STRATEGIES FOR INTEGRATION OF VARIABLE RENEWABLE GENERATION IN THE SWISS ELECTRICITY SYSTEM

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Overview

The aim of this paper is to study strategies to increase the penetration of stochastic renewable electricity in a long-term horizon. We present the case of Switzerland, wherein the national energy strategy proposes to gradually phase out nuclear power and to adopt strong policies for promotion of energy efficiency and integration of renewable energy by 2050 [1]. Switzerland is a hub of Northern and Southern Europe electricity grid linking the three biggest Central European markets, with significant interactions in the electricity systems of all countries involved [2]. Thus, studying integration strategies for increased penetration of renewable electricity is not only relevant to the electricity network of Switzerland but also to the networks of its neighbouring countries (Italy, Germany, France and Austria). We examine the following strategies on integration of renewables in the electricity grid, in order to identify potential grid barriers or bottlenecks that may hinder the penetration of certain supply or demand technologies:

- Deploying a range of storage options at both the transmission and distribution grid levels.
- Increasing the penetration of dispatchable loads in order to shift electricity demand in time, so that the generation/load balance may be temporally preserved.
- Reinforcing and expanding the network as required by the energy flows in the grid.

Methods

The analytical tool used in this study is the Swiss TIMES energy systems model (STEM) [3-5]. The STEM model is based on The Integrated MARKAL-EFOM System (TIMES), a model generator developed by the International Energy Agency – Energy Technology Systems Analysis Program (IEA – ETSAP) allowing for specific models to be created and analysed by individual users [6]. The electricity and heat sector of the STEM model have been enhanced in the context of this study to include: a) representation of the different electricity grid levels from low voltage (0.4 – 1 kV) to very high voltage (220/380 kV); b) a set of power plants which can be connected to the different grid levels, ranging from large scale centralised generation to small scale distributed options; c) a range of different electricity storage options connected to different electricity grid levels (from low to very high voltage) and addressed to different applications (from buildings to transmission nodes), such as pump hydro, compressed air storage, and NaS, VRFB, NiMH, Li-Ion and Lead-Acid batteries; d) different possibilities for dispatchable loads such as electrolysers, water heaters and heat pumps. Fig.1 presents an overview of the enhanced electricity sector of the model.

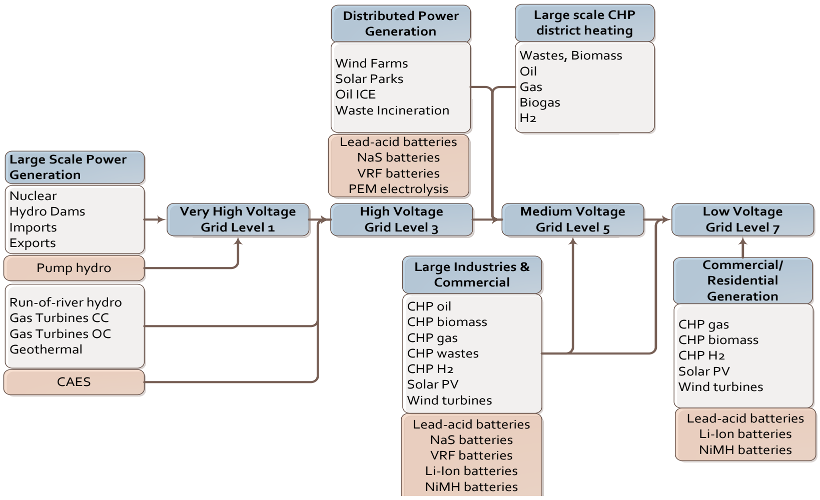

Fig. 1: Overview of the electricity sector in the STEM model

In addition, a topology of the Swiss electricity grid is included in STEM as an add-on, based on a detailed electricity grid model. For representing the grid topology, the country is divided into seven sub-regions, where each one corresponds to a node in the simplified electricity grid network in STEM. Additionally, four nodes were identified for the four existing nuclear power plants in Switzerland, and another four nodes for the four neighbouring countries. In total, the electricity transmission grid in the STEM model consists of 15 nodes, each one associated with a load injection (electricity generation) and load withdrawal (electricity demand) variables. The electricity exchanges in among the nodes are based on DC power flow equations by taking into account N-1 security constraints. In total, 638 power flow constraints are modelled in the model, according to the following compact formulation $\mathbf{H}\times\left(\mathbf{g}-\mathbf{l}\right)\leq\mathbf{b}$, where $\mathbf{g}$ is Nx1 vector of electricity injections in each node, $\mathbf{l}$ is Nx1 vector of electricity withdraws in each node, $\mathbf{H}$ is ExN power flow distribution matrix across the lines E and nodes N and $\mathbf{b}$ is an Ex1 vector with the thermal capacities of the lines. For the analysis, data at hourly, monthly and annual levels were used. Regarding the costs and learning rates of the different electricity, heat and storage technologies, these are taken from [5].

