SIMZUKUNFT: STUDIES ABOUT INTEGRATING A LARGE AMOUNT OF PV INTO THE GRID OF A SMALL SWISS TOWN

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ABSTRACT: The Swiss people decided in a public vote on phasing out nuclear energy and switching to renewable energy until 2050. For this change there is a so-called “energy-strategy 2050”. This energy strategy details how exactly the path from the current energy system to the future energy system will look like, but the detailed impact of those changes on the low voltage grids in Switzerland hasn’t been researched yet. The “SimZukunft” research project focuses on that. It evaluates the impact of different scenarios from the official planning documents on the grid of the town “Burgdorf”. Additionally, two extreme scenarios are evaluated. This paper shows some early results and that it will be for example possible for the town to become a net-zero-energy town.
Keywords: see enclosed list of keywords

1 INTRODUCTION

In 2017 the Swiss population voted to adopt the Energy Strategy 2050 (ES2050), which is a plan for the adoption of renewable energy in Switzerland. This will mean large changes in the energy distribution system in Switzerland. For the ES2050 very detailed scenarios and development paths were created for the entire country. But what is missing so far is an analysis what this would mean for the grid in a typical small town. In the SFOE-funded project SimZukunft, that started in December 2017, we analyze the impact of these plans on the city of Burgdorf, a Swiss town with about 16.000 citizens. The important part is that the scenarios include not only renewable energy adoption, but also electro mobility, climate change with increased air conditioning, increased electric heating with heat pumps and much more. Since the resulting higher energy demand partially cancels out the issues with very high shares of photovoltaic in the low voltage grid, the results are highly relevant for calculating possible PV adoption rates in Switzerland.

2 SCENARIOS

The project uses five different scenarios for Burgdorf. These scenarios are described below. Three of the scenarios are based directly on the document called “Energieperspektive 2050” [1]. This document was originally created by the research institute Prognos and is the foundation of the energy strategy 2050. The other two scenarios evaluate extremes such as a very high penetration of electromobility and photovoltaics, to analyze the sensitivity of the grid to such developments.

2.1. ES-2050 POM-E

This scenario uses the values from the scenario “Politische Massnahmen” (Political Measures) in the variant “renewable energy”.
In detail this scenario includes a (from todays perspective) moderate implementation of renewable energy, a fairly low percentage of electromobility and extensive renovation of the existing houses to reduce heating energy demand. The economy is growing slowly and steadily. The nuclear power plants are being turned off and replaced with a mixture of renewable energy and energy purchases from other countries. There will be no smart grid technologies included in this scenario. This scenario will be our reference scenario.

2.2. ES-2050 POM-E Smart

This scenario will use the same basic values as the previous one but add smart grid technology. Technologies such as intelligent curtailment, smart charging, decentralized energy storage and intelligent heat pump control will be included. These technologies have the potential to significantly reduce the need for grid expansion by making sure that the local demand peaks match up with the local generation peaks. Comparing the results of this scenario with the previous one will make it possible to see if it is better to invest in technology or in copper.

2.3. ES-2050 NEP-E

This scenario is rather similar to POM-E but uses somewhat different values for the development path that will enable Switzerland to meet the COP21-targets without getting rid of the nuclear power plants.

2.4. Utopia

This scenario models one of the two extremes: Maximum photovoltaic deployment, very cheap and ubiquitous energy storage, full switch to electric cars, moderate climate change with the corresponding air conditioning deployment, no large population changes and a number of completely grid-independent single-family houses.
This scenario is meant together with the next one for the sensitivity check of the calculations. Therefore, the idea is to set all the parameters to values that are from today’s perspective maybe unrealistic, but that will tell if the grid will be able to cope with even those extremes. Additionally, we’ll be able to deduce which parameters will have the biggest influence and thus need to be watched closely over the next few years.

2.5. Dystopia

The last scenario models the worst case where everything goes wrong: barely any renewable energy, no decentralized energy storage, large climate change with the associated need for massive air conditioning, barely any electric cars, bad economy and on top of that a lot of climate change refugees.
This scenario models what could happen for example with a shortage of the rare earths, combined with a global trade war with the associated recession and further accelerating climate change.

