# Electricity Prices and Value of Flexible Generation in Northern Europe in 2030

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*Abstract*— **The aim of this paper is to quantify the value of flexible power generation technologies in Northern Europe in 2030, and in particular hydropower with storage. Two scenarios for the European power system in 2030 are presented. The study uses a fundamental hydrothermal power system model for the combined North- and West-European power system. The model gives optimal operation of the system, including operation strategies for individual hydro reservoirs, dispatch of power plants and simulated power prices. The results show power generation, income and realized power prices for a selection of hydropower and gas power plants, as well as wind and solar power. It is demonstrated that the value of flexible power generation increases with increasing shares of variable renewables in the power system, even if the average prices are reduced.**

***Index Terms*— Fundamental market models, Hydroelectric-thermal power generation, Power generation planning, Power system economics, Power system simulation.**

## I. INTRODUCTION

Variable renewable energy (VRE) such as wind and photovoltaic solar is growing rapidly and is expected to constitute a large share of the future European power system in 2030. Higher penetration of VRE increases the variability in residual load and introduces new challenges in planning and operation of the power system. VRE has diurnal- and/or seasonal patterns, and the generation patterns are often non-coincident with the load pattern [1]. Larger shares of VRE, with low or no ability to adjust generation to demand, means that other sources of flexibility are required to ensure continuous balance in the system. A generation mix with more VRE gives a supply curve that can vary substantially between time periods, giving large variations in the power price. VRE has close to zero marginal generation costs. Hence, in periods with high generation from VRE, the power price will fall towards zero and even below zero in systems with production-based subsidies. In periods with low generation from VRE, the power price will increase. In such periods, the power price is given by the cost of the marginal generation unit, demand elasticity or the price of curtailment.

Flexibility is in [2] defined as: *"the ability of a resource, whether any component or collection of components of the power system, to respond to known and unknown changes in power system conditions at various operational timescales"*. In this study we focus on the active power flexibility provided by power generation and storage units in the system. The needs for flexibility in power systems with high penetration of VRE are much discussed in recent literature [3]-[6]. Hydropower is a reliable and cost-efficient supplier of flexibility and energy storage [7]. The Nordic region holds about half of the total hydro storage capacity in Europe with about 85 TWh of storage. Studies have shown that Nordic hydropower can provide large-scale flexibility services to continental Europe, and a significant impact on the operation of the European power system and peak power prices have been demonstrated [8], [ 9].

This paper focuses on the realized value of flexible generation units in the wholesale market. Power market structures and prices are highly uncertain in the long-term perspective. To evaluate the value of flexibility seen in the power market, it is necessary to develop scenarios for the future using a fundamental market model. Previous studies of the North-European power system in year 2030 that include detailed modelling of the Nordic hydropower system assess the transmission grid needed to balance European wind power with Nordic hydropower [10] and the effect of long-term variability of VRE on the profit of power plants [11]. The contribution of this paper is to quantify the value of the flexibility needed to balance generation and load in systems with increasing shares of VRE in two scenarios for year 2030. The impact of larger shares of VRE on the power prices and the corresponding changes in income for flexible generation technologies, in particular hydropower with storage, are assessed. The main differences compared to previous work are: (1) results are given for specific hydropower plants and gas power plants with different characteristics, (2) the focus is on flexible generation technologies, and (3) updated scenarios for the European power system in year 2030 are used based on recent political targets. The hypothesis is that the value of flexible generation is higher in a power system with higher shares of VRE. Two scenarios for the European power system in 2030, with different shares of VRE, are used. The realized power prices for a selection of different individual hydropower plants with storage, gas power plants and

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intermittent renewables in the Nordic region, Germany and Great Britain are presented for both scenarios.

The paper is structured as follows. First the method is presented in section II, including a short description of the long-term model and scenarios. Then the main results from the analysis are presented in section III, and further discussed in section IV. Finally, the paper is concluded in section V.

