Norway as a battery for the future European power system – comparison of two different methodological approaches

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Abstract. This paper compares the simulation results for two stochastic optimization power market models. EMPS uses aggregation and heuristics to calculate the optimal dispatch. SOVN simulates the operation of the power system in one large linear programming problem taking each single plant and reservoir into consideration. The comparison is for a future system in Europe where wind and solar power production supplies 61 % of the annual demand. Three different alternatives for the Norwegian hydropower system is studied: present generation capacity (about 30 GW), increased capacity to about 41 GW and further to about 49 GW. The analyses show that SOVN to a larger degree than EMPS manage to increase production in high price periods and pump in low price periods. This particularly applies to the weeks before the change from the depletion (winter) to the filling (summer) period for EMPS. This better ability to exploit the flexibility of the hydropower system is due to applying a formal optimization in SOVN compared to advanced heuristics in EMPS. For regions without pumping possibility, there is less difference between the models.

Keywords: Stochastic power market optimisation models, Increases in hydropower capacities, Pumped storage.

1 Introduction

The future European power system is expected to include large shares of variable wind and solar power resources. Reference [1] shows that Norwegian hydropower can balance part of the variability and significantly decrease peak and average power prices in neighbouring countries like UK, Germany, the Netherlands and France in 2050. The reference shows results from analyses with two stochastic optimisation models, EMPS and SOVN. Due to the application of a formal optimisation in SOVN compared to heuristics in EMPS, the hydropower system flexibility can be exploited much better. Hence, analysed with SOVN the power prices decrease more than analysed with EMPS. While [1] focus on power prices, this paper compares results from the two models related to power production, and development of energy content in reservoirs for the power system of Northern Europe in 2050.

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2 OBJECTIVE

The objective of this paper is to compare the results from two stochastic dynamic optimization models with different methodological approaches for the simulation of the power system. Previous research compared the models for the Nordic region in 2020 [2]. This paper expands the analysis to Europe in 2050 and a power system with very high shares of wind and solar resources in the production portfolio.

3 METHODOLOGY

3.1 Models

A potential future power system in Europe is analysed by two stochastic optimisation and power market simulators, EMPS [3] and SOVN [2]. Both models maximize the expected total economic surplus in the simulated system through the dispatch of generation, given a consumption profile and transmission constraints. EMPS executes two phases: the strategy and the simulation phase. In the first phase, water values are calculated as option values of the stored energy. In the second phase, the operation of the power system is optimized and simulated for the different stochastic outcomes (climatic years). The simulation procedure starts with calculating the optimal dispatch with hydropower aggregated to one plant and one reservoir per region. In a next step, the aggregated production is distributed on the individual hydropower plants based on advanced heuristics.

SOVN simulates the operation of the power system in one formal optimisation taking each single plant and reservoir into consideration in a large linear programming problem. In the following analyses, SOVN uses the same water values as EMPS.

Norway, Sweden, UK and Germany are modelled with 11, 6, 6 and 7 regions respectively, while other countries in Europe are more aggregated modelled. Reference [4] shows a full European map with all the regions. Figure. 1 shows the regions that are focused in these EMPS and SOVN analyses.

3.2 Scenario data

The EU 7th Framework project eHighway2050 scenario X-7 is used for quantification of the future European power system [5]: generation capacities per region, demand, transmission capacities between regions and fuel prices. Fig. 1 to the right shows the annual power production per generation type for the whole Europe for the X-7 scenario. The annual consumption aggregated for Europe is 4277 TWh. Wind and solar resources supply about 61% of the demand in the scenario. Wind and solar resources are Reanalysis data [6] for the period 1948 to 2005. Reference [4] describes the modelling of wind and solar data. Modelling of the Nordic hydropower system is from the EU 7th Framework project TWENTIES. The capacity in Norwegian power production is increased from its present value of ca 30 GW to ca 41 GW (11 GW extra capacity) and further to ca 49 GW (19 GW extra capacity) respectively. The inflow to

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the Nordic hydropower system is represented by 75 years of historical data. Table 1 shows the increases distributed on four EMPS/SOVN regions in southern Norway (see Fig. 1).