3 METHOD

To evaluate the impact of the scenarios detailed simulations for the entire year will be performed. For the loads are simulated with an agent-based behavior simulation [2]. The individual agents are controlled by their desires. This enables a very flexible modelling of many different behavior patterns, such as singles, families, retirees or shift workers. Having detailed individual household profiles is especially important to evaluate the impact of decentralized energy storage.
Additionally, the simulations also model the mobility behavior. Because for every simulated person it is clear for every point in time where that person is and what the person is doing, it is possible to create detailed mobility profiles and for example calculate for each car where it is, how far it has driven, if it can be charged and if so, how much energy it will demand.
This enables us for example to compare different smart grid charging control algorithms and the impact of those on the top loads of the grid. The load profiles are then used by Adaptricity to do grid simulations with their proprietary grid simulation software and it is evaluated where problems such as over-voltages, under-voltages or transformer overloads can occur in the grid.
The time plan in the project is that in 2018 the overall sum calculations for the scenarios will be done and the simulation of the presence will be created. In 2019 the scenarios will be implemented into the simulation and the detailed grid planning will be performed.
The project uses the following data sources:

- The local utility company Localnet provides the data about the grid and the consumption of electricity, gas and district heating.
- The building data is from the central Swiss building and apartment registry.
- The potential for photovoltaics is based on studies by the research project Sonnendach.ch. [3] They evaluated for every single building in Switzerland, how high the potential for photovoltaics on the building would be.
- To estimate the energy demand of buildings heated for example with oil or wood, data from the Canton Bern is used. The Canton Bern keeps a database of the estimated energy use of all buildings in the canton.
- To figure out how each building is heated, the data from the local chimney sweeper association is used.
- The population statistics are provided by the local city council.

2.3 Data Merging

One big challenge in the project is creating a comprehensive model from all the different data sources that are as usual not very well integrated. The building registry has a unique identifier, which is used in some of the other data sets and is a great first step. But if, for example, an apartment complex with multiple building is heated with a central heating system, it is not easy to automatically distribute the consumption. Additionally, not all the data sets are referenced to buildings, so some of the data needs to be assigned by address, with all the problems that this brings: one building can have multiple addresses, one address can have multiple buildings and so on.
In this project we used the approach of defining building complexes to deal with these issues. One building complex can have:

- One or more buildings
- One or more addresses
- One or more consumption data entries

The simplest building complex is a single-family house, which is exactly one building with exactly one address and exactly one consumption entry.
After creating the building complexes, the heating and energy demands per building can be summed up per complex and then averaged over the various buildings. This lets us get a reasonable first impression of the building stock energy demand and how much the energy demand might be reduced in future.
Due to privacy reasons the city council couldn’t just hand over the data of citizens per address. So here a workaround over statistic values had to be used. For this the citizens were semi-randomly distributed over the building complexes. For this a fuzzy logic engine [4] has proven to be very helpful. We defined a number of heuristics, that try to estimate based on living area and energy consumption how many people are living in each apartment. The fuzzy logic rules were then tweaked iteratively until the sums match up with the statistics from the city council. This data is then the foundation for all future simulations.

4 CURRENT SITUATION

3.4 Energy Demand

The current energy demands in Burgdorf are shown in Figure 1 and Figure 2. It is visible that the largest part of the energy is needed for heating. The main energy sources in Burgdorf are fossil fuels, that is oil and gas. Not included in the chart is the energy use for vehicles.
According to [5] Swiss people drive on average 10’165 km/year and there are about 7000 cars in Burgdorf. That results in an energy demand of gasoline of about 50-60 GWh, depending on which average consumption values one uses and if you consider the energy demand of long-distance drives for such as vacation trips to be part of the energy demand of the city.