## II. METHOD

### A. Long-term strategic model (EMPS)

The study uses a fundamental hydrothermal power system model for the combined North- and West-European power system, called EMPS (Elektrisitetsforsyningens Forskningsinistitutt's Multi area Power market Simulator) [12]. The model is applied to price forecasting and power system studies by almost all major players in the NordPool marked area. It is a stochastic optimization model that maximizes the expected total socioeconomic surplus for the modelled electricity system. The model includes more than thousand reservoirs, cascaded water courses and power plant characteristics such as storage and turbine capacity, efficiency curves, head dependencies and minimum flow restrictions. Thermal power units are modelled with capacity, efficiency, $CO_2$-emissions and start-up costs. The model is stochastic and uncertainties about the future will affect decisions made today. The combined weather uncertainty in space and time is accounted for using 58 historical weather years. The weather years represent uncertainty and natural variation in inflow, wind and solar power generation, and temperature that affect the load. Hourly wind and solar resources are calculated based on Reanalysis data from 1948 to 2005 with a spatial resolution of 2.5 degrees both in latitude and longitude [13]. The problem is dynamic mainly due to reservoir storages but also in the short run due to start-up costs of thermal units. The model has a temporal resolution of three hours and include 53 onshore and offshore price areas that are modelled in detail. The spatial resolution in the model is highest in the Nordic region, Germany (DE) and Great Britain (GB) where each country is divided into several areas.

The main strength of the model is the large-scale, detailed modelling of hydropower with storages. Determining the optimal strategy for operation of hydropower storages is a very complex problem due to limited availability of water and uncertain demand and inflow. Inflows to hydropower reservoirs in the Nordic system have large yearly and seasonal variations. The goal is to find a strategy for operation of the reservoirs that maximize the annual profits, i.e. that uses the water to generate electricity when the prices are the highest. Hydropower has very low operational costs. Still, the option to store water for later use, gives an alternative cost of using water. The alternative cost is called the water value and represents the expected future value that can be achieved if the water is stored for later use. Flexible hydropower plants generate when the market price is higher than the water value.

EMPS calculations consist of two phases: First, in the strategy phase, water values for an aggregate hydro model in each modelled area are calculated using stochastic dynamic programming. Secondly, in the simulation phase, the whole system is simulated for the different weather years using the calculated water values as the marginal cost of hydropower generation. A heuristic is used in the simulation phase to ensure that generation in the aggregated hydro model is feasible for the detailed hydro system model.

### B. Scenarios

Two scenarios for the European power system for year 2030 have been developed as part of this work. The areas included in the model are given in Fig. 1. The main difference between the scenarios is the installed VRE capacity in Europe. In scenario 1 (Scen. 1), the VRE capacity is based on the EUCO30 scenario [14], while in scenario 2 (Scen. 2) the assumed VRE capacity is based on more recent political targets and commitments in Europe [15]. About 20 TWh of wind power generation and 5 TWh of solar power generation have been added to the Nordic region in scenario 2 compared to scenario 1. Furthermore, about 35 GW wind power and 90 GW of solar power generation capacity have been added in the rest of Europe from scenario 1 to scenario 2, and coal-based generation capacity in Germany has been reduced with about 50%. In addition, the transmission capacity is increased with 1,400 MW between Norway and Germany (NO-DE) and 1,400 MW between Norway and Great Britain (NO-GB). This gives a share of 47% renewable power generation and a share of 23% VRE for the whole modelled system in scenario 1. In scenario 2, this has increased to 54% renewable power generation and 30% generation from VRE. Fig. 2 shows the consumption and power generation mix for selected countries in scenario 2.

