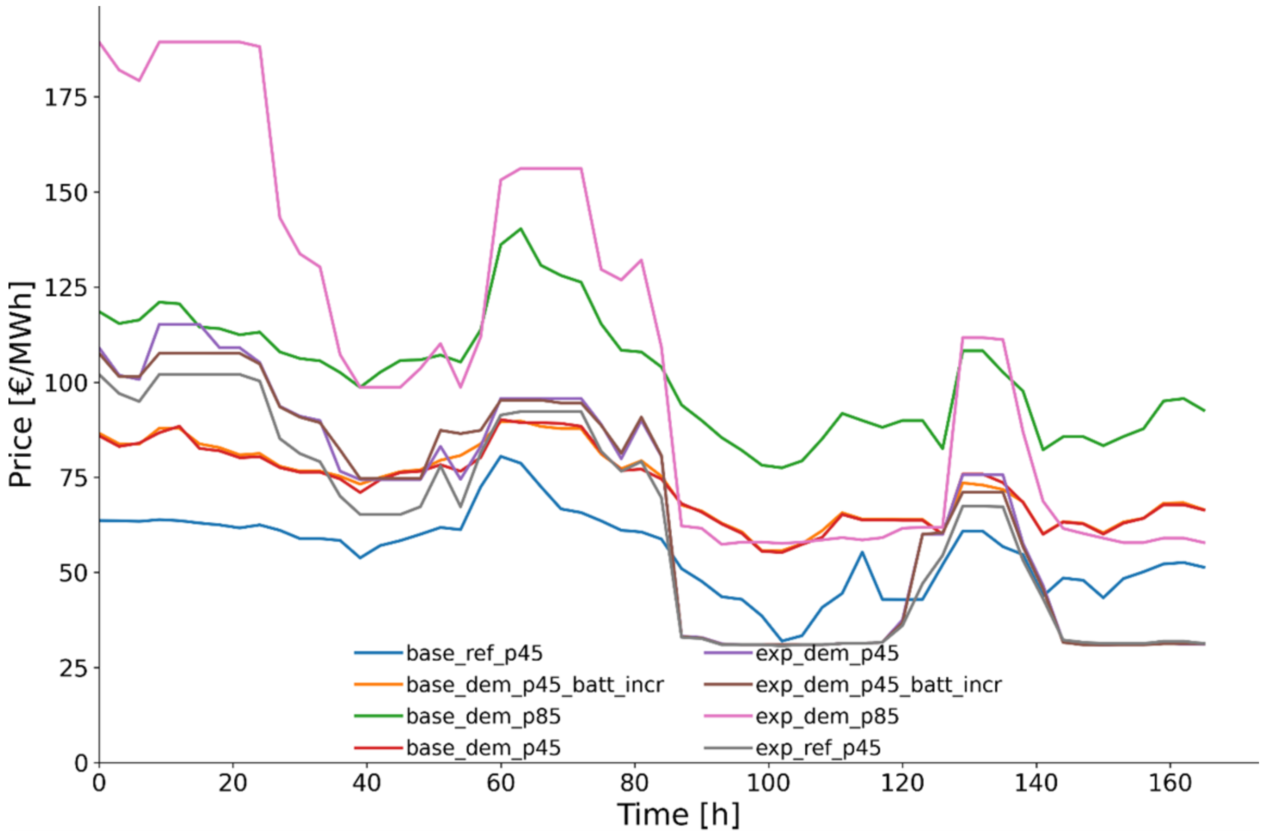
RenewHydro

Forskningssenter for miljøvennlig energi

RenewHydro Report 1

Simulated power prices in previous research projects:

Scenario overview and file access for RenewHydro



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RenewHydro

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RenewHydro has around 40 national and international partners from research, industry, and public administration.

RenewHydro is one of the centres under the Research Council of Norway’s scheme for Centres for Environment-friendly Energy Research (FME).

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Summary

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This report provides an overview of simulated power price data generated by the FanSi and EMPS models in the research projects SumEffect and HydroConnect. While SumEffect represents a power system that is still influenced by fossil fuels in 2030, HydroConnect represents a renewable scenario for 2050. All price data are open and uploaded to a RenewHydro web page.

In this report we also describe the scenario assumptions, present sample outputs, explain how the files are organized and stored, and offer guidance on how they may be used for future analyses within the centre.

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Abstract

Wolfgang, O. 2025. Researcher. Simulated power prices in previous research projects: Scenario overview and file access for RenewHydro. RenewHydro Report No. 1. Norsk forskningssenter for fornyelse av vannkraft.

Simulated power price data from the FanSi and EMPS models—produced for the HydroConnect and SumEffekt projects—are open and uploaded to a FME RenewHydro web page. This report outlines the file structure, storage locations, and naming conventions used. It also provides brief descriptions of the two projects, covering their objectives, methodologies, scenario assumptions, and sample results.

The simulated prices vary across scenarios and between projects, reflecting a transition from a fossil- influenced energy system in 2030 (SumEffekt) to a highly renewable system in 2050 (HydroConnect). Future work may include new RenewHydro-specific scenarios or post-processing adjustments to better align simulated prices with desired characteristics.

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Foreword

From our experience in previous research projects, we have seen that simulated future power prices are often a needed—or even essential—input for various activities related to energy and power markets. We believe this is also the case within FME RenewHydro. The importance of this topic is reflected in the structure of the FME, where this report is part of "FP3 Future Power Price Dynamics".

By making price simulations from earlier projects available through a web page, and by documenting the corresponding scenarios and file naming conventions in this report, our aim is to provide a practical starting point for other project activities that require power price inputs.

Going forward, we consider following up either by developing new RenewHydro-specific scenarios and price simulations or by evaluating a methodology for scaling price series to reflect anticipated future price variability.

Trondheim, 24th June 2025, Ove Wolfgang

1 Introduction

Several activities within FME RenewHydro require future power prices as input, for example assessing the profitability of investments in new generation capacity or pumping facilities. As part of FP3 Future Power Price Dynamics, we provide simulated future power prices that can serve as input to these activities. Several earlier research projects have already developed future power price scenarios for Norway and Europe. Since these remain relevant, we begin by making them available for RenewHydro.

The power price data from the following two former projects have been uploaded to the RenewHydro web page:

1. HydroConnect
2. Nye miljørestriksjoner – samlet innvirkning på kraftsystemet (hereafter referred to as SumEffekt)

The reports present the two projects in chapter 2 and 3 respectively, including their aims, methods, scenarios, and example price outputs. Thereafter, file locations for downloading and file formats are specified in chapter 4. We provide concluding remarks and possible next steps in chapter 5.