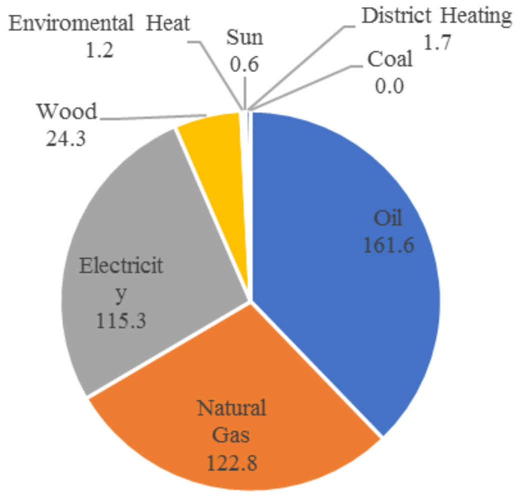

Figure 1: Current energy demand of the buildings in Burgdorf by energy source, based on data from [6]

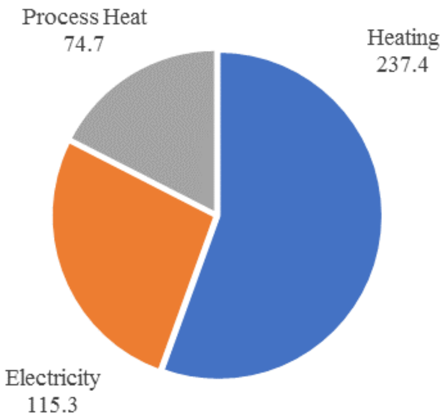

Figure 2: Current energy demand in Burgdorf by sector, based on data from [6]

4.1. Potential for Photovoltaics in Burgdorf

In the project «Sonnendach.ch» [3] an analysis of the potential for photovoltaics for all buildings in Switzerland was performed. The results are occasionally a bit optimistic, because small roof elements have not always been correctly excluded, but the results give a very good first estimate.

The results are shown in Figure 3. It is visible in Figure 4 that it is sufficient to cover the areas with a yearly yield of over 700 kWh/m^2/year to reach 97.6% of the maximum power.

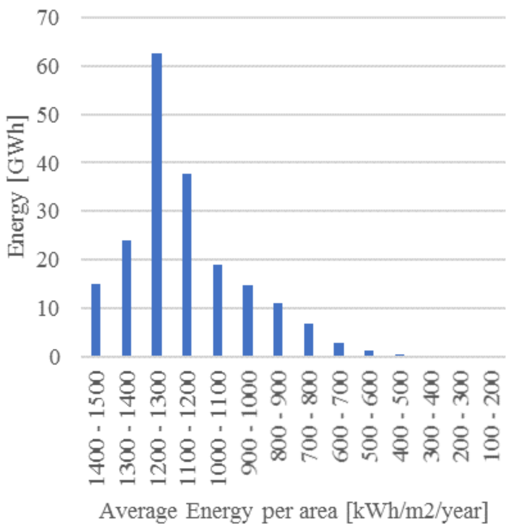

Figure 3: Histogram of the solar energy potential of all roofs in Burgdorf

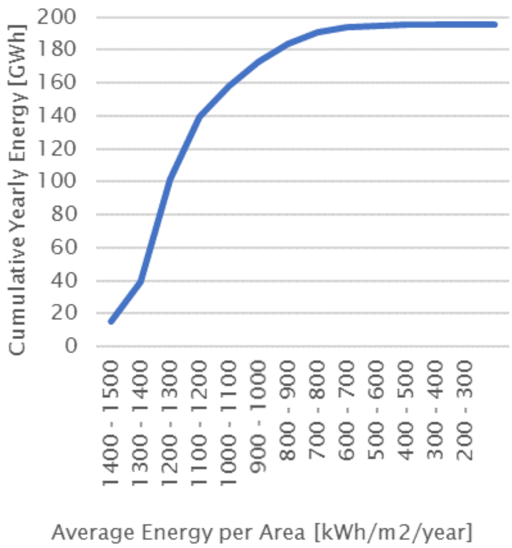

Figure 4: Cumulative energy yield for increasing PV coverage.

4.2. Validation of the building energy data from Canton Bern

To estimate the quality of the heat demand estimates of the Canton, a comparison was performed of the calculated data with the real energy demand of all buildings that are heated with either gas or district heating. The results are shown in Figure 5.

It is visible that the energy demand is partially overestimated and partially underestimated. Mostly these compensate each other. The average over all buildings is 64.3 kWh/m2/year. It seems likely that the extreme differences at the higher and lower end are either data errors or process energy. The average over just the differences between -200 and 200 is -45.2 kWh/m2/year. That means that the cantonal data overestimate the real heat demand slightly, but that they are entire usable for this project. A possible cause of the overestimate might be the increasing adoption of high efficiency condensation boilers.