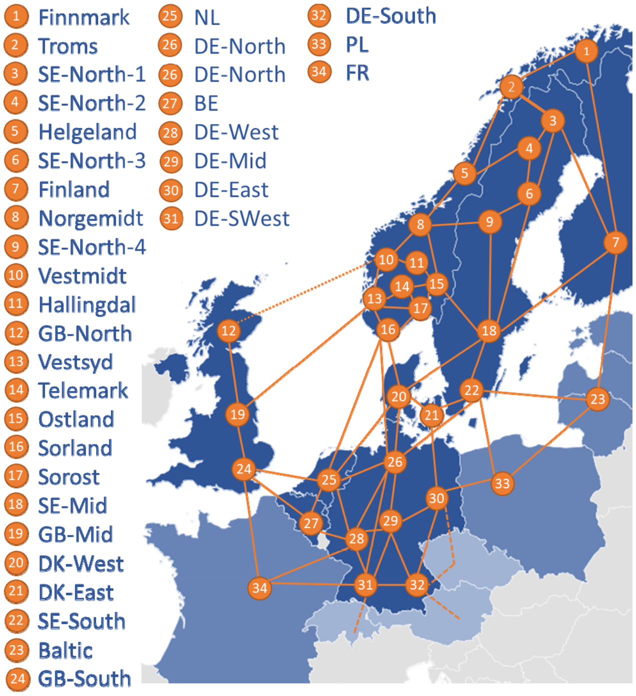

Figure 1. The modelled areas and interconnectors

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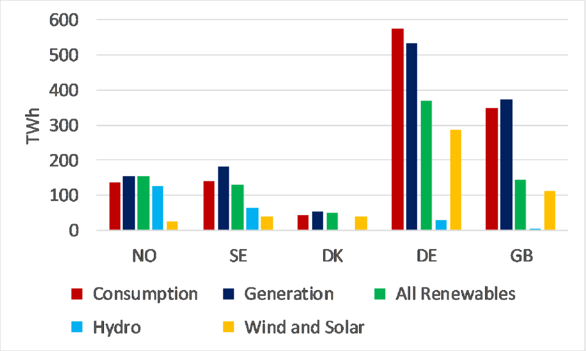

Figure 2. The power generation mix in scenario 2 for selected countries

The remaining assumptions for year 2030 are equal in both scenarios. This includes assumptions for demand, thermal generation capacity (except for Germany), the hydropower system, transmission capacity between the areas (excluding NO-DE and NO-GB), fuel prices and the $CO_2$-price. Nuclear power is assumed decommissioned in Germany in 2030 but remains an important generation technology in several countries, such as Great Britain. With a substantial amount of other thermal power generation remaining in the system, fuel- and $CO_2$-prices still have an important impact on the power prices. In the scenarios, the $CO_2$-price is 30 €/ton, the fuel price for gas is 20 €/MWh and for coal 70 \$/ton. Demand is assumed to be price independent. In the Nordic region, the demand is temperature dependent. Thermal power generation or curtailment will be setting the price in continental Europe in hours with high demand and low generation from VRE. The curtailment price is set to 300 €/MWh.

### C. *Assessing the value of flexibility*

The average realized power prices of individual power plants and technologies are used to assess the value of flexibility. The realized power price is the average price per unit of energy a given power station or technology achieve over a defined time period. The performance of a plant or technology refers to the percentwise difference in the realized power price for a plant or technology compared to the average power price in the same area. The performance is used as a measure of how flexible a plant or technology is to adjust generation to variations in the power price. In our case the calculated values are based on the average of 58 simulated weather years.

The gas power plants used in this assessment are combined cycle (CC) plants with relatively high efficiency that are located in several different countries, as given in Table I. The selected hydropower plants are highly flexible plants from Norway and Sweden with different sizes. For comparison, one non-flexible hydropower plant, Sagnfossen, is also included. Some important characteristics of the hydropower plants are given in Table II and III. The ability of a hydropower plant to operate flexible depends on the plant's degree of regulation and the capacity factor. The degree of regulation (the reservoir volume divided by the average yearly inflow) is a measure of the plants capability to store water and to deliver long-term flexibility. The capacity factor is the average power generated, divided by the rated peak power. Hydropower plants with a high degree of regulation combined with a low capacity factor have a high ability to deliver flexibility. Still, the characteristics of the hydropower plants do not give a complete picture of the complexity in the hydropower system. Plants located far down in a cascaded hydro system receive discharge water from stations higher up in the system in addition to the local inflow. A plant with low local inflow or a small reservoir can therefore have an operational profile well-adjusted to the power price, depending on the operation of the plants and reservoirs higher up in the system. Often all the plants in the system are operated by the same owner, hence the operation of the whole hydro system will be considered in the same optimisation problem.

