TRADEOFFS BETWEEN REGIONALLY EQUITABLE AND COST-EFFICIENT ALLOCATION OF DECENTRALIZED RENEWABLE ELECTRICITY GENERATION

Jan-Philipp Sasse, University of Geneva Switzerland, +41 (0) 22 379 06 03, Jan-Philipp.Sasse@unige.ch
Evelina Trutnevyte, University of Geneva Switzerland, +41 (0) 22 379 06 62, Evelina.Trutnevyte@unige.ch

Overview

Decentralized renewable electricity generation (DREG) has been growing at an unprecedented pace, which was driven by substantial reductions in technology cost and generous policy incentives in some countries [1]. As in every transition, however, there is a risk that regions that are most able to take advantage of new technologies will enjoy the benefits of DREG first while others could stay behind [2]. Low-carbon transition that is based on DREG thus risks generating new patterns of spatially uneven regional development in terms of investments, jobs and policy support [4]. Finding ways to address the regional impacts and to anticipate emerging inequities is a new and recently noticed policy challenge [5].

In the global context, Switzerland plays a pioneering role with its ambitious Energy Strategy 2050 (ES2050) that, for the first time worldwide, was approved in a national referendum in 2017 by 58% of the Swiss voters [6]. ES2050 supports DREG and efficiency improvements in order to replace five existing nuclear reactors that currently constitute 32% of the electricity mix [7]. To achieve this, non-hydro DREG need to grow substantially from 2.5 TWh/year in 2017 to 11.4 TWh/year in 2035 [8] and are incentivized by one-time subsidies or feed-in-tariffs. The early evidence so far shows that DREG was adopted regionally unevenly [9], but little is known to what extent the emerging spatial pattern can have unintended consequences in terms of DREG electricity generation costs or regional equity implications.

Current scientific evidence lacks a more nuanced understanding of the trade-offs between regionally equitable and cost-efficient (least-cost) allocation strategies for the rapidly growing DREG. First, especially in countries like Switzerland with spatially uneven renewable energy resources, the trade-offs can be expected not to be negligible. Second, in-depth assessments of the actual spatial patterns in DREG growth are necessary [10] to identify whether DREG transition is on a path to deepen regional disparities or to deviate from cost-efficient futures.

Methods

In this study, we use a spatially-explicit, bottom-up, technology-rich, perfect-foresight electricity system model EXPANSE [11] to assess various spatial DREG allocation scenarios for all 2'258 Swiss municipalities in 2035. EXPANSE relies on the linear optimization of total electricity generation costs at a municipal level with national-level constraints and therefore puts municipal decisions on DREG siting at the core. The model includes spatially-refined data on electricity demand and generation for key centralized technologies (large hydro dams, large run-of-river hydro and gas power plants), DREG technologies (small hydro, solar PV, wind, EGS and biomass), net import, and electricity savings through end-use efficiency measures. By applying Modeling to Generate Alternatives (MGA) [11], EXPANSE does not only investigate cost-efficient (least-cost) allocation scenarios, but also computes so-called near-optimal scenarios that have up to 20% higher total electricity generation costs. In this way, the trade-off between regional equity and cost efficiency can be quantified for a very large number of scenarios that are still at reasonable costs.

With the described method, we generate a set of least-cost and 2'000 near-optimal spatial allocation scenarios to explore the trade-offs in terms of electricity generation cost, capital investment needs, DREG capacity, and regional equity. For the equity analysis, we introduce a measure for regional equity that is based on an adapted Gini coefficient [12] and reflects the evenness of DREG generation or investment, proportional to either the population or the electricity demand within municipalities. In our definition, it is perfectly equitable (Equity=100%) if every municipality produces the same amount of DREG electricity per capita or per kWh demand, and it is perfectly inequitable (Equity=0%) if all DREG electricity is generated by only one municipality.

Results

We find a substantial trade-off between cost-efficient (least-cost) and regionally equitable DREG allocation strategies in Switzerland (Fig. 1). The least-cost scenario is the least regionally equitable scenario, and the most regionally equitable scenarios have the highest electricity generation costs. In the least-cost scenario, the total electricity generation costs are 8.54 Rp./kWh (100 Rp.≈100 US cents). Regional equity values are 28.6% (weighted by population) and 28.3% (weighted by electricity demand). In the most regionally equitable scenarios by population and by electricity demand, the total electricity generation costs are up to 18% higher and equal to 10.10 Rp./kWh and 10.04 Rp./kWh, respectively. The regional equity outcomes are 43.1% by population and 43.0% by demand. By comparing the least-cost and maximum equity scenarios, we find that an increase in regional equity per population by 50% from the least-cost scenario leads to an increase in electricity generation costs of 18% (+1.56 Rp./kWh). Our results suggest that at least in Switzerland, where DREG resources are not evenly distributed throughout the country, the sole focus on the cost efficiency principle in siting DREG means

that DREG installations will be spatially concentrated to fewer locations. The strategy of a regionally equitable DREG distribution comes with a significant negative impact on electricity generation costs. When examining the current trend scenario, we find that it deviates from the Pareto frontier of equity-costs trade-off in terms of both, electricity generation cost and regional equity (Fig. 1). This finding indicates that there is space for improvement in Switzerland, either in terms of lowering generation costs or improving regional equity when allocating DREG.

