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The impact of policy actions and future energy prices on the cost-optimal development of the energy system in Norway and Sweden

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ABSTRACT

This paper studies the effects of policy actions on the energy systems in Norway and Sweden, including a nuclear shutdown, a cancelation of restricted hydropower and an expansion of export capacity to Europe. This study apply a stochastic TIMES model that considers the short-term uncertainty in electricity supply and value the flexibility of hydro reservoirs. It is the first time this approach is used to quantify the effects of these policy actions on cost-optimal investments and operations. To consider the uncertainty of the energy market, we analyse the policy actions under four different price developments for biomass, fossil fuels and electricity. The results demonstrate that our stochastic approach provides different model decisions compared to the traditional deterministic approach. Further, we show that the future role of the large hydro reservoirs in Norway and Sweden depends both on the adopted policy actions and on future energy prices, and that the policy actions have a significant impact on the development of the energy system. This insight is valuable when considering the development and management of the hydro reservoirs. It is also valuable for other European countries so that they can evaluate the interplay of the hydro reservoirs with other energy storage options.

1. Introduction

Insights from energy system investment models contribute to a cost-effective development of the system and illustrate the long-term impact of energy and environmental related policies. For Norway and Sweden, it is essential to use tools that consider the flexible hydro production in the light of the increased share of intermittent renewable electricity generation in Europe. Although Norway and Sweden are two relatively small countries, the energy-related decisions in these countries can have a significant impact on the European energy system. Norway and Sweden have about 70% of the European hydro reservoir capacity, at 82 TWh and 34 TWh respectively (Nord Pool Spot, 2014), and are highly interconnected to northern Europe. However, the contribution of the hydro flexibility is uncertain in both the short and long term since it relies on the climate dependent hydro inflow and on the future development of the energy system.

This paper use a stochastic TIMES model (the Integrated MARKAL-EFOM System) (Loulou, 2008; Loulou and Labriet, 2008; Loulou et al., 2005a, 2005b, 2005c), with an explicit modelling of the short-term uncertainty related to electricity supply, to study the effects of important energy and environmental policy actions on the energy systems in Norway and Sweden from a social welfare perspective. The policy actions include a nuclear shutdown, a cancellation of restricted hydropower and an expansion of export capacity to Europe. For comparison, we also include a benchmark case, with no political action taken on these issues. Further, we analyse these policies under four different assumptions on price development on biomass, fossil fuels and electricity outside Norway and Sweden. Consequently, we can indicate the key impact of the policies under different market assumptions.

The first contribution of this paper is analysis of the impact of the selected policy actions on the energy sector in Norway and Sweden. For the various policy actions and energy price assumptions, we present investments and operation in the energy sector towards 2050, including the handling of flexible hydro reservoirs, development of renewable electricity generation, heating technologies in buildings and the interaction with the European electricity market. This insight is valuable for decision makers in Norway and Sweden in order to design policy instruments that give optimal investments, from a macroeconomic perspective. As the policy actions influence the future interaction with the European electricity market, their implications are also interesting for decision makers located outside the borders of Norway and Sweden.

Abbreviations: CHP, Combined Heat and Power; DH, District Heat; EMPS, Multi-area Power-market Simulator; PV, Photovoltaic Power; ROR, Run-Of-the-River; TIMES, The Integrated MARKAL-EFOM System; VSS, Value of Stochastic Solution

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For northern Europe, the possible contribution and role of the flexible hydro reservoirs in Norway and Sweden should be evaluated together with alternative back-up technologies and other energy storage options for an optimal integration of intermittent electricity generation.

The second contribution of this paper is the applied stochastic methodology, which provides investment decisions that take into account a range of operational situations that can occur. We include a stochastic representation of the short-term uncertainty of hydropower, wind power and electricity trade prices outside Norway and Sweden in order to consider the uncertainty of intermittent electricity supply. Here, the stochastic electricity trade prices represent the short-term uncertainty of the market equilibrium in the countries with interconnection to Norway and Sweden. Our analysis shows that a stochastic modelling approach, with a more realistic representation of electricity sector, provides different investment strategies compared to a deterministic representation of the intermittent electricity supply.

The policy on a nuclear shutdown is included as the future of nuclear power is uncertain due to the political agenda of some parties (Qvist and Brook, 2015). The taxation of the nuclear capacity and subsidised renewable electricity generation are current policy instruments that reduce the profitability of nuclear power. The Swedish tax on nuclear capacity, which is justified to cover future decommission costs, was increased to 14770 SEK per MW and month (corresponding to EUR 1507 with 9.8 SEK/ EUR), by 1 August 2015 (Regeringskansliet, 2015). After this tax increase, it was agreed to shut down the two oldest reactors at Ringhals and the two oldest reactors at Oskarshamn from 2015 to 2020 (Fortum, 2015; Vattenfall, 2015) in October 2015. This resulted in a 25% reduction in the Swedish nuclear capacity to 6.7 GW (Svensk Energi, 2015). Consequently, further taxation can result in no nuclear power generation in Sweden. A possible absence of the Swedish base load nuclear power supply can influence the available hydropower flexibility to Europe. For example, if the nuclear capacity is replaced by wind power, the hydro reservoirs can be used to a larger degree as back-up capacity within Norway and Sweden in periods with poor wind conditions.