Table I. CHARACTERISTICS FOR A SELECTION OF THE GAS POWER PLANTS INCLUDED IN THE MODEL

| **Plant** | **Type** | **Location (area)** | **Capacity** | **Marginal cost** |
|---|---|---|---|---|
| | | | ***[MWel]*** | ***[€/MWh]*** |
| Gas 1 | CC | DE-South | 1,079 | 42.5 |
| Gas 2 | CC | DE-Mid | 377 | 42.9 |
| Gas 3 | CC | GB-South | 1,240 | 39.5 |
| Gas 4 | CC | GB-Mid | 4,134 | 40.8 |
| Gas 5 | CC | SE-Mid | 424 | 39.1 |
| Gas 6 | CC | DK-West | 942 | 56.1 |

TABLE II. INFLOW AND RESERVOIR CHARACTERISTICS FOR A SELECTION OF THE HYDROPOWER PLANTS INCLUDED IN THE MODEL

| **Plant** | **Location (area)** | **Local inflow** | **Reservoir capacity** | **Degree of regulation** |
|---|---|---|---|---|
| | | ***[mm3/yr]*** | ***[mm3]*** | ***[%]*** |
| Saurdal | Vestsyd | 1,143 | 3,105 | 309 |
| Aurland 3 | Vestmidt | 165 | 448 | 310 |
| Duge | Sorland | 516 | 1,398 | 298 |
| Sagnfossen | Ostland | 2,246 | 0 | 0 |
| Ritsem krv | SE-North-1 | 1,230 | 640 | 128 |

Table III. TURBINE CHARACTERISTICS FOR A SELECTION OF THE HYDROPOWER PLANTS INCLUDED IN THE MODEL

| **Plant** | **Location (area)** | **Turbine capacity** | | **Capacity factor** |
|---|---|---|---|---|
| | | ***[m3/s]*** | ***[MW]*** | ***[%]*** |
| Saurdal | Vestsyd | 173 | 640 | 27 |
| Aurland 3 | Vestmidt | 80 | 270 | 14 |
| Duge | Sorland | 100 | 200 | 22 |
| Sagnfossen | Ostland | 75 | 6 | 65 |
| Ritsem krv | SE-North-1 | 240 | 341 | 19 |

## III. RESULTS

The resulting total power generation, total income, realized power price and performance for the different power plants in scenario 1 and scenario 2 are given in Table IV. Examples of simulated power prices for scenario 2 are illustrated in Fig. 3 and 4.

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Table IV. RESULTS FOR SELECTED HYDROPOWER AND GAS POWER PLANTS IN THE TWO SCENARIOS

| **Plant** | **Type** | **Total generation [GWh/yr]** | | **Total income [k€/yr]** | | **Realized power price [€/MWh]** | | **Performance [%]** | |
|---|---|---|---|---|---|---|---|---|---|
| | | ***Scen. 1*** | ***Scen. 2*** | ***Scen. 1*** | ***Scen. 2*** | ***Scen. 1*** | ***Scen. 2*** | ***Scen. 1*** | ***Scen. 2*** |
| Saurdal | Hydro | 1,531 | 1,492 | 67,716 | 64,887 | 44.2 | 43.5 | 5 | 10 |
| Aurland 3 | Hydro | 326 | 313 | 14,351 | 13,446 | 44.0 | 43.0 | 6 | 11 |
| Duge | Hydro | 393 | 372 | 17,689 | 16,569 | 45.0 | 44.5 | 7 | 15 |
| Sagnfossen | Hydro | 35 | 35 | 1,450 | 1,340 | 41.1 | 38.0 | -3 | -4 |
| Ritsem krv | Hydro | 516 | 517 | 21,204 | 20,420 | 41.1 | 39.5 | 4 | 7 |
| Gas 1 | Gas CC | 3,921 | 3,410 | 197,118 | 186,496 | 50.3 | 54.7 | 9 | 19 |
| Gas 2 | Gas CC | 1,460 | 1,292 | 79,639 | 79,984 | 54.6 | 61.9 | 17 | 34 |
| Gas 3 | Gas CC | 9,045 | 7,912 | 394,053 | 346,234 | 43.6 | 43.8 | 3 | 9 |
| Gas 4 | Gas CC | 25,581 | 20,822 | 1,117,866 | 920,088 | 43.7 | 44.2 | 4 | 11 |
| Gas 5 | Gas CC | 2,569 | 1,844 | 110,683 | 79,112 | 43.1 | 42.9 | 6 | 12 |
| Gas 6 | Gas CC | 1,392 | 1,236 | 79,360 | 71,287 | 57.0 | 57.7 | 27 | 45 |

For most of the power plants, the results show that the total generation and income in scenario 2 is lower than in scenario 1. The total power generation is 0% to 5% lower for the hydropower plants and 11% to 28% lower for the gas power plants. The total income is reduced with 4% to 6% for the flexible hydropower plants and 0% to 29% for the gas power plants. The only exception is the Gas 2 power plant, that has slightly higher income in scenario 2 than in scenario 1.

