losses for their owners.

The pump storage plants are a Plan C for further management of surplus PV power, if some of the assumptions such as the percentage of "east-west", "PV façades" or "smart consumers" will not evolve so quickly. The Plan B is simply a higher rate of "curtailment" above 30%. There is also a Plan D, namely more "wind-energy" from sites in Switzerland or from cheaply imported "wind-electricity" in winter. We should not neglect that Swiss utilities own and still buy several GW wind energy plants in Europe and hence, the reality will be a mix of the different renewable energy sources.

6 TIMING AND COSTS

Regular further reflection on cost and timing is needed (see Fig. 5). In 2018, we had only 2 GWp installed PV power. The market is currently (2019) around 300 MWp. For an installed power below 10 GWp there are only minor measures needed (such as “east-west-installations”), some smart consumers (such as heat pumps and EVs), and some PV plants with 30% peak shaving are necessary. If the **market stagnates at 300 MWp**, there will never be much more than 10 GWp PV in the grid. With this size, the goals of the “Swiss Energy Strategy 2050” will fail. A decarbonization of the energy system will not be possible.

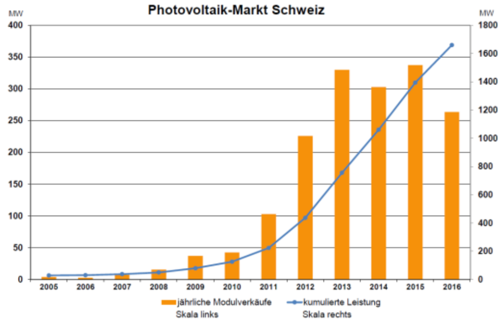

Figure 5: Swiss PV market from 2005-2016 (Swissolar)

The most important action is, therefore, a strong growth of the Swiss PV market towards the 1,5-2 GWp market size per year. Even then we have more than 20-year time (2040) to establish all the measures as listed in Table 3.

The costs of these PV installations are 2-3 billion per year for a 1,5-2 GWp market. Actually, the prices are sometimes higher, especially for small PV plants. For bigger plants and in the future, there are still costs below 1 sFr. / Wp possible. The costs for the limitations and the management of the peak power are all below 50% surplus. Some of them, such as the “smart consumers” and the “EVs”, are still cheaper than traditional users. Therefore, we don’t expect much higher costs from this side.

There are not only costs, but also saving. For example, just the annual savings for the imported fossil fuel in Switzerland, for the last 20 years, are estimated to amount to 5-14 billion sFr. It hence becomes obvious that Switzerland and the single consumer will save money, if the country moves away from fossil fuel.

7 HYDROPOWER - THE STRONG PARTNER OF PV IN SWITZERLAND

Switzerland started his industrialization with hydro energy power more than 200 years ago. In 1879, the first electric generator propelled by water power illuminated a Hotel in St. Moritz. Since then, hydro has been the main source of electricity in Switzerland. The two world wars stimulated the further growth of the hydroelectricity in Switzerland because, unlike electricity, coal needs to be imported. Switzerland quickly switched to a broad use of electricity for cooking, electric trains, trolley busses in towns, hot water and heating systems. Currently, about **55% of the electricity is produced with hydropower**. Hydroelectricity is generated at river power stations, barrier lakes, and increasingly pump storage plants. Most of the power stations were built before the 1960es. Today, plans to construct such a high number of barrier lakes in the Alps and in the pre-Alps would create resistance from the general public due to the drastic spatial dimensions of some dams and lakes and perceived impacts on the alpine landscape.

Recently, the utility companies announced the construction and expansion of barriers lakes to pump storage plants. These plants can be used with short and medium storage capabilities. More than 10 years ago, the idea was to import nuclear electricity and to sell the electricity to Germany/Italy, etc. during peak needs (on noon). Today, this business model is not valid any more as these countries have nearly 100 GWp PV on the grid and no need for noon-electricity anymore. Most of the expansion projects in Switzerland could be stopped at the last minute. The first plant “Linth-Limmern” started in 2017 and has over 1 GWp pumping power. The project produces financial losses and causes trouble for the owner and the local state [19].

