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Long term climate change mitigation goals under the nuclear phase out policy: The Swiss energy system transition

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ABSTRACT

The Swiss electricity system is dominated by low-carbon hydro and nuclear generation. The Government's decision to phase-out nuclear energy exacerbates Switzerland's climate change mitigation goals. Response to this challenge requires systemic changes to the energy system, which is generally a long-term, uncertain and systemic process, affected by technology choices across the entire energy system. A comprehensive Swiss TIMES Energy system Model (STEM) with high temporal detail has been developed for the analysis of plausible low-carbon energy pathways focusing on uncertainties related to policy (climate change mitigation and acceptability of new centralised electricity generation) and international fuel prices. Increasing electrification of end-uses is seen across the scenarios, resulting in continuous growth in electricity demands. The electrification of heating and e-mobility substitute direct use of fossil fuels in end-use sectors and contribute to a significant carbon dioxide emission (CO_2) reduction. Centralised gas power plants and renewables become key source of electricity supply. Given the phaseout of nuclear generation, clear policy signals are required to ensure capacity is built to achieve a low-carbon energy system. At the same time, it is also essential to ensure consistency between the electricity sector and end-use energy policies. For the long-term carbon reduction target, some non-cost-effective conservation measures are important early in the period because they are available only at the time of building renovation.

1. Introduction

Heavy dependence on fossil fuels in the global energy system has created key challenges for climate change mitigation and energy supply security. While individual countries, such as Switzerland also face the same broad issues, specific features of the Swiss energy system affect the nature of these challenges and give rise to additional concerns. For instance, the Swiss electricity system is nearly decarbonised (hydroelectric (~56%) and nuclear (~40%) generation (BFE, 2014)). While this supports climate change mitigation, the high share of hydroelectricity contributes to large seasonal variations, which are partly managed through integration into the European electricity grid, but potentially contribute to additional challenges to supply security. Imports of oil and natural gas account for about two-thirds of final energy demand (BFE, 2013a) and this dependence on fossil fuels not only increases vulnerability to developments in international energy markets, but also threatens the realisation of climate change mitigation objectives. Moreover, the policy decision to phase-out nuclear generation threatens both climate change mitigation and supply security.

An effective response to this range of challenges will require substantial and likely systemic structural changes to the energy system. Many technological options exist on the supply and demand sides to facilitate these changes, but it is not clear which combination offers the best approach. Structural change in the energy system is generally a long-term, uncertain and systemic process, affected by patterns of demand and technology choices across the entire energy system–that is, the optimal transition in one part of the energy system is likely to be affected by developments in other parts of the energy system. For example, electrification of the heating or transport sector will have major implications for electricity sectors, whereas technology choice in electricity generation (e.g., a nuclear phaseout) will affect the choice of technology in end-use sectors. Moreover, given the likely increasing role of intermittent renewable supply options in addressing the challenges confronting the energy system, the need to ensure supply is available over seasonal and daily time periods may emerge as an increasingly significant issue. Thus, understanding how structural changes in the energy system may occur requires analytical approaches that are able to account for: (1) system-wide effects, (2) uncertainty over the medium/long term and (3) intra-annual variability in supply and demand. Energy models have emerged as a useful methodology for evaluating future options for the energy system and generating insights into some of the associated uncertainties (Pfenninger et al., 2014).

In Switzerland, a range of energy models, like energy-economy equilibrium models, technology-rich MARKAL energy system models and sector-specific energy models have been implemented for analysing energy and climate change mitigation policies (Kannan and Turton, 2013). However, none of these existing models of Switzerland

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includes a system-wide technology-rich methodology that combines a long time horizon with a sufficient level of detail to account for the impact of important seasonal and diurnal variations of energy demand and supply. While studies applying a systems approach do exist, they apply a highly aggregated intra-annual time resolution (Schulz et al., 2008). Similarly, while a Swiss TIMES Electricity Model (STEM-E) with long model horizon and an hourly time resolution has been developed and extensively applied (Kannan and Turton, 2011a, 2013; Kannan et al., 2015), it lacks a true system-wide perspective—that is, it is unable to account endogenously for interactions between electricity generation, non-electric supply, and end-use demand, including the future electricity demand profile (load curve). This represents an important limitation of electricity models (Deane et al., 2014; Schlecht and Weigt, 2014) more generally, in which the future electricity load curve is often assumed to follow the pattern of today, ignoring potential changes arising from electrification of hitherto non-electric end uses. Therefore, a comprehensive and flexible model (the Swiss TIMES Energy system Model—STEM) has been developed for Switzerland. STEM has an hourly intra-annual time resolution combined with a long time horizon. Most importantly, the electricity demand profile is determined endogenously in STEM, and thereby has the potential to shed new insights into long-term transitions of the Swiss energy system. To our knowledge, this is the first time that an hourly time resolution is implemented in a TIMES/MARKAL whole energy system model. In this paper, we present the STEM model and a set of low-carbon pathways that have been analysed using STEM. In Section 2, the model is described with two core scenarios and key socioeconomic input drivers. The analytical results are presented in Section 3. Some policy options are discussed in Section 4 with conclusions in Section 5.