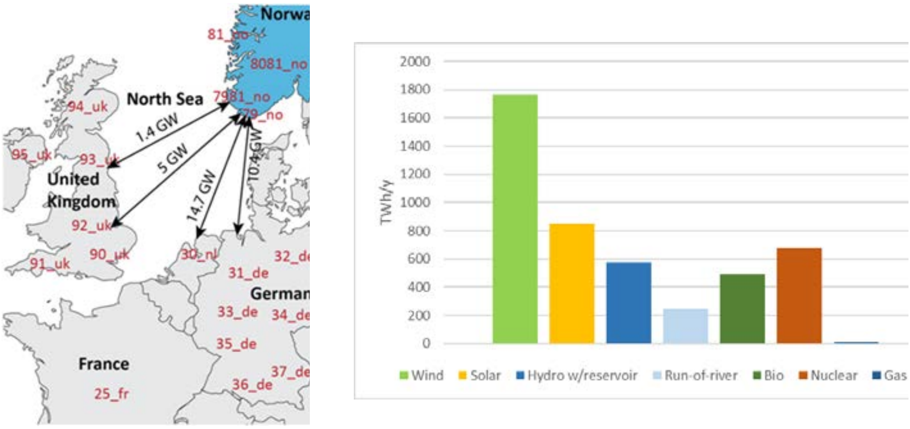

Fig. 1 To the left: EMPS and SOVN regions mainly focused in these analyses. To the right: yearly power production per technology eHighway2050 X-7 scenario, EMPS analysis.

Table 1 Increases in hydro generation capacities in four Norwegian regions

EMPS/SOVN region (see Figure 1)	Present capacity [GW]	New capacity 11 GW [GW]	Pump capacity 11 GW [GW]	New capacity 19 GW [GW]	Pump capacity 19 GW [GW]
79_no	4.1	7.6	1.4	8.3	1.4
7981_no	3.6	7.8	2.1	10.1	3.4
81_no	5	7.9	0	8.5	0
8081_no	2.1	3.1	1	6.3	4.4
TOTAL	14.8	26.4	4.5	33.2	9.2

4 RESULTS

The paper compares EMPS and SOVN results related to: i) Production at aggregated level (region) and for a single plant and ii) Reservoir handling at aggregated level. Fig. 2 shows hydropower production in two regions, 79_no and 81_no, averaged hour-by-hour for 75 climatic years. The regions 7981_no and 8081_no have similar patterns as 79_no. For these three regions, the resulting production patterns are significant different for EMPS and SOVN. SOVN pumps much more than EMPS in periods with low prices. Due to the pumping, there is more energy available for production in high price periods. Furthermore, as shown in Fig. 2, there are small differences between EMPS and SOVN production patterns for region 81_no, as there is no pumping capacity in the region (see Table 1). Thus, there is no extra flexibility. However, for

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region 81_no we observe that SOVN produces more in the winter and less in the summer than EMPS. EMPS has less production in the late winter due to its seasonal heuristic approach.