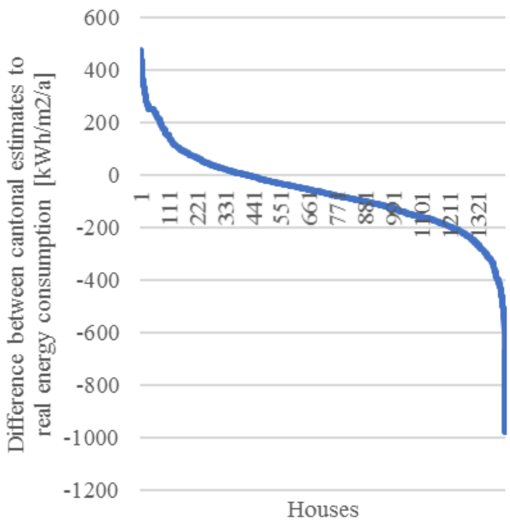

Figure 5: Comparison of the real energy use to the estimates of the Canton

5 RESULTS

The detailed simulations with a 15 min time resolution are only planned for 2019, therefore this paper can only show first, preliminary results. For space reasons this paper will focus on the utopia scenario, since this one yields the most impressive results.

5.1. Assumption in the Utopia Scenario

The most important assumptions in this scenario are as follows:

- A full sector coupling will be implemented, meaning that all fossil fueled heating systems will be replaced. All heating systems will be replaced with heat pumps with an efficiency of 3.
- All cars will be replaced with electric cars. A demand of on average 15 kWh/100 km is assumed.
- All current electricity use will be decreased through efficiency measures such as new lighting and new devices by 10% to 90% of the current value.
- All industrial natural gas heating processes will be optimized for a total efficiency gain of 50%, but they will remain powered by natural gas.

5.2. Air conditioning

The future air conditioning demand is difficult to estimate. The summer 2018 with sold out mobile air conditioning units showed clearly that even in Switzerland there is a large demand for air conditioning. The estimates from [1] show a electricity demand of 13.3 GWh for future air conditioning in Burgdorf. Typical numbers from the US on the other hand seem to be around 3 kW/household and about 1000 hours per year (3-4 months/year with 8-10h runtime per day). Using those numbers, the future electricity demand for Burgdorf would be around 24 GWh, which is almost twice the official estimate. To make the scenarios more comparable though, the utopia scenario will also use the estimates from the "Energieperspektiven"-document, meaning 13.3 GWh/year energy demand.

5.3. Yearly Summary

The results for the utopia scenario are shown in Figure 6. It shows the total energy demand in Burgdorf in 2009 and the final energy demand in 2050 and compares it with the maximum potential for local energy generation.
The first column is the current energy demand of Burgdorf from [6]. The second column shows what would happen with the total energy demand if only the heating is switched over to heat pumps. The third column then adds the efficiency factors. The forth column shows the total generation potential.

6 DISCUSSION

The discussions in this paper mainly focus on the Utopia-scenario again. The results mostly apply to the other scenarios too, but in weakened form.

6.1. Energy independence

A very interesting result is that it is theoretically possible in the utopia scenario that the entire city becomes a net energy neutral city, which would mean that over the year the city generates just as much energy as it consumes.
But to reach actual energy autarky would require a large amount of energy storage, to which there is no good and economical solution yet. The current state of the research seems to suggest that such a solution could be realized for example by the following measures:

- Large scale deployment of facade photovoltaics to maximize energy generation in the winter months.
- A large seasonal heat storage for the entire city, since storing heat is much cheaper than storing electricity.
- A suitable amount of battery storage, to cover up to two weeks of bad weather, especially in winter.

Facade photovoltaics are so far mostly not used, since they generate less energy. But with appropriate financial incentives and a time-dependent feed-in-tariff they could easily become more widespread. Because the differences in yield are not very large and they feed in more at times when electricity tends to be more expensive (mornings, evenings, winter), this could be almost cost-neutral to the utility companies. It seems therefore that a significant increase in the percentage of façade photovoltaics is entirely feasible, but this will be evaluated in more detail during the rest of the project.