2 HydroConnect

About the project

HydroConnect[1] (2021-2024) investigated whether Norwegian hydropower can play a major role in climate change mitigation. This was a knowledge-building project for industry (KSP) funded by the Research Council of Norway, five Norwegian hydropower producers, and Renewables Norway. The research partners were SINTEF Energy Research, NTNU, Fraunhofer IEE, and University of Trento.
There are many publications from different parts of the project. We focus on the final report [1], and [2] which provides additional information about scenario assumptions.

All power market prices were calculated using the FanSi model [3], which is one of SINTEF's power market simulation tools.[2] An important part of the methodology was the soft-linking of Fraunhofer's general energy system model SCOPE and FanSi. The analyzed scenarios and assumptions were developed through a dynamic, collaborative process involving all project participants.

Time-aspects and geographical coverage

All FanSi simulations were carried out for potential power system configurations in the year 2050. Each system was simulated using 30 historical weather years (1981-2010), with a time resolution of 3 hours. The geographical coverage of simulations is illustrated in Figure 1.

Premises and exogenous inputs to the SCOPE model simulations

SCOPE model simulations were carried out for 2030 and 2050. However, we focus on the 2050 scenarios since soft-linking with FanSi was not performed for 2030 scenarios. The 2050 scenarios were based on the H2020 project openENTRANCE. The following are key premises of the study:

- Net zero emissions in the energy system
- Carbon capture and storage (CCS) is not included
- Nuclear power is set to a negligible amount

Fossil-fuel power generation is not included as it would result in positive emissions when CCS is not included. In addition, the following factors are treated as exogenous inputs to the study:

- Transmission capacities
- Hydropower capacities

However, transmission capacities and hydropower capacities vary for Norway between scenarios. Other assumptions such as investments costs are documented in [2].

Optimal power generation mix in 2050 in the SCOPE model

Due to the premises for the study, the optimized European power generation in the 2050 scenarios is dominated by renewable energy sources. The annual generation (in thousand TWh/year) is: 2.5 from onshore wind, 1.0 from offshore wind, 1.9 from photovoltaics (PV),

[1] https://www.sintef.no/en/projects/2021/hydroconnect/
[2] https://www.sintef.no/fagomrader/vannkraft/kraftmarkeder-og-markedsmodeller-for-vannkraft/

0.4 from hydropower, and less than 0.3 from thermal power based on hydrogen and nuclear. Hence, more than 85% of power generation comes from fluctuating wind- and solar-power generation. This variability was balanced by flexible demand – such as hydrogen electrolysers that can operate at partial load or be shut down - as well as energy storage technologies, such as batteries, hydrogen storage, and hydropower.

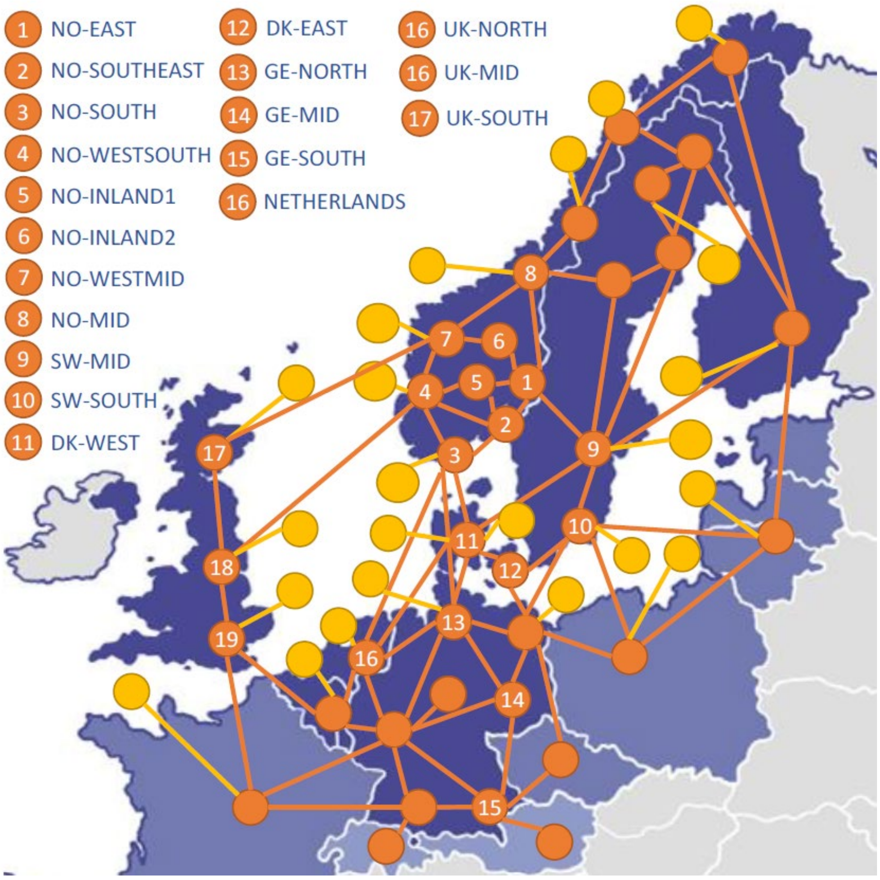

Figure 1: Map of the power system modelled with FanSi. The circles represent the geographic regions included in the model, with names and numbers identifying areas that are key or chosen for illustration in the results presentation of this study. Less significant areas are shown without labels. Darker blue shades indicate regions modelled with higher detail in terms of power demand and supply. Copied from [1].

Soft-linking between SCOPE and FanSi

In principle, the main assumptions and scenarios was aligned in the two models SCOPE and FanSi. The results transferred from the SCOPE model (i.e., simulation results from SCOPE) to the FanSi model (i.e., input to FanSi) were the optimal:

- Capacities for power generation
- Capacities for energy storage, notably batteries and hydrogen
- Capacities for electrolysers
- Electricity demand

However, SCOPE and FanSi are very different models. For instance, FanSi represent weather variability and hydropower in greater detail. Therefore, the data originating from SCOPE was tuned in an iterative process to reduce excessive regional price differences and extreme power prices observed in initial FanSi model runs.