2. Methods

STEM is a bottom-up, technology-rich model built in the Integrated MARKAL EFOM System (TIMES) framework (Loulou et al., 2005). In STEM, the full energy system is depicted from resource supply to end-use energy service demands (ESDs), such as space heating, and personal/freight transport. The model combines a long time horizon (2010-2100) with an hourly representation of weekdays and weekends in three seasons. The model is used to identify the least-cost combination of technologies and fuels to meet exogenously given ESDs. The model outputs include energy demand and technology choices across all sectors, electricity demand and supply options, carbon dioxide (CO_2) emissions, and cost of energy supplies, among others. All cost data are defined in 2010 Swiss Francs (CHF_{2010}) (1 $US\$_{2010} \approx 1.04$ CHF_{2010}). Fig. 1 shows the STEM framework, which represents a broad suite of energy and emission commodities, technologies and infrastructure. It has a modular structure for each of the five end-use sectors, primary energy resource supply, electricity generation, and infrastructure (fuel distribution). The model is calibrated to the actual energy balance in 2010 (BFE, 2013a). In the base year 2010, ESDs are estimated from the final energy use for each application (BFE, 2013a; BFE, 2013b) using a set of assumptions on end-use technologies. It is a spatially aggregated, single-region model, and thus ESD and energy distribution infrastructure are highly aggregated. The following subsection provides an overview of the model structure and assumptions. We encourage readers to refer the model documentation (Kannan and Turton, 2014).

2.1. End use modules

The end-use sector module includes ESD and end-use technologies. Since a large share of Swiss final energy is used for heating (31%) and transport (26%) sectors (BFE, 2013b; BFE, 2013a), and since most of the CO_2 emissions are from these two sectors, a higher level of detail has been included in STEM for these applications. Residential space heating demand is disaggregated into four subcategories, *viz.* existing single-family houses, existing multifamily houses, new single-family houses and new multifamily houses, which enables analysis of the potential role of energy conservation measures and differences in economies of scale in heating technologies. Air conditioning and lighting demands are also modelled in detail, whereas other end-use applications (e.g., appliances) are depicted as final electricity demands without an additional efficiency factor (see also scenario assumptions in § 2.4.1).

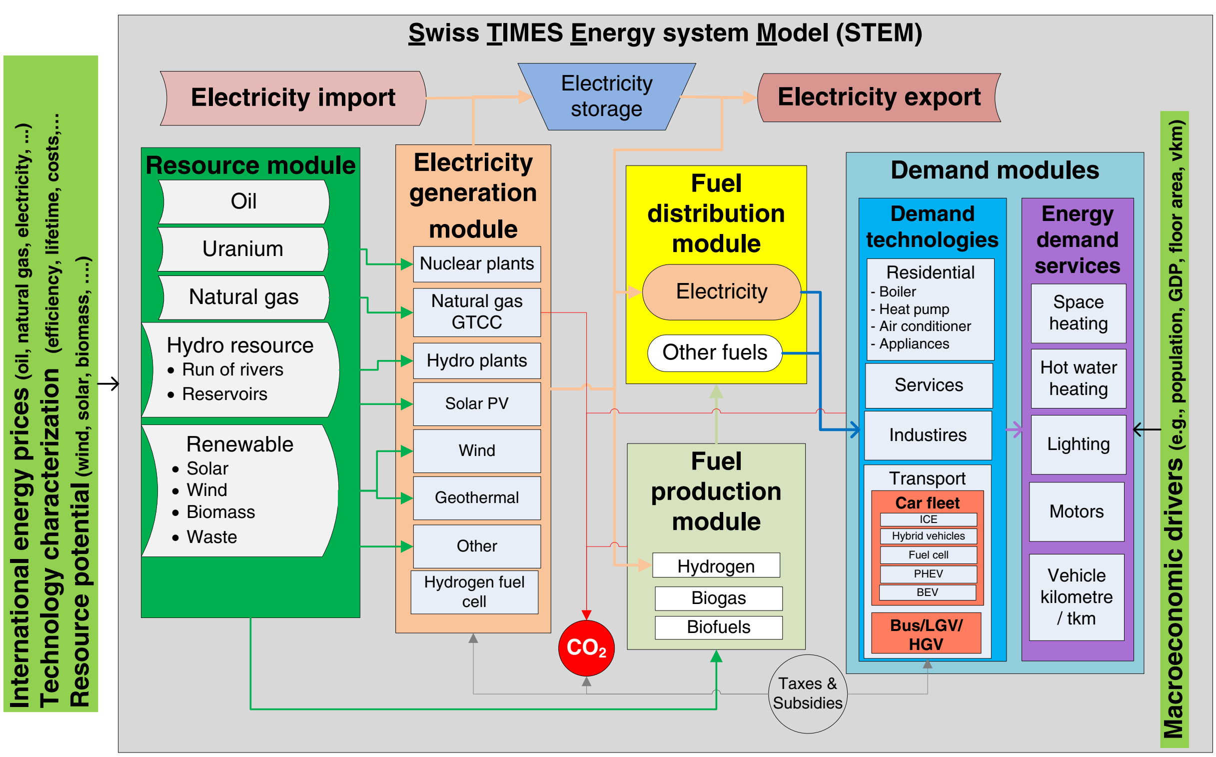

Fig. 1. Simplified reference energy system of STEM.