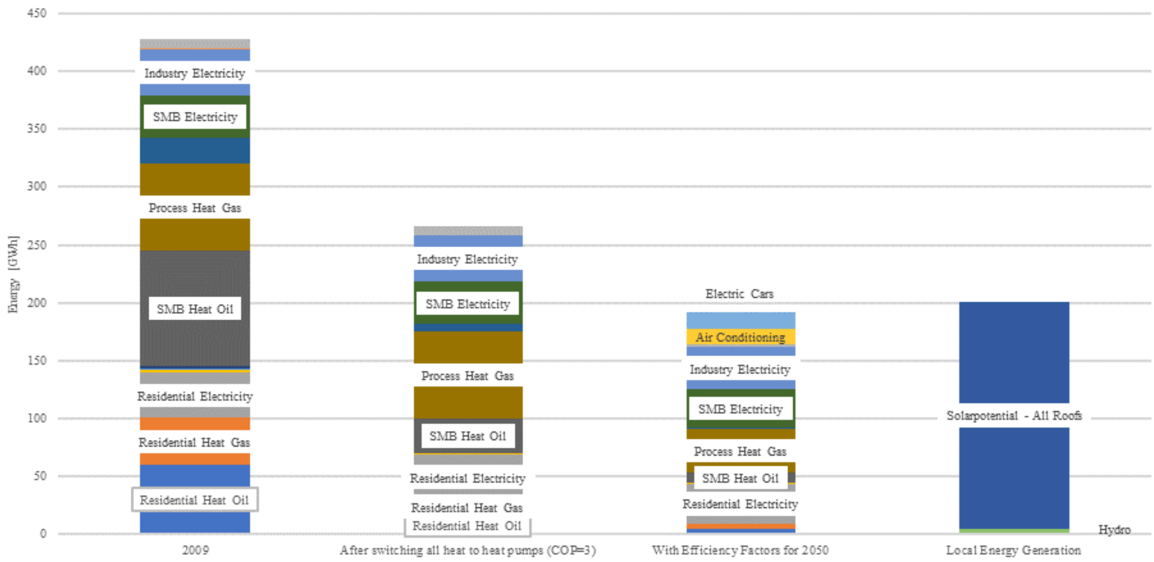

Figure 6: Current and future Energy Balances in Burgdorf in the Utopia scenario

Seasonal heat storages using borehole fields are well-tested and state of the art. Of course, building such a system for an existing, densely populated city would be quite challenging and require large investments.
Especially the battery storage would be quite expensive though. Per day Burgdorf needs about 500 MWh of electric energy. Some people suggest future battery prices of 100 CHF/kWh [7]. This would mean costs of about 50 million CHF per day of battery storage.
Using the electric vehicles as Vehicle-to-Grid battery storage would also not cover this demand. As mentioned there are about 7000 cars in Burgdorf. Even if every car has a 50 kWh Battery that will be drained entirely, that is only 352 MWh and won't cover a single day.
Real energy independence seems therefore with the current technology even in the utopia-scenario not likely.

6.2. Gas-Grid – Tipping Point

One interesting early result is the influence of the adaption rate of heat pumps. As soon as a previously gas-supplied district reaches a certain heat pump adoption rate, then the maintenance of the gas grid suddenly doesn't pay off anymore and the most cost-efficient thing for the utility company is to incentivize all other customers to move away from gas to get rid of the gas grid as soon as possible.

6.3. Smart Grid Technologies

From the early calculations it already becomes obvious that the use of appropriate Smart Grid technologies is able to reduce the grid load significantly, since the load from heat pumps, air conditioning and electromobility is very suited for demand management [8]. In [9] it was shown for example that cars on average tend to be connected to the grid much longer than needed for charging and therefore a huge potential for load shifting exists.

7 OUTLOOK

The project will continue based on the current results and the discussed detailed grid simulations will be performed. The results will be published next year.

8 PARTNER

The project is executed by a cooperation of the Bern University of Applied Sciences (Laboratory for Photovoltaic Systems), the city council of the town of Burgdorf, the local utility company Localnet and the Adaptricity AG, a company that specializes in grid planning.

9 ACKNOWLEDGEMENT

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