It can be summarized that it will not be very realistic, and it cannot be expected that additional pump storage plants will be built in Switzerland in the future. But the already constructed existing river flow and barrier lake hydro energy plants are a fantastic basis for transforming Switzerland to a fully 100% renewable energy system.

8 SIMILAR PUBLICATIONS AND STUDIES FOR A HIGH PV CONTRIBUTION IN SWITZERLAND TOWARDS 100% RES

In addition to [16], several other studies on PV and the role of PV for the “decarbonization” of Switzerland are publicly available (see Sections below). These publications provide evidence that the discussion on how to achieve decarbonization in Switzerland is vigorously led by the civil society, involving both academia and Swiss policy makers.

8.1 Study by the “Swiss Federal Office of Energy” (SFOE): PV potential in Switzerland

On 15 April 2019, SFOE published a study on the solar potential on roofs, façades and infrastructure buildings. SFOE carefully studied the potential of roofs and façades on buildings in collaboration with the Federal Office of Topography swisstopo and the Federal Office of Meteorology and Climatology MeteoSwiss. Together, the three Federal Offices developed an application called “Solarkataster”. This is basically a map on which all interested citizens in Switzerland can calculate the solar potential of their house roof or house façade [10]. For the roof, the three Federal Offices see a realistic total potential of 50 TWh, and for the façades a potential of 17 TWh. Besides buildings, an additional potential of 15 TWh is identified on infrastructure structures. This potential of 82 TWh is below the technical potential.

8.2 “Le plan solaire” or “Sonne für den Klimaschutz - ein Solarplan für die Schweiz”

In his book “Le Plan Solaire” (in French) or “Sonne für den Klimaschutz" (in German), the Swiss politician Roger Nordmann demonstrates how we can transform the Swiss energy system to 100% renewable [6]. Mr. Nordmann is a Member of the Swiss Parliament and chairs the socialist fraction in the Swiss National Parliament. He is also the president of the Swiss Solar Industry Association "Swissolar".

Nordmann calculates the needed PV energy to transform the Swiss energy system into a mainly renewable system. He ends up with an estimate of 50-60 GWp PV-power, avoiding import from electricity from wind turbines outside of Switzerland. For the winter electricity, he plans 5,6-8,8 TWh electricity from gas turbines to avoid electricity import. He manages the overproduction of PV in summer with peak shaving ("PV curtailment") up to 35% of the installed power. The use of "smart users" is not considered in detail. This could support the high PV power integration into the grid, too. Nordmann sees annual subsidizes of about 550 mio. sFr. But the main investments should be paid by the user and owner of the PV plants.

The reaction of the Swiss association utility companies (VSE) to the book of Roger Nordmann is interesting [21]. They agree with the big picture, but they emphasize more "smart users" and want a European CO_2-market. They also want subsidizes for their hydro plants, which is not surprising for a lobby organization.

8.3 PlusEnergie Bau Gebäude Studie 2019 (plusenergy building study 2019)

In August 2019, the privately organized "Solar Agentur" presented their views on how to reduce the CO_2 emission in Switzerland **by 90% up to the year 2045**. They propose the renovation of buildings and 100 TWh PV in the year 2029 and even 280 TWh in 2045. To match the peak power production and the need at night and in winter, they propose additional 20 - 30 pump storage plants like the one at "Lint Limmern", and 60 to 90 similar plants in 2045.

This vision would need massive investments in the grid infrastructure. It is hard to see how these pump storage plants pay back their investments if even the first two of these plants are not profitable (see [19] and [20]). In the presentation of their plan, "Solar Agentur" had support from politicians from several political parties.

8.4 "The solution project"

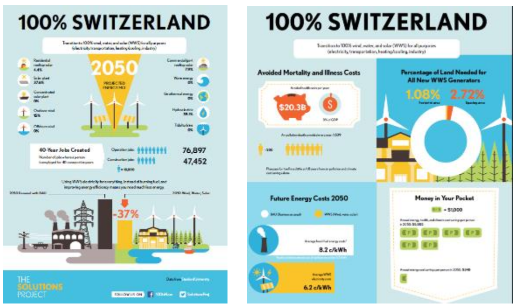

Figure 6: Suggested energy mix for Switzerland in "the solution project" for 100% RES [22]

Professor Mark Z. Jacobson (Director of the Atmosphere and Energy Program, Stanford University, USA) studies how all 50 states of the USA and about 160 countries of the world can be transformed to 100% renewable energies [22]. The numbers for Switzerland are shown in Fig. 6.