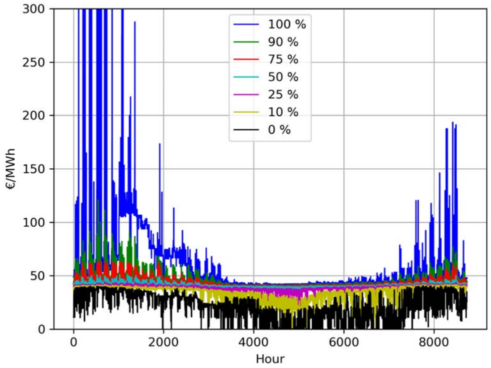

Figure 3. Percentiles of the simulated power price in the Ostland area in Norway for scenario 2

The performance of the flexible power plants, which is a measure of the added value of flexibility, is 3% to 27% in scenario 1 and 9% to 45% in scenario 2. The German and Danish gas power plants have the highest realized power prices and the highest added value of flexibility in both scenarios. This is a result of the power prices in these countries, which are very volatile and with several occurrences of high peak prices. Comparing the scenarios, the added value of flexibility increases with 5-18% from scenario 1 to scenario 2 for the gas and hydropower plants. The realized power price is 1% to 4% lower in scenario 2 than in scenario 1 for the flexible hydropower plants and 8% lower for the inflexible hydropower plant. For the gas power plants, the realized power price increase with 0% to 13% in scenario 2 compared to scenario 1. However, for the Gas 5 power plant the realized power price decreases slightly.

Table V shows the realized power prices for wind and solar power in the areas where the flexible power plants are located and for the countries discussed in this study. The realized power prices for wind and solar power are quite similar for most areas in scenario 1, with a variation of 1% to 4% between the technologies. In some areas wind power has a slightly higher realized power price than solar power, while in other areas it is the opposite. In scenario 2, the difference between the two technologies becomes larger. In this scenario, wind power has a realized power price that is 1% to 15% higher than solar power. An exception is the overall realized price for wind power in Great Britain and Denmark. Large installed wind power capacities in parts of these countries cause the realized power price for wind to collapse, significantly pulling down the realized power prices for wind power in these countries.

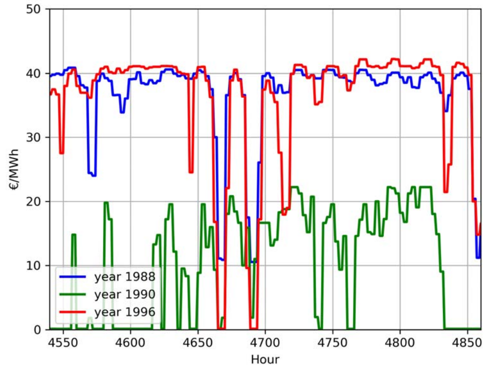

Figure 4. The simulated power price in two summer weeks for three historical weather years in the Ostland area in Norway for scenario 2

Table VI shows the performance of wind and solar power in the same areas. The performance of both wind and solar power is lower in scenario 2 than scenario 1, when the shares of VRE are higher. However, the reduction in performance is much larger for solar power, implying that there is a large surplus of energy in hours with high generation from solar in the studied areas.

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Table V. REALIZED POWER PRICE FOR WIND AND SOLAR POWER GENERATION IN SEVERAL AREAS

