FACING CLIMATE CHANGE: DOES SWITZERLAND HAVE ENOUGH WATER?

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Overview

Climate change forces electricity systems to change radically (Bruckner, Alexeyevich, & Mulugetta, 2014). Thus, many countries have been developing different policies that encourage the transition from fossil fuels to renewables, such as sun and wind, to mitigate the greenhouse gas emission (GHG) footprint (Carley, Baldwin, MacLean, & Brass, 2017; Connolly, Lund, Mathiesen, & Leahy, 2011; Pattupara & Kannan, 2016).

The use of Renewable Energy Sources (RES) has increased sharply over the last decade due to technological progress and economies of scale (Batalla-Bejerano & Trujillo-Baute, 2016; Kaldellis & Zafirakis, 2011). In 2009 the total renewable installed capacity (including hydropower) was of the order of 1.2 TW, compared to 2.4 TW at the end of 2018 (REN21, 2019). Due to their intermittent nature, a high share of RES in the electricity mix reduces flexibility and security of supply (Carley et al., 2017; Clerjon & Perdu, 2019), making it challenging to balance the market at all times.

Energy storage has been introduced in the system to solve the mismatch between the daily and seasonal patterns of demand and generation (Barbour & González, 2018; Zsiborács et al., 2019). Today the most popular energy storage technology is hydro-storage plants. Conventional hydro-storage plants rely on natural water inflows; adding pumping mitigates the limitation and variability of natural inflows (Deane, Gallachóir, & McKeogh, 2010). However, there are some future challenges for hydro-storage.

Our study focuses on the Swiss case. Some studies suggest that natural inflows (for run of rivers and hydro-storage) will vary depending on the different climate change scenarios. It is expected that run of river generation will increase by 2% (2050) before decreasing to only 0.5% (2070) above current level (Finger, Heinrich, Gobiet, & Bauder, 2012). Meanwhile, over the same period reservoirs are expected to receive less water in summer and more during fall. Gaudard et al. (2014) conclude that by 2050 hydro storage plants will increase their generation by 0.2%, but by 2070 their total generation will decrease by 10.3%. Overall, the reduction in hydro-generation by 2070 is expected to be around 10.1%, increasing the challenge of replacing nuclear in Switzerland. Another effect to be considered is the decrease in the reservoir capacity due to sedimentation.

The aim of this paper is to explore different policies to mitigate the effects of climate change. We develop a stylized model of an electricity system which consists of a technology that is being phasing-out (e.g., nuclear), an intermittent technology (PV) and base load generation (e.g., run-of-river), as well as an energy storage technology (pump hydro storage). We calibrate this model using the Swiss case and we explore different energy policies to understand how this kind of system can achieve a transition towards 100% green generation. We also considered a change in demand pattern: climate change is expected to generate more extreme summers, which will increase demand for air conditioning, while in winter demand should decrease due to lower consumption of electricity used for heating. Our model also assumes an increase in electric vehicle adoption, leading to a substantial growth during the simulation period.

Our research aims to understand how the government should intervene under an uncertain demand and also with a reduction in natural resources. This research contributes to the existing literature by working in a strand of research that has being mainly forgotten that is to study the uncertain long-term effects of climate change in electricity markets.

Methods

We propose a System Dynamics (SD) based model. This methodology is useful to incorporate causalities, feedbacks and delays between variables (Morecroft, 2007; Sterman, 2000), which allows understanding the behavior of a system by studying its structure. SD uses two main elements: levels (state variables which accumulate information or material, referred to as stocks) and flows (which modify the levels). The other elements are parameters or auxiliary variables used to make calculations and represent the information network. SD is based on first-order non-linear differential equations.

Our analysis takes a high-level view; we take an hourly approach, using a typical day for each month to analyze demand and supply. The model considers two types of hydro generation: from natural inflows (Hn) and pumped water (Hp). Figure 1 provides an overview of the model; our key state variables are installed capacity of PV and pumps. A blue arrow represents a causal link between two variables. The "+" ("-") next to an arrowhead indicates a positive (negative) causal relationship. The clockwise arrow with a B inside indicates a balancing loop. If the electricity price increases, PV becomes more profitable, inducing investments in PV capacity; this leads to more PV generation and thus decreasing prices.

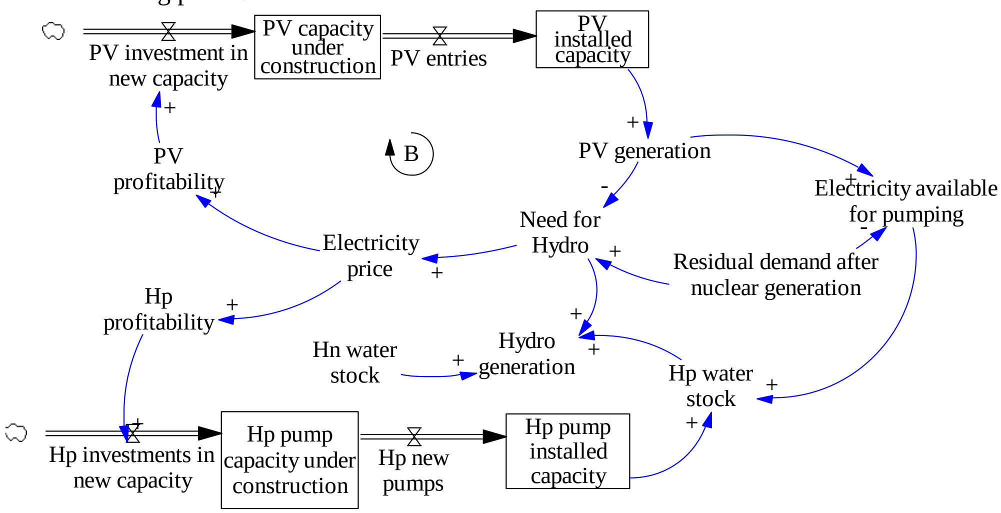

Figure 1. Main variables and relationships of the proposed model

Results

Figure 2 points to the risk of a boiling frog effect: due to an increase of inflows during 2030 to 2050 policy makers could postpone intervention, and consequently not be prepared to face the second phase of climate change (2050-2070).

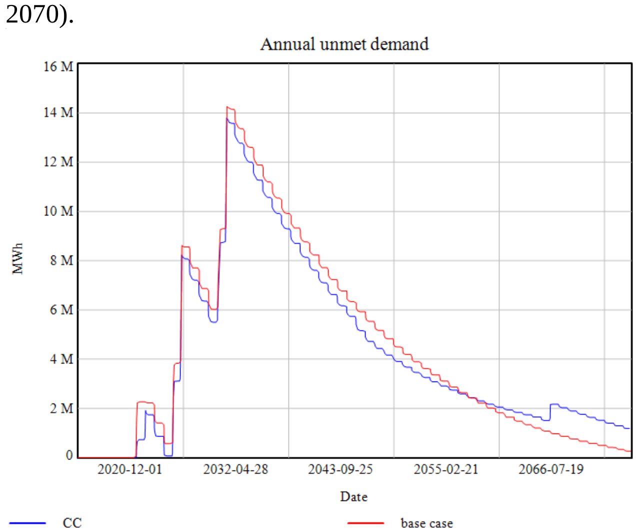

Figure 2. Annual unmet demand

Conclusions

We developed a stylized SD model to examine the effects of climate change on a system that faces a transition. The model enables us to analyze the possible outcomes of a system that relies on hydro and PV in a country such as Switzerland for different climate change scenarios which considers less water resources, shifts in seasonal and hourly demand patterns and an increase in demand due to an improvement in the efficiency of process as a transition towards electric transportation.