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The role of domestic biomass in electricity, heat and grid balancing markets in Switzerland

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ABSTRACT

The Swiss Energy Strategy targets to reduce per capita energy consumption, to decrease the share of fossil energy and to replace nuclear electricity generation by gains in efficiency and renewable energy sources. In view of the above objectives, we evaluated the prospects of biomass in stationary applications and grid balancing from an energy system perspective. We quantify a number of "what-if" scenarios using a cost-optimisation bottom-up model, with detailed representation of biomass production and use pathways, electricity and heat sectors, and grid ancillary services markets. The scenario analysis shows that domestic biomass can contribute 5–7% in electricity and 14–21% in heat production by 2050, depending on natural gas prices and climate policy intensity. Pooling of biogenic driven cogeneration plants can provide about 22–44% of the total secondary control power in 2050. Generally, biogenic technologies complement other assets in heat, electricity and ancillary services markets such as heat pumps, new renewable sources and hydropower.

1. Introduction

The Swiss energy policy aims at achieving an ambitious transformation of the Swiss energy system. The Swiss Energy Strategy to 2050 [1] anticipates a 50% reduction in the final energy consumption, a stabilisation or reduction of electricity consumption, and a decrease in CO_2 emissions by 70–80% in 2050 form 2010 levels [2]. At the same time, it aims at a gradual phase-out of the Swiss nuclear power plants by the time when they do not comply anymore with safety standards [3]. To achieve these targets, the Swiss Energy Strategy focuses on energy efficiency, promotion of electric heat pumps, electrification of mobility, exploitation of the remaining limited potential of hydropower and deployment of new renewable energy sources (wind, solar, biomass, geothermal). In overall, the goals of the Swiss Energy Strategy pose significant challenges to the Swiss energy system, with the most important being the provision of clean, economic and climate-friendly supply of energy.

Bioenergy, which includes energy from woody biomass (such as forest wood, industrial wood residues, wood from landscape maintenance and waste wood) and wet biomass (food waste, green waste, industrial bio-waste, sewage sludge, animal manure) [4], can contribute to the above objectives of the Swiss Energy Strategy. Given the limited domestic biomass potential in Switzerland, which is estimated to be between 82 PJ [4] and 122 PJ [5] or 7–11% of total Swiss primary energy consumption [6], a question of interest is the most energy efficient and cost-effective use of the resource in electricity and heating applications. In addition, flexible biogenic gas CHP plants[1] (CHPP), i.e. CHP units fuelled with biogas or bio-methane from the natural gas grid, can be seen as a carbon-free solution to electricity grid balancing requirements in view of increased penetration of intermittent renewables. However, the extent of the penetration of biomass in electricity, heat and grid balancing markets largely depends not only on the energy policies in place, but also on the cost and the potential of biomass resources and technologies.

In this context, we analyse four scenarios to 2050, with focus on bioenergy from an energy system perspective. We apply the Swiss TIMES Electricity and Heat model (STEM-HE), which is a bottom-up

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[1] The biogenic gas CHP plants use the same engine as the natural gas fuelled CHP plants, which implies that they both have the same technical and economic characteristics. Thus the only difference is the choice of the input fuel.

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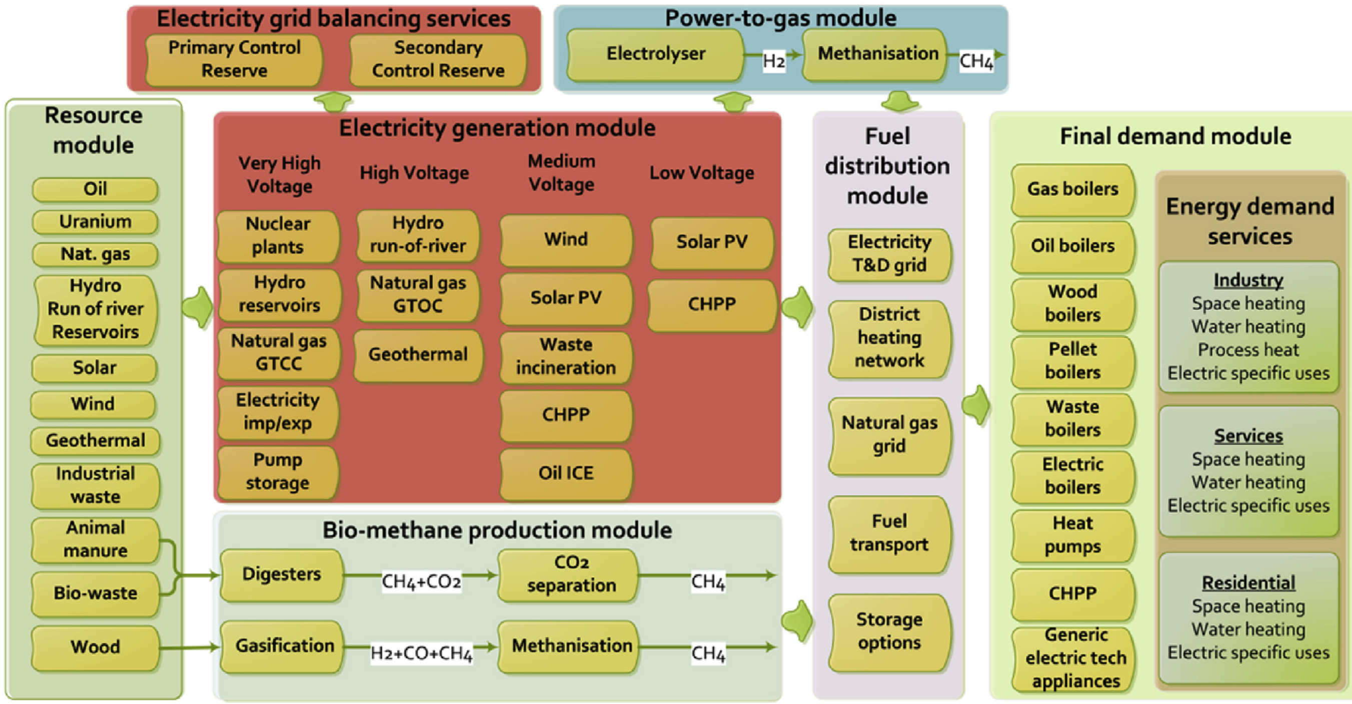