| Area | Wind power | | Solar power | |
|---|---|---|---|---|
| | *Scen. 1* | *Scen. 2* | *Scen. 1* | *Scen. 2* |
| DE-South | 41.4 | 38.3 | 40.7 | 33.3 |
| DE-Mid | 40.8 | 37.1 | 41.2 | 34.6 |
| GB-South | 39.5 | 35.3 | 41.2 | 34.8 |
| GB-MID | 41.5 | 38.7 | 40.8 | 34.4 |
| Sorland | 41.3 | 36.9 | 40.8 | 34.0 |
| Vestsyd | 41.5 | 38.4 | 40.8 | 35.5 |
| Vestmidt | 41.3 | 38.1 | 40.1 | 34.9 |
| Ostland | n.a. | n.a. | 40.9 | 35.7 |
| SE-Mid | 39.5 | 36.4 | 39.7 | 34.9 |
| SE-North-1 | 38.2 | 35.4 | 38.2 | 33.8 |
| DK-West | 40.6 | 30.6 | 41.1 | 33.6 |
| Germany | 41.1 | 37.5 | 41.1 | 34.2 |
| Great Britain | 34.4 | 31.1 | 39.3 | 32.6 |
| Norway | 40.6 | 37.5 | 40.7 | 35.2 |
| Sweden | 38.3 | 35.3 | 39.0 | 34.4 |

## IV. DISCUSSION AND FURTHER WORK

We have in this study done an assessment of the value of flexibility in the wholesale market for power generators. The results show an improved value of flexibility for all the flexible power generation technologies with increasing shares of VRE. There are some differences in the performance between the different types of flexible power plants mainly related to their locations. Higher shares of VRE are giving periods with low power prices that are pushing the average power price down, especially in central Europe. Similarly, shortage of generation capacity in periods are giving hours with high peak prices. However, limited transmission capacity reduces the impact of these periods on power prices in Norway. This gives less price variations and consequently less value of flexibility in Norway. Because power prices vary between the areas, the results cannot be directly compared between plants in different locations.

TABLE VI. PERFORMANCE OF WIND AND SOLAR POWER PLANTS

| Area | Wind power | | Solar power | |
|---|---|---|---|---|
| | *Scen. 1* | *Scen. 2* | *Scen. 1* | *Scen. 2* |
| DE-South | -10 % | -16 % | -12 % | -27 % |
| DE-Mid | -12 % | -20 % | -11 % | -25 % |
| GB-South | -7 % | -12 % | -3 % | -13 % |
| GB-MID | -1 % | -3 % | -3 % | -13 % |
| Sorland | -2 % | -5 % | -3 % | -12 % |
| Vestsyd | -1 % | -3 % | -3 % | -10 % |
| Vestmidt | 0 % | -1 % | -3 % | -10 % |
| Ostland | n.a. | n.a. | -4 % | -10 % |
| SE-Mid | -3 % | -5 % | -3 % | -8 % |
| SE-North-1 | -4 % | -4 % | -4 % | -9 % |
| DK-West | -9 % | -23 % | -8 % | -16 % |
| Germany | -11 % | -19 % | -11 % | -26 % |
| Great Britain | -15 % | -18 % | -1 % | -18 % |
| Norway | -1 % | -2 % | -3 % | -10 % |
| Sweden | -4.8 % | -6.0 % | -2.9 % | -8.5 % |

The realized power prices for different technologies are closely related to the penetration of VRE. When the shares of VRE become large enough to cover demand in several hours, the power price is being pushed towards zero as there is no need for other power generation technologies (with higher marginal costs) to produce. As a result, the realized power prices for wind and solar power plants will eventually decrease as larger amounts of variable renewables are integrated into the power system. Still, the income potential of VRE technologies also depend on other factors, such as the correlation between intermittent generation and demand. In this study there are significant differences in realized power prices between VRE technologies, which are a result of differences in correlation with simulated prices and the degree of penetration of VRE in the different areas.

The measure for value of flexibility used in this study considers the income and realized power price from power generation in a single market based on a three-hour time resolution. Using finer temporal resolution and including several markets, such as balancing markets, is expected to increase the value of flexibility in both scenarios. Furthermore, the fundamental market model does not include demand flexibility. Realistic modelling of demand flexibility would reduce price variation and the value of flexibility somewhat. In addition, other costs than production dependent (variable) costs, such as maintenance costs, are not included in the modelling. Changed operational patterns can impact the maintenance costs of the plants differently and therefore also the profitability of providing flexibility. The associated costs and profitability of delivering flexibility for different technologies are interesting topics for further studies. Finally, in general, power system models always find more optimal solutions than what is seen in the real world and therefore underestimate price variation and the value of flexibility.