Scenarios for 2050

The following factors were varied in the FanSi scenarios conducted for year 2050:

a) Norwegian hydropower capacity and HVDC cable capacity to/from Norway
b) Power consumption in Norway
c) Import price for hydrogen to Europe
d) The total battery capacity included in the European power system

These four scenario dimensions result in 16 possible combinations. Half of these were selected and analysed using FanSi. In the following we briefly elaborate on points a) through d).

a) Norwegian hydropower capacity and transmission capacity (Baseline/Expanded)

Two scenario variants were defined for hydropower and transmission capacity in 2050: Baseline and Expanded. For hydropower, the starting point for Baseline was SINTEF's existing dataset for 2030. This was updated with projections for small-scale and refurbished hydropower, aligned with NVE's data for 2040. The resulting total Norwegian hydropower capacity was 36 GW. In the Expanded case, there is 11.2 GW extra hydropower capacity, of which 5 GW reversible (pumped storage) turbines.

For Norway-Europe subsea (HVDC) transmission links, the Baseline largely reflects the current transmission infrastructure, with two exceptions: reduced capacity towards western Denmark and a new interconnector to the UK. In the Expanded case, the total HVDC cable capacity to/from Norway is increased by 11.2 GW compared to Baseline. Thus, the increase in transmission capacity matches the increase in hydropower capacity.

b) Power consumption in Norway (ref/dem)

There are two power consumption variants, of which one assumes higher electricity consumption in Norway. The two variants are labelled Reference (ref) and Increased Norwegian demand (dem) and are based on scenarios from the SCOPE model. In the Reference case, consumption in Norway is 176 TWh/year, while in the dem scenario it is 21 TWh/year higher.

c) Import price for hydrogen to Europe (H2p45/ H2p85)

Although FanSi is primarily developed as a partial model for electricity markets, it can also be used to study related markets. In HydroConnect a European market for hydrogen was included, and FanSi was used to calculate hydrogen prices endogenously. However, the import price for hydrogen from non-European countries was an input to the model. Two import price scenarios were considered: H2p85 with an import price of 85 Euro/MWh, and H2p45 with an import price of 45 Euro/MWh.

d) Batteries (batt_incr)

Based on the simulated prices in the Reference case, battery investments yielded a calculated payback time of 4-7 years. In the Battery scenario variant (batt_incr), the battery capacity was adjusted to ensure a payback time of 8 years, corresponding to the depreciation period for batteries used in the SCOPE model.

Simulated scenarios
The following eight scenarios were simulated in FanSi:
1) baseline_dem_H2p45
2) expanded_dem_H2p45
3) baseline_dem_H2p45_batt_incr
4) expanded_dem_H2p45_batt_incr
5) baseline_dem_H2p85
6) expanded_dem_H2p85
7) baseline_ref_H2p45
8) expanded_ref_H2p45

Only two SCOPE scenarios were used as input for the soft-linking to FanSi: one with the reference demand ("_ref"-scenarios) and one with increased demand in Norway ("_dem"-scenarios). Both the linked SCOPE scenarios (and the utilization of corresponding optimal capacities) were based on the Baseline configuration for hydropower and batteries, and an import price of 85 Euro/MWh for hydrogen.

Example results for prices
Several statistical measures for simulated prices, also including averages and standard deviations, are described in [1]. Here, we present only a few illustrative examples of simulated prices. For the OSTLAND and SORLAND areas, figures include both duration curves of all simulated prices and example price profiles for a single week in one specific climate year. Notice that price values are shown with an interval of 20 units Euro/MWh up to 100, and 100 units above that point. A break is indicated on the axis. The orange curve is mostly under the red one, while the purple curve is mostly under the brown curve.

Further information
For more information and additional details about the HydroConnect scenarios, see [1].

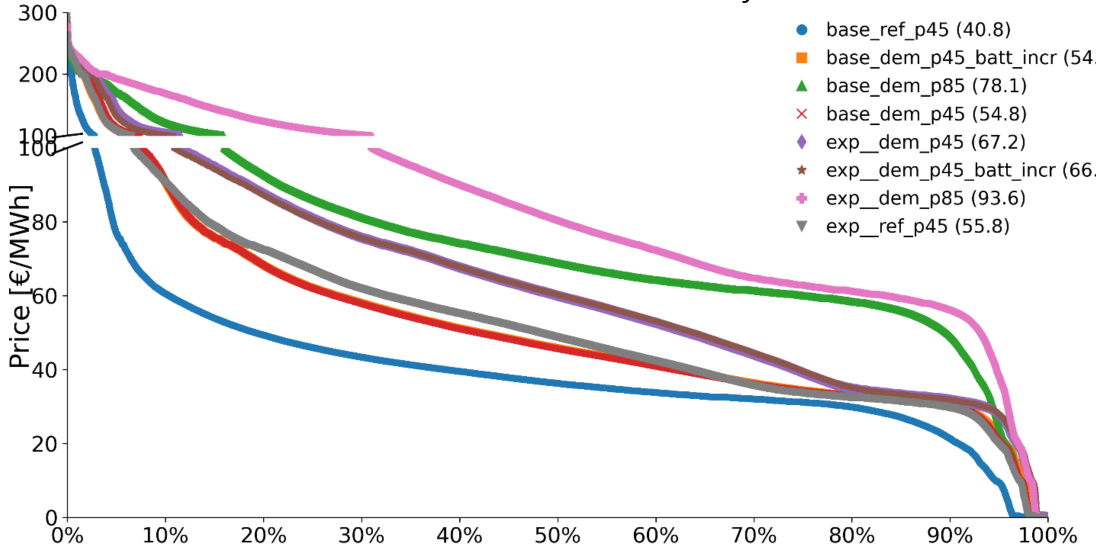

Figure 2: Duration curve for simulated prices in OSTLAND for 8 scenarios, and with corresponding average price. HydroConnect study.