The authors believe there will be less wind energy, more hydro energy and some other renewable such as "waste incineration" and biomass energy (mainly wood). The price of electricity will drop from 8,2 cents US$/ kWh to 6,2 cents US$/ kWh (see Fig. 6 right). There are also major savings in the health costs, and Switzerland is expected to save a lot of money from not having to import fossil fuel anymore.

8.5 Project "SimZukunft"

This project aims to calculate different scenarios for anticipated future electricity changes and their effects on the grid at the local utility company "Localnet" in the city of Burgdorf in the year 2050. The project is led by the PV Laboratory at Bern University of Applied Sciences BHF in Burgdorf-Switzerland (www.pvtest.ch).

One focus in the "SimZukunft" project, in collaboration with the city of Burgdorf, the local utility company "Localnet" and the company "Adaptricity AG", is on the "Utopia" scenario (Fig. 7): There will be only electric consumers and a few industrial companies (foundries) with gas-fired power. All the heating and mobile applications (cars) run with electric energy produced in the annual balance with PV. However, in real life, an exchange with hydro plants in winter is likely expected.

The results (Fig. 7) show that it is possible to switch to mainly electric energy produced by renewable energies, predominantly PV. Due to climate change, the peak consumption changes in 2050 from winter to summer. In 2050, much air conditioning will be needed to cool houses. This load is higher than the load for heating if the houses are retrofitted. **Air conditioning can then be used to consume peak power at noon**. This is a chance for PV power.

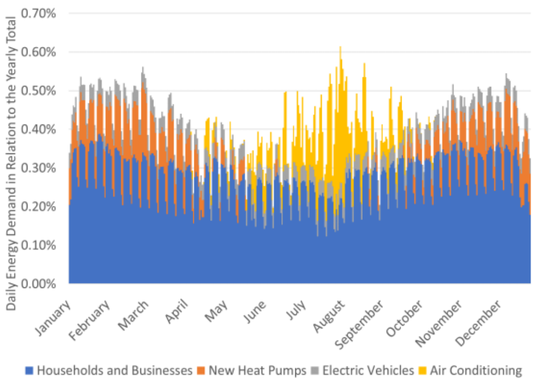

Figure 7: Simulation of the electric load in Burgdorf-Switzerland in 2050 for the "Utopia" scenario in "SimZukunft". Summer needs the highest production due to the "air conditioning"

9 CONCLUSIONS AND OUTLOOK

The Energy Strategy 2050 of the Swiss Government seeks to phase out the five old nuclear power plants and replace nuclear energy by renewable energy sources. Our contribution illustrates how 50% PV electricity can be achieved in the future. Evidence is provided that the management of high PV production in Switzerland is quite simple. If the PV installations are built and used along the actions 2-7 defined in Table 3, we can control the PV power in a simple and economical way.

The most difficult problem seems to be the ramp-up of the installation of PV plants from about 250 MWp to nearly 1-1,5 GWp per year. For this purpose, the supporting measures of the Swiss Government and the electricity companies should mainly concentrate on PV on the production side.

On the consumer side, the renovation of the existing building stock is a big challenge. The switch to electric cars is less complicated as cars are replaced about every 12 years. Car users will like the increased performance and comfort of electric cars. However, the charging outlet construction for tenants without private carport has to be addressed.

Because most of the needed hydro plants already exist, mounting a sufficiently big amount of PV infrastructure is the key towards 50% PV electricity in the future.

PV electricity will **not** lead to higher electricity prizes, as PV, together with wind energy, is now the cheapest new electricity source in Switzerland.

Expected benefits of this dramatic transition of the energy system in Switzerland (and many other countries worldwide, too) towards 100% renewable energies will include reduced CO_2 levels (climate protection), better air quality (due to lower emission of air pollutants) and thus overall health benefits, increased expertise and knowhow in PV, and massive financial savings because no fossil fuel need to be imported any more.

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