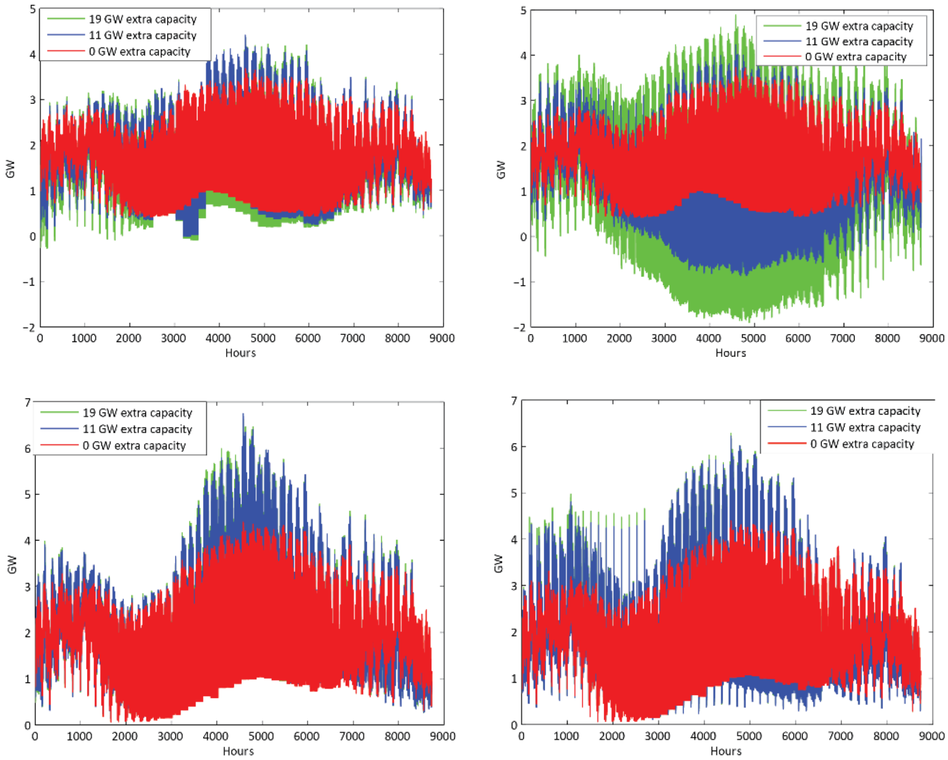

Fig. 2 Average production hour-by-hour in 79_no (upper row) and 81_no (lower row) with increased hydropower capacities for 75 simulation years, EMPS (left) and SOVN (right) results

Fig 3 shows the hydropower production for the Kvilldal plant EMPS and SOVN results.

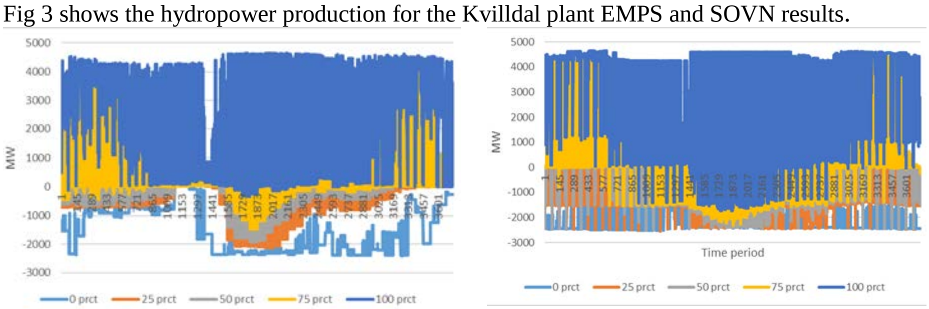

Fig 3. Percentiles for hydropower production for Kvilldal plant in region 7981_no, time period-by-time period for 75 simulation years, EMPS results to the left and SOVN results to the right Generation capacity increased to 4.6 GW (19 GW increase in Norway). New pump capacity with 2.4 GW. Capacity of upstream reservoir: 237 MM3.

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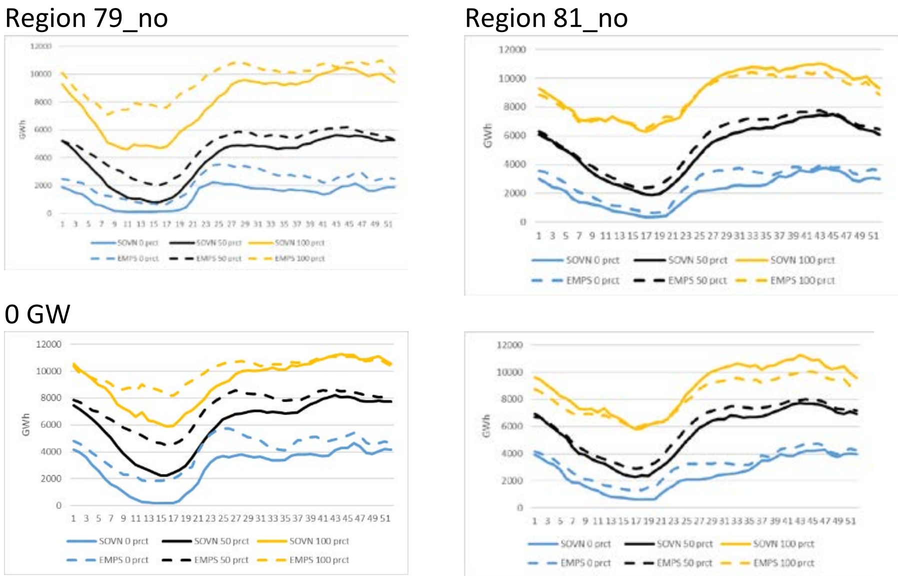
One important difference between SOVN and EMPS, is that EMPS hardly pumps in the winter months. In the winter months, there is limited inflow to the reservoirs. According to the heuristic in EMPS, the reservoirs are depleted such that the relative water values for reservoirs in the same river system are approximately the same. With limited difference in water values for reservoirs, there will not be any pumping. However, in the summer, when there is significant inflow to the reservoirs but only minor production, pumping is used in EMPS to avoid spillage from the reservoirs.