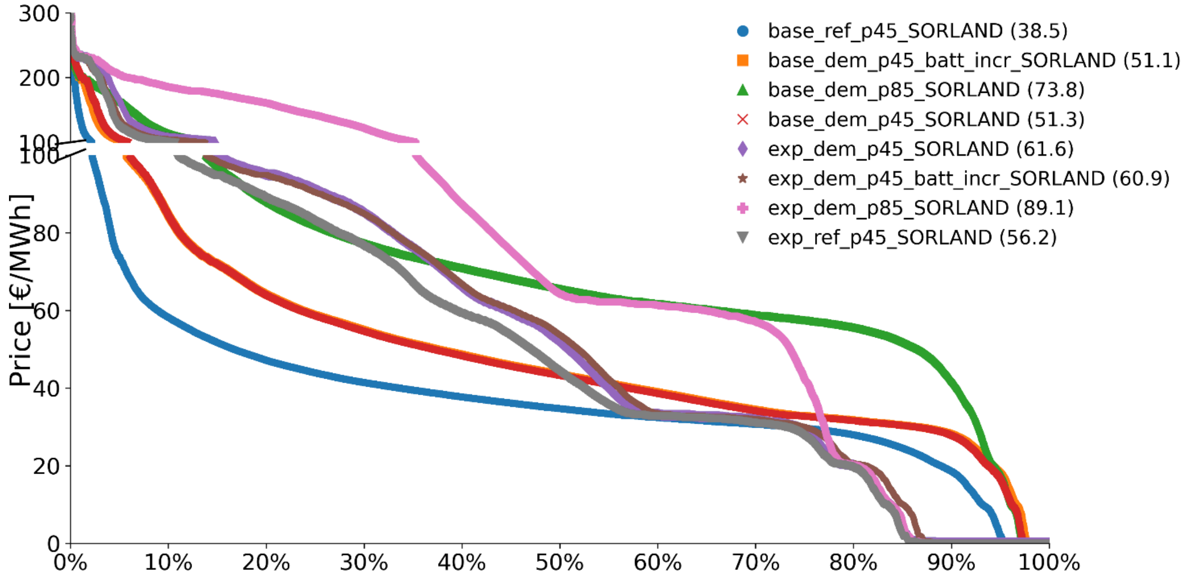

Figure 3: Duration curve for simulated prices in SORLAND for 8 scenarios, and with corresponding average price. HydroConnect study.

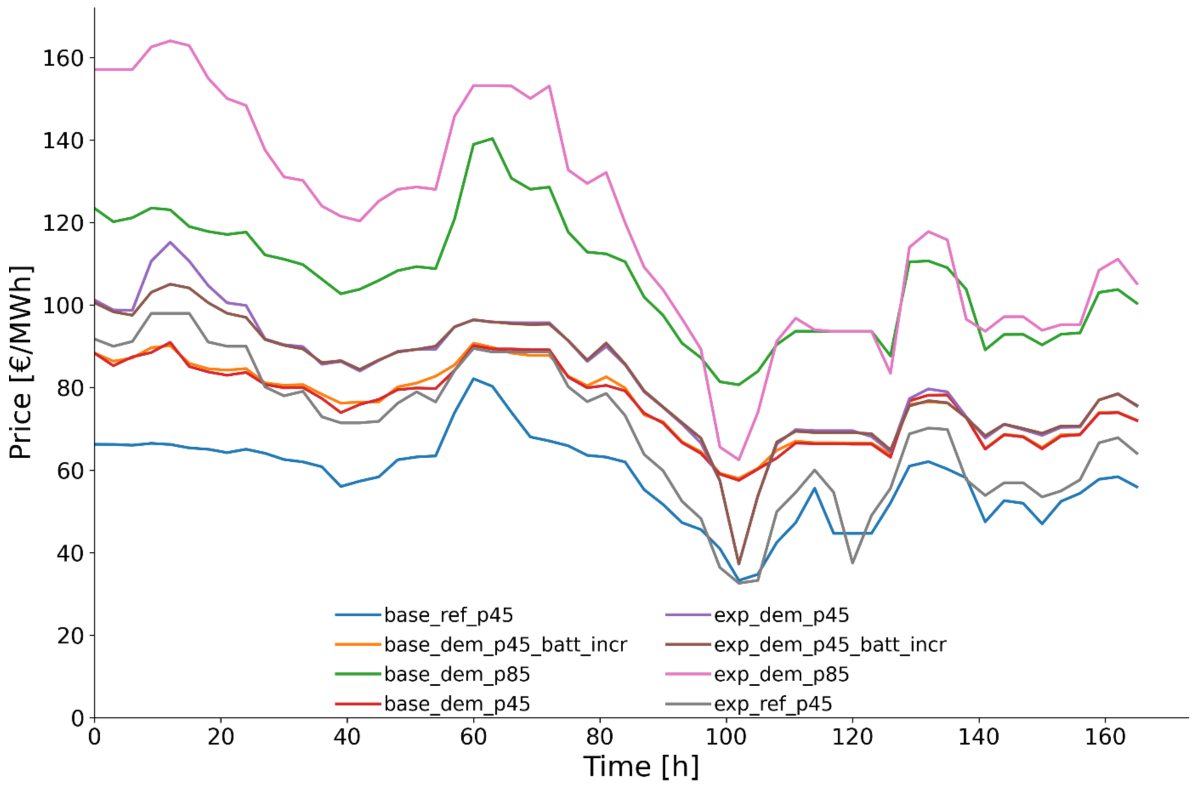

Figure 4: Example of simulated prices in one week in OSTLAND for 8 scenarios. HydroConnect study.

