Decentralized Generation and Storage Technologies in Future Energy Systems of Swiss Communities

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Overview

Power systems worldwide have traditionally been structured according to a centralized generation and distribution scheme. However, the development and uptake of decentralized generation and storage technologies (DGSTs) is rapidly evolving and this motivates the need for a reassessment of the role of DGSTs in the future energy systems planning of our cities.

Energy system and policy planners face decision-making under uncertainty, including future technology development, resource availability, and cost uncertainties. However, scenario analysis using a long-term energy systems model can aid in the decision-making and planning process. In this study, a model is developed to examine the role of DGSTs in the future energy systems of Swiss rural and urban agglomerations.

Using a cost optimization approach, the model determines the energy capacity investment and operation required to satisfy electricity and heat demand across major agglomeration sectors until 2050. A number of scenarios are developed to analyse various uncertainties within the system. Scenarios introduce different technologies, carbon mitigation policies, and energy carrier and technology price sensitivities, and cost-optimal solutions are compared to a baseline scenario.

Both a rural and urban community are modelled, represented by different energy systems and scales. The models can serve as valuable inputs for local policymakers.

Methods

The cost optimization model for this case study is developed using the MARKAL/TIMES framework (IEA-ETSAP, 2011). TIMES is a bottom-up, energy systems, cost optimization modelling framework maintained by the International Energy Agency. It enables the development of perfect-foresight models which provide details on optimal capacity allocation and dispatch patterns for given scenarios. The developed model captures the entire energy system and conversion chain of the agglomeration, including residential, services, industrial, and agricultural sectors. End-use energy demand includes building space heat, domestic hot water, process heat, and electricity.

TIMES has been used to develop several national and international scale models (Goldstein & Tosato, 2008; Ramachandran & Turton, 2013); however, in this study, a lower-level model is developed in which individual decentralized technologies are modelled on an aggregated building level in a community. Time slices are also introduced with a relatively high time resolution, with average days represented on an hourly scale for each season.

Baseline scenarios reflect a centralized generation scheme, while alternative technology scenarios introduce decentralized and storage technology options. Decentralized heat and electricity generation technologies include small hydro (rural case only), gas micro-CHP (urban case only), photovoltaics, solar thermal heaters, and boilers, while storage options include a hydro reservoir (rural case), batteries, and heat storages. The impacts of carbon mitigation policies on capacity planning are also evaluated, including different carbon tax and feed-in tariff scenarios. Technology and energy carrier price sensitivities are measured as well.

Results

DGSTs enter into the cost optimal solution in both the rural and urban community studies. The results presented below focus on the rural community study as an example.

Small hydro and photovoltaics enable the rural community to become largely self-sufficient with over 80% reductions in national grid electricity usage by 2050 compared to the baseline scenario in one case. Storage is essential for full utilisation of the local hydro resource, however. To illustrate, Figure 1 below compares the electricity supply to the community in a decentralized technology scenario with and without storage options.

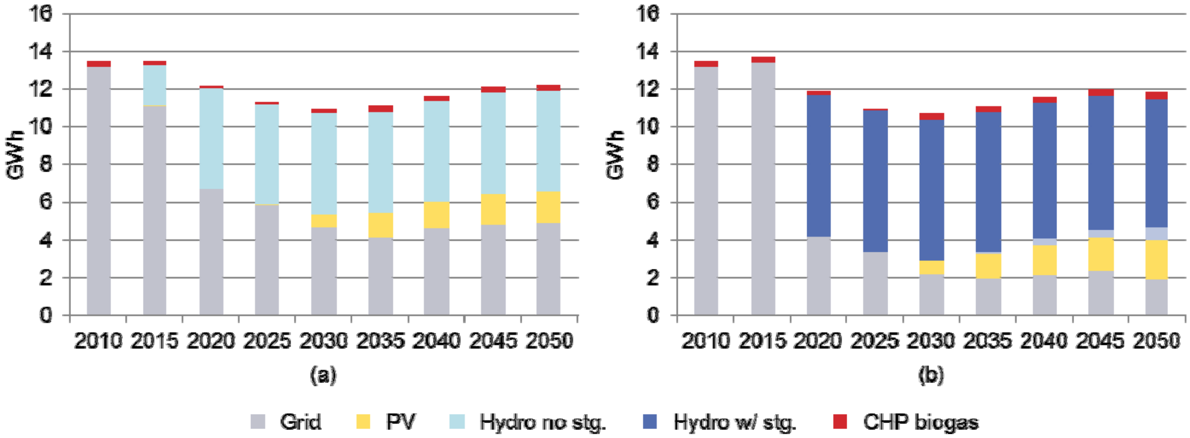

Figure 1: Electricity supply for a rural community in a decentralized technology scenario with (b) and without (a) storage options

The deployment of storage results in cost savings through transmission network upgrade deferrals, and prompts a 30% increase in photovoltaic installations as well. The overall decrease in electricity demand observed in Figure 1 is due to the replacement of electric heaters in 2010 with higher efficiency heat pumps over time.

The introduction of DGSTs results in a significant reduction in total discounted system costs for the rural community. The system cost reduction is approximately 8.5% compared to the baseline scenario when decentralized technologies are introduced without storage options. With the introduction of storage, the system cost reduction is 14%.

Investment decisions in small hydro are robust against hydro power technology cost variations, while heating technology investment decisions are found to be sensitive to oil and grid electricity prices.

DGSTs are found to play an important role in the future energy system of the urban case study as well. PV and gas micro-CHP technologies, in particular, enable a 60% reduction in national grid electricity imports by 2050 compared to the baseline scenario. Investment decisions in these technologies are not highly sensitive to cost variations.

Carbon pricing policies are found to be effective in mitigating local fossil fuel emissions in both the rural and urban case studies.

Conclusions

DGSTs play a significant role in the cost optimal, future energy systems of the communities considered. Small hydro with storage (in the rural case), gas micro-CHP (in the urban case), and photovoltaics (in both) play a dominant role in optimal capacity planning, even under uncertain cost conditions. The deployment of DGSTs results in increased self-sufficiency for the communities and enables electricity network deferrals. It must be borne in mind, however, that these results are specific to the communities considered; results will differ depending on site-specific conditions, including the existing energy system, local resource availability, and technology access.

Further cases are being developed in order to identify the broader conditions under which DGST uptake is favourable in Switzerland.

References

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