Fig. 4 shows the 0, 50 and 100 percentiles for development of the energy content in reservoirs for EMPS and SOVN for the regions 79_no and 81_no.



19 GW extra capacity in Norway, 4,2 GW extra in 79_no, 1,4 GW pumping

19 GW extra capacity in Norway, 3,5 GW extra in 81_no, no pumping

Fig. 4. Percentiles for reservoir development region 79_no and 81_no week-by-week for 75 simulations years, EMPS and SOVN analysis

For region 79_no we observe that the energy content in the aggregated reservoir increase with increased hydro generation capacity. For EMPS, there will be less probability for overflow with increased capacity. Thus, more water can be stored in the reservoirs and the energy content increases. For 79_no the pump capacity increases from the 0 to the 19 GW case. SOVN pumps in periods with low prices, and the energy content increases. For 79_no, the largest difference in reservoir level between EMPS and SOVN is around the weeks where EMPS change seasonal strategy and goes from depletion (winter) to filling (summer). In the last weeks of the depletion period, EMPS will have limited water left in reservoirs upstream to plants with increased capacity. All reservoirs are depleted in such a way that they have about the same risk of spillage in the coming spring (melting) inflow period. SOVN will, if

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possible, distributed water between reservoirs in such a way that there is water available upstream to plants with increased capacity. Thus, SOVN can produce more in the weeks before the melting starts (about week 17), and the energy content in the reservoirs will be lower. SOVN uses in these analysis water values from EMPS. These values are too low for SOVN for the 79_no 0 GW case. The reservoirs are empty in long periods (the 0 percentile). Region 81_no does not have any pumping capacity. For this region, there is less difference in development of energy content between EMPS/SOVN, than for 79_no with pumping capacity.

5 CONCLUSIONS

This study compares analysis results from two different stochastic optimization models: EMPS and SOVN. The analyses show that SOVN to a larger degree than EMPS manage to increase production in high price periods and pumping in low price periods. This particularly applies to the weeks before the change from the depletion to the filling period. This better ability to exploit the flexibility of the hydropower system is due to applying a formal optimization in SOVN compared to advanced heuristics in EMPS. Power production particularly increases in high price periods with SOVN compared to EMPS for regions with pumping capacity. For a region without pumping capacity there is less differences between the models.

REFERENCES

[1] Graabak I, Korpaas M, Jaehnert S, and Belsnes M, "Balancing future variable wind and solar power production in Northern Europe with Norwegian hydro power," *Submitted to a journal*, 2017.

[2] Helseth A, Mo B, Henden A, and Warland G, "Detailed Long-Term Hydro-Thermal Scheduling For Expansion Planning in the Nordic Power System," *IET Research Journals.*, 2017. ISSN 1751-8644.

[3] Wolfgang O, Haugstad A, Mo B, Gjelsvik A, Wangensteen I, and Doorman G, "Hydro reservoir handling in Norway before and after deregulation," *Energy*, vol. 34, pp. 1642-1651, 2009.

[4] Graabak I, Jaehnert S, Korpås M, and Mo B, "Norway as a Battery for the Future European power system - Impacts on the Hydropower System," *Energies. Special Issue. Hydropower 2017.*

[5] Bruninx K, Orlic D, Couckuyt D, Grisey N, Betraoui B, and Anderski T et. al, "D 2.1 Data sets of scenarios for 2050," 2015, Available: http://www.e-highway2050.eu/results/ (Accessed June 2017).

[6] Kalnay E, Kanamitsu M, Kistler R, Collins W, Deaven D, and Gandin L et.al, "The NCEP/NCAR 40-year reanalysis project. ," *Bull. Amer. Soc., 77, 437-470*, 1996.

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