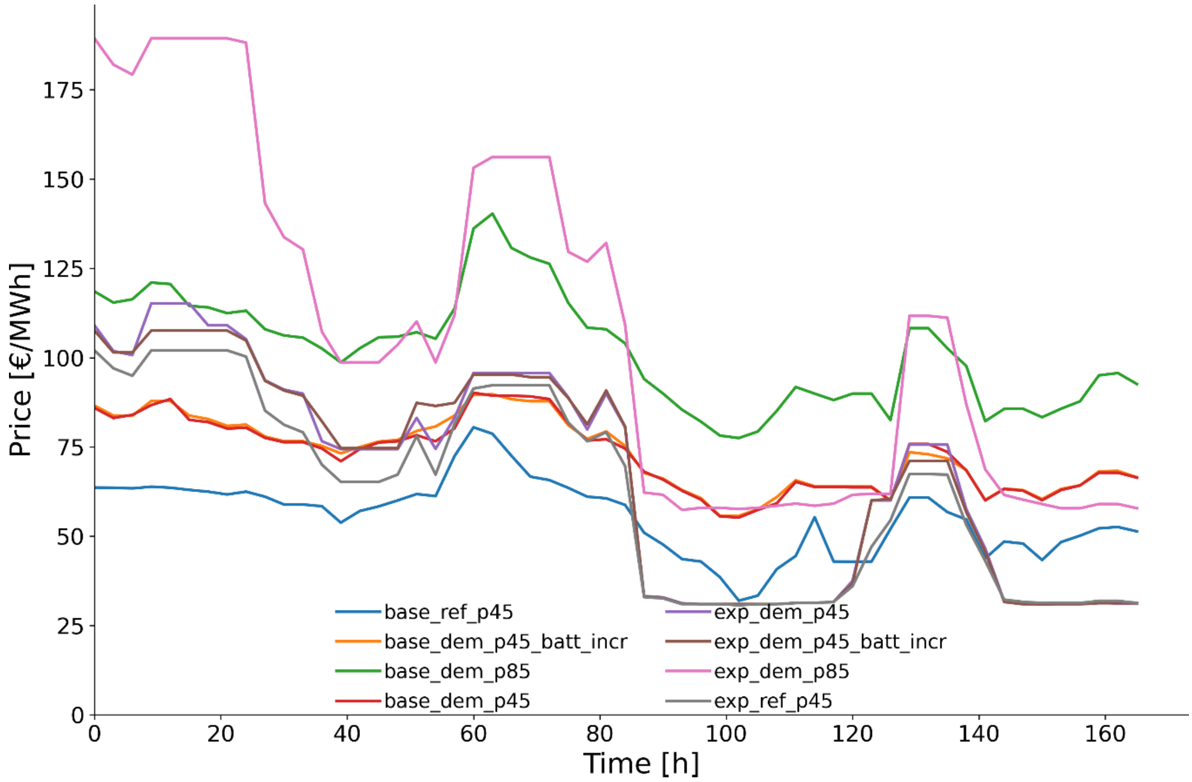

Figure 5: Example of simulated prices in one week in SORLAND for 8 scenarios. HydroConnect study.

3 SumEffekt

About the project

SumEffekt (2020-2022) was an innovation Project for the Industrial Sector (IPN project) funded by the Research Council of Norway and 16 industrial partners, which studied the impact of the EU Water Framework Directive on the Norwegian power system. The aims and methodologies of the SumEffekt study are described in the final report [4]:

"... aimed to provide a thorough understanding of the effects of new hydropower environmental constraints on the power system. The project employed three power system models, FanSi, Primod and EMPS, to analyse the power systems for the year 2030 under varying assumptions. Results and insights into the effects of environmental restrictions were obtained by comparing results from model runs with and without restrictions [i.e., using only those restrictions that existed prior to the Water Framework Directive]. Variables quantified by the models included power prices, power balances and exchanges between regions, power production patterns, flooding, availability of spinning reserve capacity and socioeconomic surplus."

Time-aspects and geographical coverage

All FanSi and EMPS simulations were carried out for possible power system configurations in the year 2030. Each configuration was simulated with 35 historical weather years (1981-2015), with a time resolution of 3 hours.
The geographical system boundaries are the same as in HydroConnect (cf. Figure 1). Apart from additional offshore nodes in HydroConnect, the included areas are largely identical. See [4] for a discussion of how areas in the model correspond with Nord Pool bidding zones.

Methodology

As previously mentioned, three models were used:

"The primary power system models utilized are FanSi and Primod. In addition, the EMPS model [no: Samkjøringsmodellen] [5] is used as a supplement to FanSi. FanSi is a prototype fundamental long-term market model that we use for analyzing hydro-thermal electricity markets. Primod [6] is a prototype fundamental short-term model for multi-market power system analyses. EMPS has a long history of successful applications. EMPS is functionally equivalent to FanSi in terms of types of results produced but employs a different mathematical methodology. All three models optimize the operation of the power system by maximizing socioeconomic surplus. While their scope encompasses the broader power system, they hold particularly detailed descriptions of the hydropower systems in the Nordic region. This includes comprehensive information about topology, waterways, reservoirs, environmental restrictions, and hydropower plants."

Main assumptions

The final report [4] gives a detailed description of the assumptions used in the study. The analysis considers scenarios for the year 2030. Power generation capacities are largely based on NVE's *Langsiktig kraftmarkedsanalyse 2020-2050* (NVE, 2020). This also includes information about hydropower generation, with modifications from SINTEF, renewable power capacities as well as thermal power generation capacities. For wind- and solar-power in

Norway, the study had the following annual production levels by 2030: 18.1 TWh from onshore wind, 1.6 TWh from offshore wind, and 1.8 TWh from solar power. By comparison, actual wind-power production in Norway by 2022 was 14.8 TWh. Start-up costs and minimum generation levels were considered for individual thermal power generation units (natural gas, biomass, oil and coal).

Scenarios
The following factors were varied in the FanSi and EMPS simulations conducted for year 2030:

a) Environmental constraints
b) Electricity consumption in Norway
c) Transmission capacity to/from Norway
d) Fuel and CO2 prices
e) Solar power generation
f) Simulation model: FanSi vs. EMPS

A total of 18 simulations were carried out, each combining selected variations of factors a) through f). The following sections briefly describe each factor.

**) Base*
This is the Base case. It includes a defined set of baseline assumptions for electricity demand and transmission capacity. Scenario names typically combine the Base label with additional attributes, which are explained in the following sections.

a) Environmental constraints (R, Q, R, Q*)*
The Water Framework Directive can be implemented in different ways. This is reflected in the scenario-specific environmental constraint attributes, which are defined as follows:

- Q: A new method for estimating minimum bypass requirements developed in the SumEffekt project.
- Q*: Minimum bypass flow requirements are set equal to Q95 (i.e., the seasonal flow that is naturally exceeded 95% of the time).
- R: New reservoir constraints are included; only local inflow must be accumulated.
- R*: A stricter version of R, where both local inflow and water from upstream power plants must be accumulated
- No R/Q attribute: No additional environmental constraints from the Water Framework Directive are applied. Pre-existing constraints from before the Directive remain in place.

Environmental constraints are attributes in scenario names. For example: Base_Q or Base_RQ*.

b) Electricity consumption in Norway
Scenarios were developed for power consumption in Norway, ranging from 156 TWh/year to 177/year. By comparison, the Norwegian power consumption was between 134 TWh/year and 140 TWh/year during the period 2020-2023 [7]. However, consumption is expected to increase towards 2030. Price elasticity was included in the modelling.