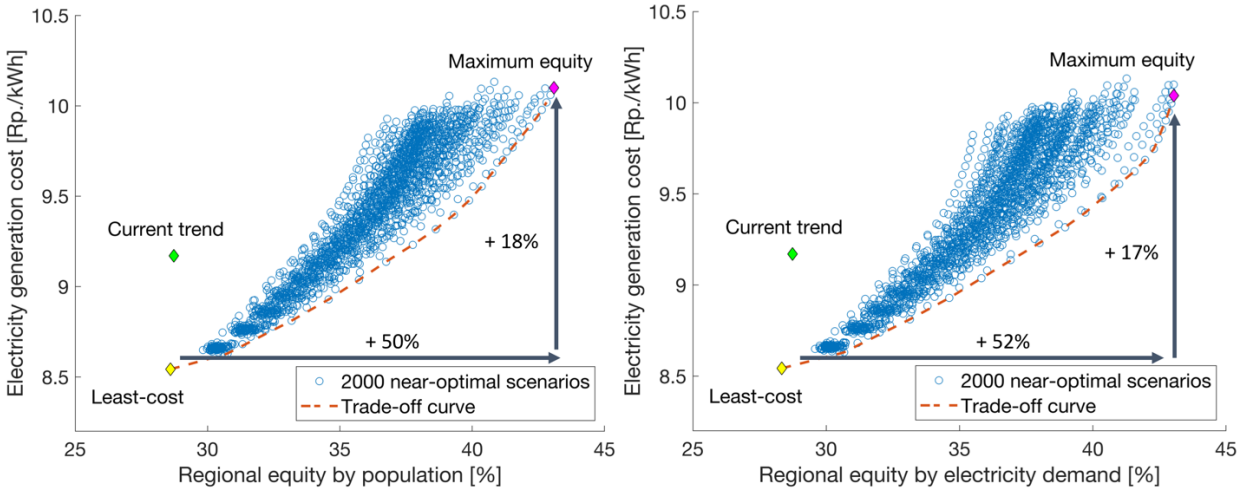

Figure 1: Trade-off between regional equity and total electricity generation cost for 2'000 spatial scenarios of DREG allocation in Switzerland in 2035. Note: 100 Rp.≈100 US cents

Conclusions

The rapid transition from centralized electricity generation to DREG will inevitably change the spatial fingerprint of the electricity sector and it could lead to land use conflicts, public acceptance issues, and widening regional disparities. In theory, any form of transformation should be a force for good across the society as a whole and in all its regions, not just where it is most cost-effective or convenient. In countries such as Switzerland, where the energy resources can vary quite significantly from location to location, we show that there is a significant and direct trade-off between regional equity in DREG allocation and total electricity generation costs. The higher generation costs are acceptable – the more regionally equitable DREG transition can be ensured.

We find that the 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. Currently, the federal economic incentives in the form of feed-in-tariffs and one-time subsidies risk fortifying the observed regional disparities. This trend of regional disparities in the energy transition is not only a Swiss but a global phenomenon [1], and it is in the interest of policymakers worldwide to encourage developments that bolster equitable economic, societal and environmental outcomes for all. Current economic incentives typically do not include mechanisms to additionally incentivize regionally equitable DREG diffusion, if DREG would not always perform at its best in terms of generation costs. Whether policy adjustments are needed and how much weight should be given to regional equity versus generation costs are ultimately the questions of values, as our trade-off curves show (Fig. 1). Due to the rapid growth of DREG and the fact that DREG systems are difficult to reallocate once they are built, now is the right time to reflect on the appropriate spatial DREG allocation and the incentive mechanisms.

References

[1] REN21. (2018). *Renewables 2018 Global Status Report*. Paris: REN21 Secretariat.

[2] Staffell, I., *et. al.* (2018). *Energising Britain: Progress, impacts and outlook for transforming Britain's energy system*. Selby, UK: Drax Group.

[3] Bridge, G., *et. al.* (2013). Geographies of energy transition: Space, place and the low-carbon economy. *Energy Policy*, **53**, 331–340.

[4] Balta-Ozkan, N., *et. al.* (2015). Spatially uneven development and low carbon transitions: Insights from urban and regional planning. *Energy Policy*, **85**, 500–510.

[5] Swiss Federal Council (SFC). (2017). *Bundesratsbeschluss über das Ergebnis der Volksabstimmung vom 21. Mai 2017 (Report No. BBl 2017 4865)*. Bern, Switzerland: Swiss Federal Council (SFC).

[6] Swiss Federal Office of Energy (SFOE). (2018). *Schweizerische Elektrizitätsstatistik 2017*. Bern, Switzerland.

[7] Swiss Federal Council. (2016). *Energiegesetz [EnG], Art. 2 (Report No. AS 2017 6839)*. Bern, Switzerland.

[8] Thormeyer, C., Sasse, J. & Trutnevyte, E. (2018). Spatial dimension of renewable energy diffusion: empirical evidence on solar PV, biomass, wind, and small hydropower in Switzerland. *Renew. Energy* (under review).

[9] Grunewald, P. (2017). Renewable deployment: Model for a fairer distribution. *Nature Energy* **2,** 17130.

[10] Trutnevyte, E., *et.al.* (2012). Context-Specific Energy Strategies: Coupling Energy System Visions with Feasible Implementation Scenarios. *Environ. Sci. Technol.* **46**(17), 9240– 9248.

[11] Gini, C. (1912). *Variabilità e mutabilità*. (ed. Cuppini, P.). Rome: Libreria Eredi Virgilio Veschi.