Optimization of an energy community in Switzerland

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Abstract

In energy planning of districts, it is often unclear what energy supply options are available and what influence different technology options have, including demand reduction through energy renovation.

Thus, the use of a simulation and optimization tools is explored in the planning process of a specific case study in Switzerland. Four different scenarios were developed and annual life cycle costs (LCC) as well as CO_2 emissions, are proposed. The results of the respective scenarios are categorized and compared according to CO_2 emissions and LCC. It becomes clear that for CO_2 emissions, there is a large reduction potential (up to 90%) with different LCC.

Key Innovations

- Optimization of different supply system options
- Considering energy conservation as well as technical improvements of the energy supply

Research Implications

This short paper gives a quick overview of the practical implications of an optimisation process. It helps to understand the financial and environmental implications of an energy community.

Introduction

Renovation strategies on building level need to be derived as a combination of energy efficiency upgrades for buildings and the use of renewable energy to decarbonise the energy supply, on district or city scale. By combining energy efficiency and renewable energy sources, both energy supply and demand in the built environment is addressed. In this sense, building retrofitting is an appropriate strategy to reduce demand, while the use of renewable energy aims at decarbonizing the energy supply system. Nevertheless, to apply the large-scale renovation strategies and achieve the projected building stock decarbonisation, identifying the technical solutions is not enough. The renovation rate in Europe remains well below the targeted annual 3% (Artola et al. 2016; Laffont-Eloire et al. 2019). Some of the main barriers to renovation have to do with the renovation cost and access to finance, as well as complexity, awareness, stakeholders' management, and fragmentation of the supply chain (BPIE 2011; Artola et al. 2016; Seddon et al. 2004).

The potential for reducing GHG emissions by district renovation is largely untapped. It not only requires a thorough Energy Master Planning (EMP) of the district but also support of the decision-making processes (Haase and Baer 2020). This can not only contribute significantly to reducing energy consumption and securing the location of energy infrastructure (generation, distribution, storage), but also to long-term sustainable development and climate neutrality. To reduce GHG emissions in the built environment (with a focus on CO_2 emissions) it is important to reduce GHG emissions from operation of facilities (Haase and Lohse 2019). It needs a reduction of energy use by including efficiency measures in the renovation of buildings. Another possibility is the decarbonisation of the energy supply. For this, (on-site) renewable energy measures must be applied. However, in renovation planning it is often unclear what energy supply options are available and what influence different technology options have, including demand reduction through energy renovation. Thus, the use of simulation and optimization tools is proposed in a two steps approach: first a reduction of energy use by implementing efficiency measures in the renovation of the building stock. Secondly, a decarbonisation of the energy supply. For this, on-site renewable energy measures should be explored in the planning process by BPS.

When it comes to costs and finance it is often critical to relate the different measures to different stakeholders. While the energy supply is of a political (municipal) matter, the renovation of own buildings mostly depends on the owners (Haase and Lohse 2019). To reach the decarbonization goals it is important to find ways to engage homeowners in the long-term investment strategies of decarbonization [(Sharp et al. 2020). Here we report on this process by applying BPS and optimization tools to simulate different options in a specific case.

Figure 1: Overview plan of the settlement.

The settlement is located near the city of Winterthur in the North of Switzerland. It was built in a first stage in 1974 and in a second stage in 1977. The 51 row houses are arranged in eight blocks and are privately owned since the 1990ies. Three blocks are north-south oriented, while five blocks have an east-west roof orientation as shown in Figure 1. There are connecting paths in between the rowhouses, two parking houses and a common swimming pool. A heating central unit supplies domestic hot water and heat to each row house.

Key innovations

- The paper showcases the use of building performance optimization in a real case
- The results will be useful to further improve the dialogue among and between different stakeholders
- The results will be useful to further improve the software and communication platform

Practical implications

The translation of complex energy systems into representative simplified dots might help to bring knowledge into the decision-making process.

Optimization process

The task was to develop optimized energy supply solutions for buildings and districts. When creating a scenario, the energy demand at the selected location, imported energy and resources must be specified. In addition, possible conversion, storage and distribution technologies have to specified. An optimization algorithm then optimizes through thousands of different supply systems. As a result, two to four different solution variants were created for each scenario. Based on the two variables annual life cycle costs (LCC) as well as CO_2 emissions, whereby the LCC refer to all technical measures proposed. Structural optimization measures, such as an energetic improvement of the building envelope, were considered as an improved value that resulted from structural renovation measures on the building. This heat demand corresponds to the heat demand of a building that has been renovated according to a certain building standard.

Simulation environment

Sympheny is a planning and simulation software that can be used to input data and the software then calculates the most suitable energy supply solutions for the selected site and the defined scenario (Allan et al. 2019). The calculated energy system of the first option is thus always designed for a minimum life cycle cost, while the energy system of option 4 has the lowest possible CO_2 emissions. The two intermediate optimization options 2 and 3 are targeting both variables (Bollinger et al. 2019).