If Base is part of the scenario name, the total consumption in Norway is 166 TWh/year. If LowDem or HighDem is used instead, the assumed demand is 156 TWh/year and 177 TWh/year, respectively. For example, a scenario with low demand and the Q environmental constraint is labelled LowDem_Q.

c) Transmission capacity to/from Norway
In the Base case, the total Norwegian exchange capacity with neighbouring countries is assumed to be 9,300 MW. This includes all interconnectors currently in operation, but no additional cables. A table listing all assumed transmission capacities, with explanations, is included in the SumEffekt report.

The label LowTransm indicates a 10% reduction in transmission capacity compared to the Base case. In such cases, LowTransm replaces Base in the scenario name. For example, a scenario with reduced transmission capacity and both Q and R environmental constraints is labelled LowTransm_Q-R.

d) Prices for fuels and CO2
The label HighPrice indicates higher prices for fuels and CO2 compared to the Base case. In the HighPrice case, the CO2 price is increased to 140 €/tonne from 90 €/tonne in the Base case. Fuel prices are also higher in HighPrice relative to the Base case: coal prices are increased by more than 50%, and natural gas prices by more than 30%.

In HighPrice scenarios, HighPrice replaces Base in the scenario name. For example, a scenario with high fuel and CO2 price combined with the Q and R environmental constraints is labelled HighPrice_Q-R.

e) Solar power generation
The label HighSolar indicates a total of 8 TWh of solar power generation in Norway in 2030, based on a target set by the Norwegian Government and Parliament. This replaces the 1.8 TWh assumed in the Base case. HighSolar is an attribute that can be combined with other scenario variants. For example, a scenario with high demand, high solar output, and both R and Q environmental constraints is labelled HighDem_HighSolar_R-Q.

f) EMPS versus FanSi simulation
The label EMPS indicates that the simulation was carried out using the EMPS model instead of FanSi. This is an attribute that can be combined with other scenario variants. If the EMPS attribute is not included, the simulation was conducted using the FanSi model.

Scenarios
The list below shows which simulations were carried out.

1) Base
2) Base_R-Q
3) Base_EMPS
4) Base_EMPS_R-Q
5) Base_R
6) Base_Q
7) Base_R*-Q
8) Base_R-Q*
9) LowDem
10) LowDem_R-Q
11) HighDem
12) HighDem_R-Q
13) HighDem_HighSolar
14) HighDem_HighSolar_R-Q
15) HighPrice
16) HighPrice_R-Q
17) LowTransm
18) LowTransm_R-Q

Example results for prices

Differences in simulated prices across all scenarios are analyzed in [4]. Here, we present only a few selected examples, corresponding to those shown for the HydroConnect project. For areas OSTLAND and SORLAND, figures illustrate both a duration curve covering all simulated prices (of the seven scenarios not including R or Q[3]) and an example week, showing simulated prices for a single week in one climate year. The scenario names in the figures correspond to those in the scenario list, except for the additional labels "krv" and "prisavsnitt". These indicate that the values shown are electricity prices and that the prices are extracted for intra-week time intervals, rather than as weekly averages.

Further information

For more details about the SumEffekt scenarios and simulation results, see [4].

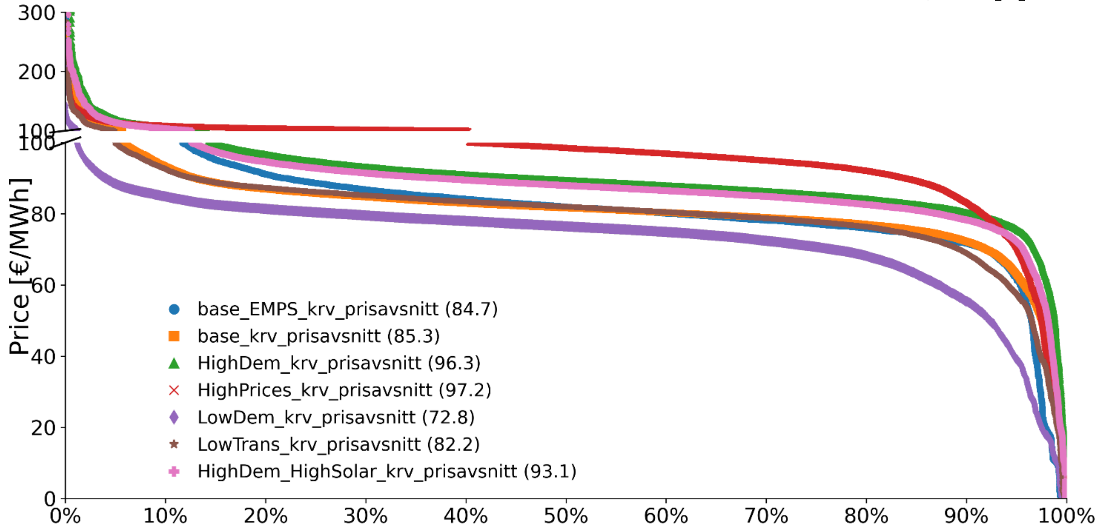

Figure 6: Duration curve for simulated prices in OSTLAND for 7 scenarios, and with corresponding average price. SumEffekt study.

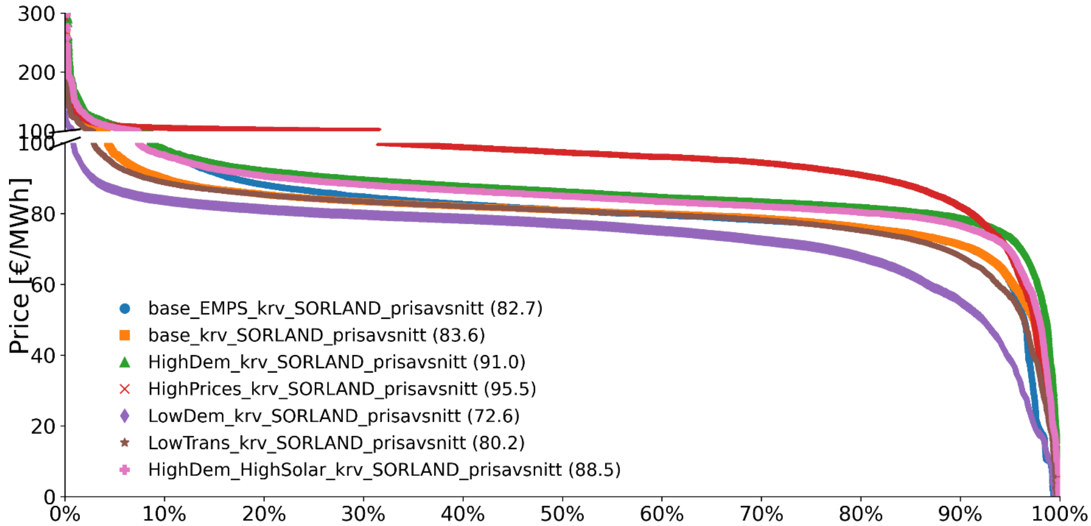

Figure 7: Duration curve for simulated prices in SORLAND for 7 scenarios, and with corresponding average price. SumEffekt study.