Results

A number of long-term national scenarios with different energy and climate change mitigation policy mixes are analysed, and insights on the impact of future electricity supply configurations on grid operation, investment and stability are generated. In a no grid expansion scenario, there is an increase in uptake of storage to balance supply and demand in order to cope with congestion. This result in high differences in electricity supply costs between seasons and triggers investments in Power-to-gas option – about 1TWh of seasonal electricity storage is seen by 2050. On the other hand, a grid expansion scenario increases electricity consumption and reduces the needs for storage compared to the no grid expansion scenario (Fig. 2). In addition, the grid expansion scenario reduces the system cost on the order of 0.5 – 3.0 billion EUR/yr., due to changes in the electricity and heat supply investments. One third of the cost reduction is attributable to changes in capital costs and two-third is attributable to changes in operating and fuel costs across both electricity and heat sectors.

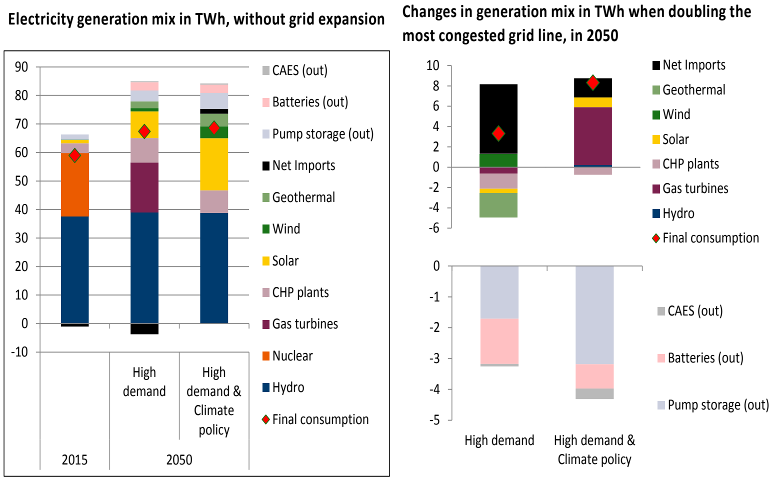

Fig. 2: Electricity mix and consumption under no grid expansion (left) and changes in them due to grid expansion (right) for two scenarios with and

Fig. 3 presents the requirements in electricity storage with respect to the installed capacity of variable generation across a set of scenarios. Battery storage is exponentially increased with deployment level of wind and solar PV capacity, reflecting the need for distributed balancing of demand and supply at the medium-to-low grid levels. On the other hand pump-hydro storage contribute for the balancing at the higher grid levels. Investments in power-to-gas options become necessary when the installed capacity of variable electricity generation exceeds 10 GW because of restrictions on pumped-hydro to offer seasonal storage (for water management reasons). In this case, about 13% of the electricity production from wind and solar PV in summer is stored in Power-to-X and used in the other seasons. To this end, seasonal storage is mostly provided by Power-to-X, while pump storage and batteries are more suitable for intra-day storage.

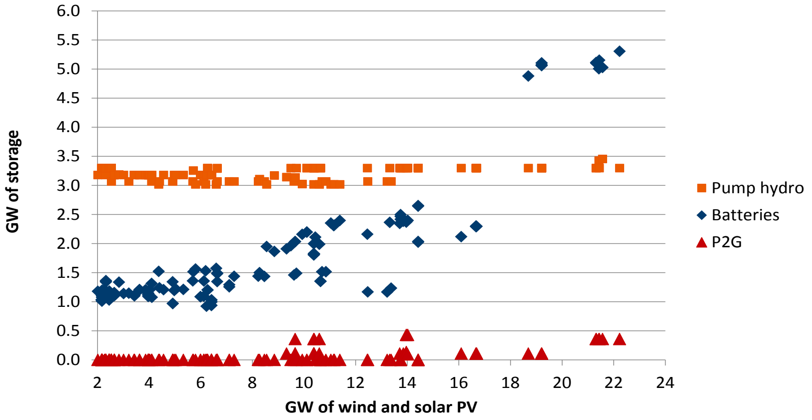

Fig. 3: Requirements in electricity storage vs penetration of variable generation

Conclusions

The results show that limitations in the electricity grid expansion infrastructure can impose high costs for the electricity and heat sector. Solar PV and wind can be deployed to their full potential if grid is expanded. The no grid expansion scenario requires alternative storage like batteries and power to gas. However, when the electricity storage is disabled, then the penetration of variable renewable generation reduces by 30% and the supply-demand is balanced through flexible natural gas-based generation which eventually increases fuel costs and emissions.

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