A total of six different scenarios were created for the settlement, which were found to be relevant. These include the base case (actual state), the actual state with reduced heat demand, the optimized system with limited storage, the optimized system with limited storage and reduced heat demand, and the optimized system with open storage and reduced heat demand (Klaiber 2022).

Scenario 1

In the first scenario, only the unchanged actual state of the settlement is shown, with the current energy consumption. The final energy sources that the settlement currently uses are electricity and heating oil. The technologies used for the conversion of these energy sources into the required useful energies are the oil boilers and the hot water tank. In addition, the required useful energies are electricity, heating energy in the form of hot water, and domestic hot water. Figure 2 shows this process using an energy flow diagram. Heating 30-40 °C (Demand)' and 'Heat 60-70 °C (Demand)' refer to the settlement's demand for heating energy in the form of hot water at 30 to 40 °C and domestic hot water at 60 to 70 °C.

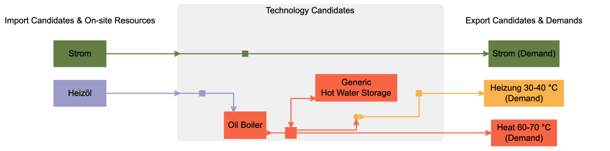

Figure 2: As-built district energy system.

Scenario 2

In this scenario all possible final energy sources as well as conversion and storage technologies for the settlement were put into the system to find the most suitable energy supply solutions (Figure 3). In addition to the heating oil and electricity already in use, wood pellets, wood chips, geothermal energy and solar energy were added as final energy sources. The conversion technologies are the oil boiler for the heating oil, the pellet boiler for the wood pellets, the wood chip boiler for the wood chips, solar thermal as well as photovoltaic systems for the solar energy and a brine-water heat pump with geothermal probes for the geothermal energy. A hot water storage tank, a battery for the photovoltaic system and a heating buffer were selected as storage technologies. Furthermore, in this scenario the storage tanks and tanks were limited according to the real space conditions for the calculations of the district, so that they are not over-dimensioned.

Accordingly, a maximum size of 74000 litres was set for the wood chip or pellet tank, which corresponds to the volume of one of the already existing heating oil tanks. The other heating oil tank with 74000 litres was used for the heating buffer. The storage capacity of the battery was limited to 100 kWh and the heating buffer to 10000 litres. The LCC of the four optimized options are shown in Figure 4. The first option with woodchip heating has relatively high fuel and energy costs. However, the

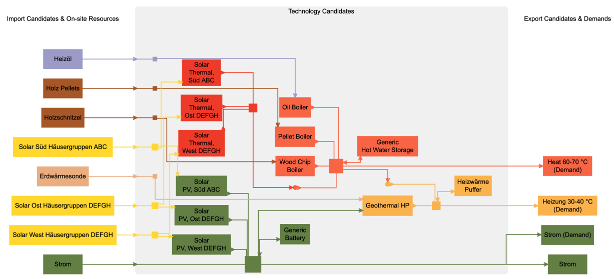

Figure 3: Optimized district energy system (scenario 1).

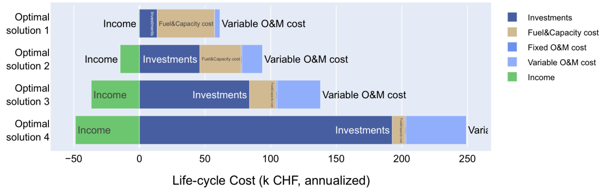

Figure 4: Life-cycle costs of Optimized district energy system (scenario 1).

maintenance and operating costs are the lowest. In addition, the maintenance and operating costs as well as the fuel and energy costs always increase and decrease approximately equally with increasing investment costs. An increase corresponding to the increasing investment costs with each option can also be recorded for the income generated by the feed-in tariff with the photovoltaic system. The total LCC of the first option amount to about 61000 CHF, while the investment costs of the fourth option, minus the feed-in tariff, amount to about 200000 CHF.

Scenario 3.1

This scenario is structured almost identically to the scenario 1, but here a potential renovation of the building envelope was included in the calculation. The original heat demand of 721500 kWh was according to Swiss "minergie standard" reduced to 197163 kWh (Minergie). Furthermore, the storage facilities are again limited in this scenario. The costs of the renovation amount to 2500000 CHF, resulting in annual depreciation of 62500 CHF. All other inputs remain the same as in scenario 1.

Figure 5 shows the measures implemented and the life-cycle costs of the individual results. The costs of the renovation of 2500000 CHF are not included. In option 1, only a woodchip heating system with a small-scale photovoltaic system and battery was implemented, with total investment costs of just under 135000 CHF. In the second option, a large solar thermal system is added, whereby the photovoltaic system with battery was also dimensioned larger. The investment costs thus amount to almost 460000 CHF. The third option shows that a geothermal heat pump with heating buffer was also installed, which accounts for almost 33% of the investment costs. The size of the solar thermal system and the woodchip heating system was reduced, while the dimensions of the photovoltaic system were greatly increased and now account for almost 40% of the investment. In total, the investments of this option amount to slightly more than 871000 CHF. The fourth option shows by far the highest investment sum of about 1855000 CHF. The solar thermal system now accounts for almost 52% of the costs. The photovoltaic system with battery remains like option 3 in terms of dimensioning and accounts for just under 21% of the investment costs. The geothermal heat pump with heating buffer was again slightly larger in size and accounts for just over 24% of the costs. The woodchip heating system was omitted in this case and only a hot water storage tank was implemented, but this accounts for just over 3% of the costs. Since the renovation costs are not included in the figure, the investment costs would increase by 2500000 CHF for all results.