[3] This report was prepared before we knew whether the R and Q price data could be published. Prices from all scenarios, including R and Q, are available on the RenewHydro web site.

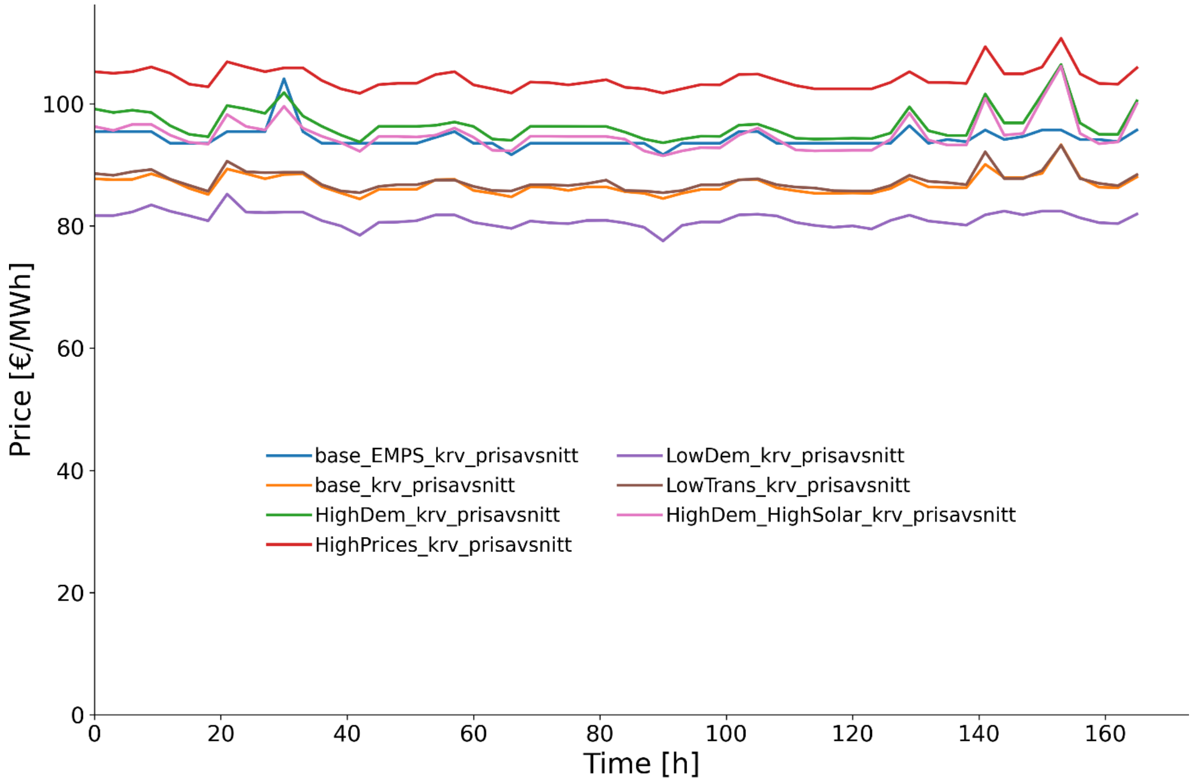

Figure 8: Example of simulated prices in one week in OSTLAND for 7 scenarios. SumEffekt study.

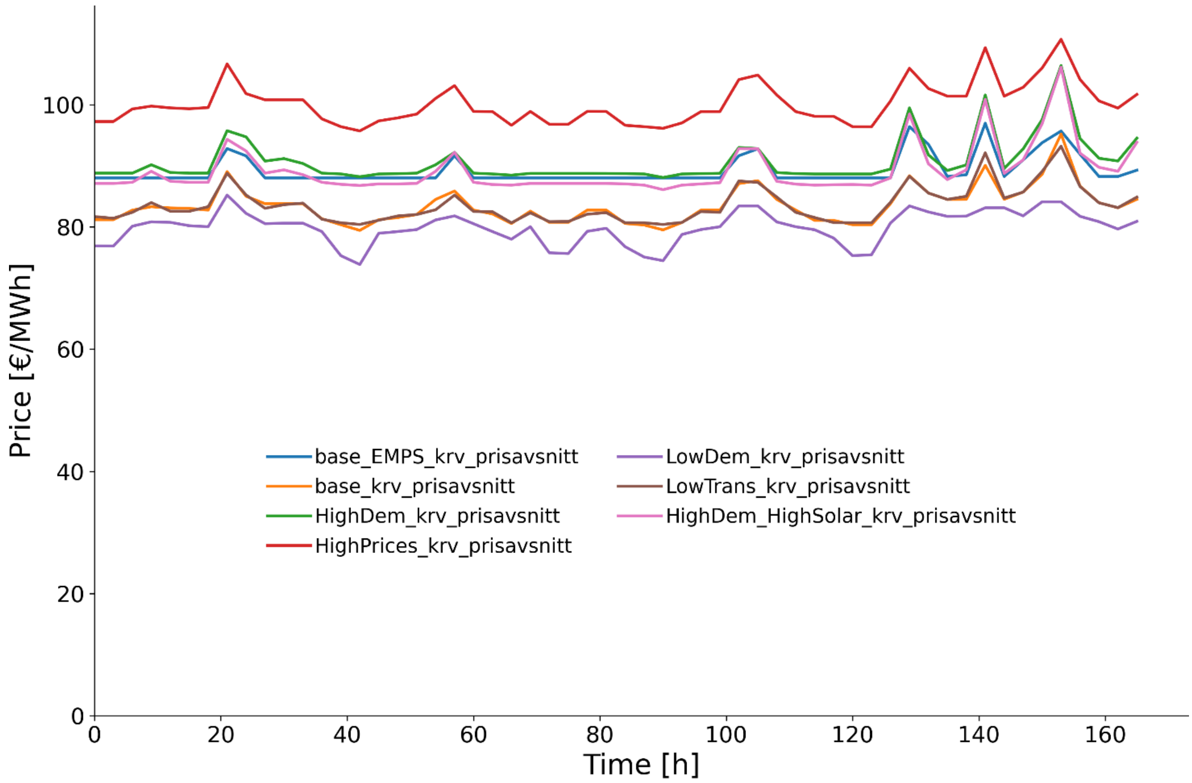

Figure 9: Example of simulated prices in one week in SORLAND for 7 scenarios. SumEffekt study.