Fig. 1. Overview of the Reference Energy System of STEM-HE model.

cost optimisation model that represents in detail the Swiss electricity and heat sectors, together with biomass production and end use pathways. It is based on the TIMES modelling framework [7], developed by the Energy Technology System Analysis Program (ETSAP), which is an implementation agreement with the International Energy Agency (IEA) [8]. Uncertainties influencing the development of the Swiss energy system, such as future electricity and heat demands, climate change mitigation objectives, technological breakthroughs and external factors (e.g. energy import prices), are assessed through sensitivity analyses in line with the main scenarios.

Despite that the Swiss Energy Strategy foresees a substantial amount of biofuels in the transport sector, less than 5% (1–2 PJ) of them is domestically produced [1]. It is argued that in Switzerland biofuels are not economically viable without high fossil prices [9] or high supports [10], and that their compliance with the Swiss environmental regulations is debated [11]. Based on Swiss Federal Office of Energy, large scale production of biofuels in Switzerland is undesirable because of food security and environmental issues [12]. Thus, we excluded the use of domestic biomass for biofuel production.

The next subsection has the literature review. Section 2 describes the modelling framework used in the analysis, together with the definition of the scenarios. The results from the analysis are discussed in section 3. The paper concludes with section 4, with the discussion and policy implications regarding the future role of the bioenergy in Swiss energy system.

1.1. Literature review

Although many studies have used bottom-up modelling frameworks and energy transition scenarios to assess the future role of bioenergy in energy systems at global (e.g. Refs. [13–17]), regional (e.g. Ref. [18] for Africa, [19] and [20] for Europe) and national scales (e.g. Ref. [21] for Sweden and France, [22] for Sweden, [23] and [24] for UK), only few exist for Switzerland. The foci of the past analysis for Switzerland were on specific biomass production and use chains. For instance, in Ref. [25] the chain of wood-based synthetic gas production and use is assessed in detail for Switzerland with respect to its interaction with the rest of the energy system using the Swiss MARKAL energy system model (SMM). In Ref. [26] optimisation strategies regarding the size and location of bioenergy plants in Switzerland are evaluated, with respect to their environmental and economic performance for electricity and heat supply. In Ref. [27] the local acceptance of biogas plants in Switzerland is assessed and the outcome of the analysis is positive. In Ref. [28] efficient pathways for electricity and heat from bio-wastes are examined based on Swiss Energy Strategy scenarios until 2035. In Ref. [29] the biomass utilisation in Switzerland was assessed, based on exogenous allocations of biomass in electricity, heat and transport application, by ignoring sectoral competition for the resource. In Ref. [30] long term scenarios of Switzerland towards the 2000 Watt society were assessed, using an energy system approach, but the analysis had limited focus on bioenergy. None of the above studies looked at temporal variation in energy supply and demand. In Ref. [31] a set of Swiss energy system transition scenarios are quantified using the Swiss TIMES energy system model (STEM). Though it has a system approach with transport demands, representation of bioenergy pathways are limited.

Thus, the present paper builds on [31] to assess the future role of bioenergy in the Swiss energy system by taking into account the objectives of the Swiss Energy Strategy to 2050. It evaluates multiple and competing pathways for the production and use of the domestic bioenergy using an energy system approach. It also quantifies the prospects of bioenergy not only in electricity and heat markets, but also in grid ancillary services [32] through biogenic gas fuelled CHPP. However, the focus of the paper is not only on technical or operational feasibility of CHPP in providing the grid balancing services (which has been already assessed in