## V. CONCLUSION

In this study the income and realized power prices of different generation technologies have been calculated for two different European power systems in year 2030. The added value of flexible operation has been quantified for selected power plants with different characteristics. The realized power prices of wind and solar power plants as well as Nordic hydropower generation decrease with increasing shares of VRE. The realized power prices for gas power plants in continental Europe increase. Still, the performance, the value of flexibility, increase for all flexible power plants with increasing shares of VRE. The realized power prices of different technologies and the value of flexibility are shown to be closely related to the penetration of VRE.

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## REFERENCES

[1] Graabak, I., and Korpås, M. "Variability Characteristics of European Wind and Solar Power Resources-A Review", Energies, vol. 9, pp. 1-31, June 2016.

[2] Ela, E., Milligan, M., Bloom, A., Botterud, A., Townsend, A., Levin, T., and Frew, B. A., "Wholesale electricity market design with increasing levels of renewable generation: Incentivizing flexibility in

This is the accepted version of an article published in 2019 16th International Conference on the European Energy Market - EEM 2019
DOI: 10.1109/EEM.2019.8916390

system operations", The Electricity Journal, vol. 29, pp. 51-60, May 2016.

[3] Alizadeh, M. I., Moghaddam, M. P., Amjady, N., Siano, P., and Sheikh-El-Eslami, M. K., "Flexibility in future power systems with high renewable penetration: A review", Renewable and Sustainable Energy Reviews, vol. 57, pp. 1186-1193, May 2016.

[4] Kondziella, H., and Bruckner, T., "Flexibility requirements of renewable energybased electricity systems--a review of research results and methodologies", Renewable and Sustainable Energy Reviews, vol. 53, pp. 10-22, 2016.

[5] Graabak, I., Korpås, M., and Belsnes, M., "Balancing needs and measures in the future West Central European power system with large shares of wind and solar resources", 14th International Conference on the European Energy Market, Dresden: IEEE, pp. 1-6, 2017

[6] Huber, M., Dimkova, D., and Hamacher, T., "Integration of wind and solar power in Europe: Assessment of flexibility requirements", Energy, vol. 69, pp. 236-246, 2014.

[7] Gaudard L., and Romerio F., "The future of hydropower in Europe: Interconnecting climate, markets and policies", Environmental Science & Policy, vol. 37, pp. 172-181, 2014, ISSN 1462-9011, https://doi.org/10.1016/j.envsci.2013.09.008.

[8] I. Graabak, S. Jaehnert, M. Korpås & B. Mo, "Norway as a Battery for the Future European power system - Impacts on the Hydropower System", Energies*,* vol 10, December 2017.

[9] I. Graabak, M. Korpås, S. Jaehnert, and M. Belsnes, "Balancing future variable wind and solar power production in Central-West Europe with Norwegian hydropower", Energy, vol. 168, pp. 870-882, 2017, ISSN 0360-5442, https://doi.org/10.1016/j.energy.2018.11.068.

[10] Farahmand, H., Jaehnert, S., Aigner, T., and Huertas-Hernando, D., "Nordic hydropower flexibility and transmission expansion to support integration of North European wind power", Wind Energy, vol. 18, pp. 1075-1103, 2014

[11] Jaehnert, S., Korpås, M., Doorman, G., and Hyldbakk, I. M., "On the profit variability of power plants in a system with large-scale renewable energy sources," 12th International Conference on the European Energy Market (EEM), pp. 1-5. Lisbon, 2015, doi:10.1109/EEM.2015.7216657

[12] 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.

[13] Graabak, I., Svendsen, H., and Korpås, M., "Developing a wind and solar power data model for Europe with high spatial-temporal resolution," in UPEC 2016, Coimbra Portugal, 978-1-5090-4650-8/16/$31.00, 2016 IEEE, http://hdl.handle.net/11250/2433457.

[14] E3M Lab & IIASA, "Technical report on Member States results of the EUCO scenarios", December 2016. [Online]. Available: https://ec.europa.eu/energy/sites/ener/files/documents/20170125_-_technical_report_on_euco_scenarios_primes_corrected.pdf

[15] 2030 Energy strategy. [Online]. Available: https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/2030en-ergy-strategy , (accessed May 2019)

This is the accepted version of an article published in 2019 16th International Conference on the European Energy Market - EEM 2019
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