4 File location and formats

File locations

To access all simulated price data go to the following web-site: https://www.ntnu.no/web/renewhydro/fp3/ and then select the link FP3.3 Future power prices. When you click this SharePoint link without having prior access, you are directed to a form where you press a "Submit" button. This automatically sends an access request to the site administrators, who only need to click "Accept" for you to be granted permanent access.

Within the Power prices folder, there are two subfolders:

- HydroConnect
- SumEffekt

Each of these contains subfolders for the different scenarios, with names corresponding to those used in this report. All price files are openly available and free for all users.

File formats

For each scenario, there is one CSV file per area. Each file contains simulated electricity prices for all within-year time-steps (rows: 52 weeks x 56 periods per week = 2912 rows), and for all climate years in separate columns —30 for HydroConnect and 35 for SumEffekt.

The file formats fit well for import e.g. to Python. They may also be opened in Excel. However, since the values are semicolon-separated, the data may appear in a single column by default. To properly display prices in separate columns in Excel, follow these steps:

1. Open the CSV file.
2. Click on column A to select it.
3. In the top menu, choose Data → Text to Columns.
4. In the wizard that opens:
    - Select Delimited, then click Next.
    - Check Semicolon as delimiter, then click Next.
    - Click Advanced, set the decimal separator to ".", then click OK → Finish.

This will organize the prices correctly in separate columns. Note that HydroConnect includes information about the climate years in the first row of each column. SumEffekt does not include the climate year label; columns only contain raw price values.

In each column prices are organized as follows:

Week 1, Period 1
Week 1, Period 2
...
Week 1, Period 56
Week 2, Period 1
...
Week 52, Period 56

5 Concluding remarks

Comparisons
For detailed discussions of price differences and other results within each project, we refer to [1] and [8] for HydroConnect, and [4] and [9] for SumEffekt. Below, we provide a few comments on differences between the two projects and their respective results for prices.

There are many differences between the two projects. Most notably, SumEffekt is for year 2030, while HydroConnect is for year 2050. The projects also differ in scope and objectives, which is reflected in the scenario design. Consequently, differences in simulated prices are expected.

Taking the Base case scenario for both projects (base_dem_H2p85 in HydroConnect) and focusing on the OSTLAND area, the average simulated price is:

- 85.3 €/MWh in SumEffect
- 78.1 €/MWh in HydroConnect

Here, the HydroConnect (2050) price is 8.5 per cent lower than the SumEffect (2030) price. There are large structural differences between the two simulated power systems. In 2030, fossil fuel prices still have a strong impact on electricity prices. By contrast, the 2050 system is based almost entirely on renewable energy, with no fossil fuels and virtually no nuclear power. In such a system, other forms of flexibility—especially hydrogen-related technologies (electrolysers, gas-fired plants using hydrogen), and energy storage—play a larger role in price formation. Still, the average prices were not very different – even though the 2050 price is somewhat lower.

Price volatility is however considerably higher in HydroConnect scenarios. Even though prices for OSTLAND ranges from near zero to around 200 €/MWh in both projects (excluding rare extreme values), the spread between the 90th and 10th percentiles is significantly greater in HydroConnect. This is also evident from the example-week plots. The reason for this increased volatility is the much higher share of variable renewable generation in 2050.

Assuming, **as a working premise**, that the base cases from SumEffekt and HydroConnect reflect reasonable price structures for a system similar to today's and the future respectively, we can draw the following implications for future developments:

1. A possible reduction in the value of generation technologies with limited flexibility.
2. A larger spread in the value between flexible and non-flexible generation capacity, with an increased value for flexible generation.
3. Increased value of pumped storage, which benefits from both high selling prices and low purchase prices.

While the average price differs greatly for each project between scenarios, the price variability is consistently much higher in the 2050 simulations from HydroConnect.

Next steps

The uploaded price data are openly available to all partners and work packages in RenewHydro. We believe these prices can be useful in several activities. Ensuring easy access to these data represents an important Step 1 in FP3.2.

The next step in this activity is to decide between two alternative approaches:

Option 1: New simulations based on modified assumptions

One possibility is to make some adjustments to the existing scenarios and run new FanSi simulations tailored to RenewHydro. In that case, we will engage with user partners to discuss and agree on the modified assumptions.

Option 2: Post-processing of existing price simulations

An alternative is to apply a post-processing method to adjust the simulated prices from FanSi. This method was developed because FanSi sometimes overestimates the system's ability to exploit flexibility, leading to unrealistically flat price profiles. This issue is context-dependent, as shown in the results presented in this report. See [10] for a discussion of how simulated price structures are impacted under stochastic prices for natural gas and CO2.

In other SINTEF projects — particularly those assessing specific investments using simulation tools such as Prodrisk or SHOP — a functionality has been developed and applied to modify price simulations from FanSi or EMPS. The purpose is to align the simulated prices with predefined statistical properties, especially in terms of price levels and variability. Since other tasks in RenewHydro will involve hydropower investment analyses, this method may also be relevant here. It would allow existing simulations (e.g., from HydroConnect) to be reused, while allowing the price structures to be adapted to specific expectations or exploratory needs—potentially in close dialogue with user partners.

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RenewHydro (Norsk forskningssenter for fornyelse av vannkraft) skal utvikle kunnskap og løsninger slik at fleksibel vannkraft kan støtte realisering av energiomstillingen og nå nasjonale energi-, klima- og naturmål.

NTNU er vertsinstitusjon og hovedforskningspartner i RenewHydro sammen med SINTEF Energi, Norges Handelshøyskole (NHH) og Norsk institutt for naturforskning (NINA).

RenewHydro har rundt 40 nasjonale og internasjonale partnere fra forskning, industri og forvaltning.

RenewHydro er et av sentrene i Forskningsrådets ordning med forskningssentre for miljøvennlig energi (FME). RenewHydro har et budsjett på nærmere 400 millioner kroner fordelt på åtte år.

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