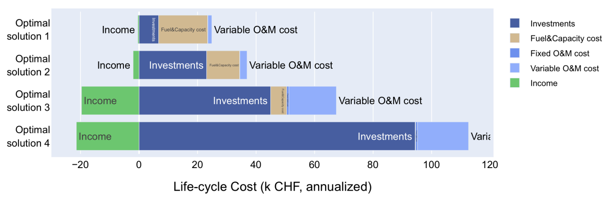

Figure 5: Life-cycle costs of Optimized district energy system (scenario 3).

Scenario 3.2

This scenario differs from the previous scenarios only in that the limitation of storage and tanks was removed. This was to find out if these limitations have an impact on the results due to real space constraints. This turned out not to be the case except for some minimal adjustments to the system. The investment costs as well as the implemented measures behave almost identically. The optimization process has only made minimal changes in the dimensions of individual measures, but this does not lead to any significant difference. In addition, the renovation costs were taken into consideration which is shown in Figure 6..

Results

The result was five different scenarios, each of which was intended to show different energy supply solutions for the settlement as illustrated in Figure 6. The first scenario, scenario served exclusively to illustrate the current state of the settlement to obtain a comparative value with the other scenarios. Scenario 1 (S1.1 without, S1.2 with renovation costs), on the other hand, was intended to illustrate how the CO_2 emissions of the settlement would change if only the heat demand were reduced by means of a building envelope renovation.

In scenario 2, technical optimization measures were included. In contrast to scenario 1, the aim of this scenario was to optimize the settlement purely based on technical measures, which mainly concerned heat generation. In addition, limits for energy storage and tanks were set according to the space available on-site, to prevent them from being oversized. The next scenario (S3.1 without, S3.2 with renovation costs)

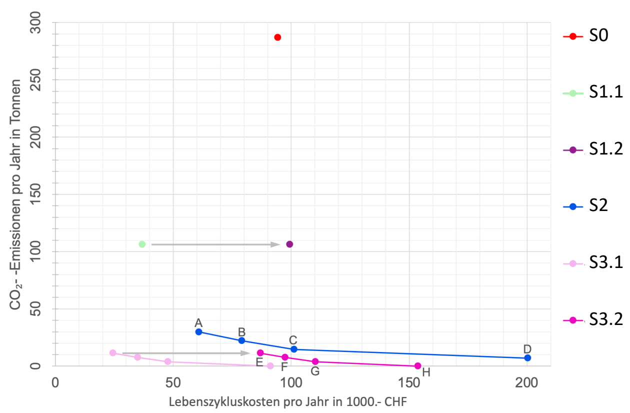

Figure 6: Life-cycle costs of Optimized district energy system (scenario 0 - 3).

was to simulate a complete energy renovation of the settlement including costs. This included not only all technical measures, but also a reduction of the heat demand by means of a building envelope renovation as in scenario 1.

Conclusion

To evaluate which energy supply solution turns out to be the most suitable for the settlement, a compilation of the four scenarios was carried out. The various results of the respective scenarios are categorized and compared according to CO_2 emissions and life cycle costs (LCC). It becomes clear that the actual state (red) causes by far the most CO_2 emissions. The LCC are in the middle range, compared to the optimized scenarios. In addition, Figure 5 shows that the annual CO_2 emissions could be reduced by more than 60% in scenario 1.2 (violet) by simply renovating the building envelope in terms of energy efficiency, and this despite the continued use of the fossil heating system. In addition, the LCC, which include the investment costs for the refurbishments of 2.5 million CHF, would be about the same as before. The reason for this is the strong savings in heating oil. However, by implementing purely technical measures in scenario 2 (blue), CO_2 emissions could be reduced even more than by refurbishing the building envelope alone in scenario 1.2 (purple). The reduction here would amount to almost 90% compared to the actual state (red), which would result in a drastic improvement. The LCC of the results of scenario 2 (blue) are wide-ranging. Thus, results A and B are both more favourable, while result C is somewhat more expensive and result D is even far more expensive than the actual state (red). An additional improvement of over 60% can be achieved through the renovation of the building envelope in combination with technical optimization measures, scenario 3.2 (pink), compared to the purely technically optimized scenario 2 (blue). Scenario 3.2 (pink) thus offers the highest improvement potential with over 95% CO_2 savings compared to the current state of the settlement (red). The LCC are also in the same range for results E and F compared to the current state (red). The results G and H are again more expensive. The results are to be discussed with the investors (building owners) but also other stakeholders like planners, financing institutions, municipality representatives etc.

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