We include the environmental policy on an expansion of the Norwegian hydro potential because the development of a large part of the potential new hydro plants in Norway is restricted by the Protection Plan for Watercourses. The protection was adopted by the Parliament from 1987 to 1995 (NVE, 2015c), and is reasoned by the environmental impact of landscape and biodiversity. A cancelation of the restrictions can cause intervention in untouched natural areas and increases the new hydro potential from 31 TWh to 80 TWh (NVE, 2015b). Although, a cancelation of the restriction has not been on the political agenda, it is relevant with increased focus on a sustainable development. For an overall assessment, this restriction should be evaluated against the environmental impact of other electricity generation technologies, such as wind power and fossil fuelled plants. Also, the value of the flexible hydro plants can significantly increase with more intermittent electricity generation since the additional flexible hydro capacity can give increased profits for Norway and Sweden.

Electricity exchange with other European countries is a prerequisite for best utilisation of the hydro reservoirs with regard to profit. Building new export capacity from Norway and Sweden to Europe is being debated. This includes the capacity expansion projects, “NSN Link” between Norway and the United Kingdom (Statnett, 2015b) and”NordLink” between Norway and Germany (Statnett, 2015a). To expand or not, is both an energy policy decision and a matter of environmental concern. The Norwegian debate on expanding the export capacity to Europe is mainly based on the effect on domestic electricity prices and on the influence on the domestic power grid (Mo Industripark AS, 2015; Stavrum, 2015). If additional trade capacity increases the electricity prices, it can threaten the competiveness of the power intensive industry. Also, more cables out of the country can require domestic grid reinforcements in untouched natural areas. On the other hand, more export capacity can increase the value of the hydro flexibility and result in additional profits for the hydro plant and public transmission owners.

Energy models are commonly used to evaluate the cost-optimal adaption of policies that deals with environmental considerations and the transition to a sustainable energy system in Europe. For models with focus on Norway and Sweden, it is mainly the modelling tool Multi-area Power-market Simulator (EMPS) (Warland et al., 2008; Wolfgang et al., 2009), BALMOREL (Ravn, 2001, 2011) and TIMES that is used. A selection of related literature that applies these modelling tools is presented below. A generic description of long-term energy models are given in Section 2.1.

For the Nordic countries (Norway, Sweden, Denmark, Finland and Iceland), the adaption of the power system towards 2050, given the 2 degree scenario in ETP 2016 (IEA, 2016a), is analysed by a BALMOREL model in IEA (2016b). Here, the climate scenario is achieved with inter alia an extensive development of wind power, increased transmission capacity to other European countries and more district heat production from heat pumps. A key finding is that the Nordic region is capable of integrating a large share of intermittent electricity generation due to the flexible hydro production and the integrated electricity market. This study also addresses the uncertainty of the future Swedish nuclear capacity, and presents the impact of a nuclear phase-out by 2030. Their results show that a decommissioning of nuclear power in Sweden increases the investments in wind power and natural gas power plants, decreases the Nordic electricity production and decreases the electricity export.

The influence of various policy routes on the development of the low-carbon power technologies in the European energy system, is analysed with a TIMES model in Simoes et al. (2016). This study concludes that a decarbonisation of the electricity sector in the European Union is achievable with an increased share of renewable electricity generation, nuclear and carbon capture and storage. Further, this paper demonstrates that the investments in renewable electricity generation technologies decreases with a higher social acceptance of nuclear power plants and increases with a higher number of available sites for renewable production. The uncertain role of nuclear power, related to costs and public acceptance, is also addressed in Fais et al. (2016), that uses a TIMES model to study the impact of technology uncertainty in the decarbonisation of the United Kingdom. A conclusion from this study is that a replacement of nuclear capacity with other low-carbon electricity options does not increase the electricity generation cost significantly.

The economic impact of the interconnector between Norway and United Kingdom is analysed with EMPS in Doorman and Frøystad (2013). A conclusion from this work is that this interconnector is in general profitable from a social welfare perspective. Using the same framework, Kjetsa and Mo (2015) shows that the profitability of interconnections from Norway to Germany and the United Kingdom, and the value of the hydro flexibility, increases with uncertain fuel prices.

The outline of the paper is as follows: Section 2 sets the context of the analysis by describing long-term energy models and the energy systems in Norway and Sweden. Section 3 is devoted to the applied methodology, including a description of the TIMES model and the stochastic model approach. Section 4 describes the combination of policy actions and energy price assumptions that is used for further analyses. Finally, the results are presented in Section 5, and the conclusions and policy implications are given in Section 6.

2. Background

The purpose of this section is to set the context for our analyses. First, we categorise various long-term energy models to justify the use of TIMES in this study. Thereafter, we give a brief description of the energy systems in Norway and Sweden with focus on the electricity sector, as this sector is most sensitive for the policy actions.