***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 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 2018 the total renewable installed capacity (including hydropower) was of the order of 2.4 TW, compared to 1.2 TW at the end of 2009 (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. 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 Switzerland. Some studies suggest that climate change will affect natural inflows (for run of rivers and hydro-storage). 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 (pumped hydro-storage). We calibrate this model using Swiss data and we explore different energy policies to understand how this kind of system can achieve a transition towards 100% green generation. We also consider 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 for heating. Our model also assumes an increase in electric vehicle adoption, leading to a substantial growth in demand over the simulation period.

Our research aims to understand what type of governmental intervention is required to successfully manage the simultaneous increase in demand and reduction in natural resources, being aware that both of these are subject to a high degree of uncertainty.

## 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 relies on two main building blocks: 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 curved 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

The meteorological forecast point to the danger of a boiling frog effect: the increase in inflows from 2030 to 2050 risks inducing a false sense of security, enticing policy makers to postpone unpopular interventions. This could lead to a lack of preparedness to face the second phase of climate change (2050-2070). We currently are in the process of calibrating the model and the different demand and climate scenarios finetuning. Preliminary runs confirm our hypothesis that without governmental interventions, the situation could worsen sharply from 2050 onwards.

## Conclusions

## We develop a stylized SD model to examine the effects of climate change in the energy transition. The model will enable us to analyze the possible outcomes of a system (e.g., Switzerland) that relies on hydro and PV for different climate change scenarios, which consider lower water resources, shifts in seasonal and hourly demand patterns and an increase in demand due to, among others, a transition towards electric transportation.