Introduction
The Swiss Energy Strategy 2050 aims at drastically increasing electricity from renewable sources until the year 2035 [1]. Decentralized renewable energy generation (DREG, i.e., solar PV, wind, biomass, and small hydropower) is growing fast, especially solar PV, which grew by more than 500% in the last 5 years in Switzerland [2]. The appropriate spatial allocation of decentralised renewable energy generators is highly controversial, because there is a trade-off between the most economically efficient distribution and a more regionally equitable distribution [3]. Investors prefer sites with good harvesting conditions (i.e., strong winds, high solar radiation) which leads to a concentration of renewable power plants to locations with the best conditions. Previous studies [4,5] have however shown the importance of a regionally even distribution in siting decentralised renewables. An uneven distribution of both negative consequences (i.e., noise, visual disturbance) and positive consequences (i.e., regional investments) can highly affect the public acceptance and therefore the successful diffusion of renewables [6]. This study is the first of its kind to study the economic and electricity generation trade-offs between the equitable and the cost-efficient spatial distribution of DREG in Switzerland. We use a bottom-up electricity generation model EXPANSE [6,7] with Modeling to Generate Alternatives (MGA) to assess the cost-optimal and 2000 near cost-optimal spatial allocation scenarios of DREG in 2'258 Swiss municipalities.

Objectives
1. Develop a spatially-explicit electricity demand and supply database for 2'258 Swiss municipalities for the years 2016 and 2035.
2. Simulate the Swiss electricity generation at a municipal level with a spatially-explicit EXPANSE model to systematically explore cost-optimal and 2'000 near cost-optimal scenarios.
3. Assess trade-offs of cost-efficient vs. regionally equitable distribution of investments in DREG and the electricity generation cost.

Methodology (complete methodology are reported in [6])
We simulate the Swiss electricity system with a spatially-explicit EXPANSE model [6,7] in order to assess the diversity of possible spatial allocation scenarios for decentralised renewables on a municipal level. The model integrates the electricity generation potentials for hydro power, gas, solar PV, wind, biomass and enhanced geothermal systems (EGS) as well as electricity savings and imports on a municipal level.

In order to assess the economic potential of each potential power generator, we incorporated the predicted future capital investment and O&M costs [8] to determine the levelized cost of electricity (LCOE) for each potential site. The additional economic potential of decentralised renewables until the year 2035 is shown in Figure 1.

With MGA methodology, the cost-optimal and 2000 near cost-optimal scenarios of renewables were simulated for the year 2035, which provided the yearly electricity generation, installed capacity and cumulative investments per technology at a spatial resolution of 2'258 Swiss municipalities and at a yearly temporal resolution.

In order to assess the most equitable spatial allocation of decentralised renewables, we introduced a measure for regional equity which reflects the burden of DREG across the Swiss population. Equity is defined as the even distribution of decentralised renewable electricity generated across the population and is measured using the Gini index [9]. In our definition, it is perfectly regionally equitable (Equity = 100%), if every municipality produces the same amount of DREG electricity per capita, and it is perfectly regionally inequitable (Equity = 0%), if all DREG electricity is generated by only one municipality.

Results (complete results are reported in [6])
We find a substantial trade-off between cost-efficient (least-cost) and regionally equitable DREG allocation strategies in Switzerland (Fig. 2). The difference in total electricity generation cost between the most equitable and the least-cost scenario amounts to 1.56 Rp.kWh (Note: 100 Rp=100 US cents), while the regional equity outcome increases from 28.6% to 43.1%.

An additional observation is that the share of electricity supplied from solar PV increases with increasing regional equity (Fig. 3), as the solar PV electricity generation per capita is dependent on the available rooftops and therefore also to the population size. In the cost-optimal scenario, up to 500MW in installed wind turbine capacity is concentrated in the canton of Vaud (Fig. 4a), while there are relatively high wind speeds and relatively low legislative land constraints for wind turbine installations. The least-cost scenario therefore leads to distorted regional investments in the canton of Vaud (CHF 1.7bn = 17% of the total investment in the country, Fig. 5a). With increasing regional equity, solar PV systems instead of wind turbines are installed evenly across all cantons (Fig. 4b), which in turn leads to more spatially even investments (Fig. 5b). The most regionally equitable scenario suggests that more investments should be allocated to highly populated cantons of Zurich (17%, CHF 4.1bn) and Geneva (6%, CHF 1.4bn).

Conclusions
We find a significant trade-off by 2035 in Switzerland: 50% increase in regional equity when allocating DREG to various Swiss regions leads to 18% higher electricity generation costs. A policy focus on cost efficiency would lead to large concentrations of DREG to few locations in Switzerland and hence would encourage an uneven regional distribution. We find that solar PV is the key technology for increasing regional equity in Switzerland with the least-trade-offs in total electricity generation costs.

References

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