Influence of hydrogen import prices on hydropower systems in net-neutral Europe

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Hydropower Scheduling Conference 2022 – Session on Scheduling in Decarbonised Power Systems
12 September 2022 | Oslo

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Chapter 01

Introduction

Motivation, objective and methodological approach

Motivation and objective

Motivation

- European Green Deal, i.e. GHG emissions -55% until 2030 and net-neutrality by 2050
- Hydropower offers unique features and a backup production option, but modelling hydropower is not straightforward in large-scale energy system models
- Green hydrogen as a key technology which can be produced domestically in Europe or imported from global fuel markets

Main contributions

- Investigation of the influence of different green hydrogen import prices on the use and scheduling of hydropower in long-term scenarios
- Quantification of the impacts of modelling hydropower with two different aggregation methods

Research questions

- How does the **hydrogen import price influence** future energy system designs in Europe and what are the **consequences for hydropower**?
- Can we use **computationally more efficient hydropower modelling** approaches to attain similar results?

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Abstract

Besides large contributions of variable renewable power generation from wind and solar PV, hydropower systems across Europe remain essential components of low-carbon electricity systems. Another key technology to reach climate neutrality in Europe is green hydrogen, which can be produced domestically in Europe or imported from global fuel markets. With renewable fuel import prices and quantities in the future being uncertain, the objective of this work is to assess and substantiate the relationship of these fuel import prices and multireservoir hydropower systems across Europe in a net-neutral energy system. Therefore, three different hydrogen import price scenarios (low, medium, and high) are combined with two aggregation methods for pan-European hydropower assets in a pan-European cross-sectoral capacity expansion planning framework. The analysis shows that the import prices for green hydrogen and renewable fuels have a major impact on European electricity production capacities, electricity production volumes, electrolyser capacities as well as the amount of hydrogen imports from outside of Europe. It also indicates that the different aggregation methods for hydropower plants only have a minor impact on the results, suggesting an unhesitating use of the clustered version with faster computing times in future simulations.

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Methodological approach – Overview on “SCOPE Scenario Development”

Input data	Linear Optimization Model (LP)	Output data
■ Fuel costs (conv. & synthetic renew. import) ■ Technology costs ■ Potentials and restrictions ■ Energy sector demand time series (power, heat, industry, transport) ■ Technology-specific time series (wind, solar, natural inflow, COP, solar thermal, …)	Europe (EU27 + CH / NO / UK – MT / CY) **Objective is to minimise investment and system operation cost** subject to compliance with climate protection targets full consecutive year, hourly resolution (8760h) historical climate reference years	■ Optimised power generation mix ■ Optimised heat generation mix ■ Optimised transport mix ■ Energy framework and installed capacities ■ CO_2 emission price(s) ■ …

Markets

- **Power market** (wholesale day-ahead & cross-border exchange)
- **Heating/cooling markets** (various building types and temperatures)
- **Fuel markets** (national / international, global import of fossil / renew. carriers)
- **Transport demands** (private, commercial, heavy goods)
- **CO_2 markets** (national / international, sector-specific, ETS, non-ETS)

Technology options

Wind, Solar	Energy storage	Electrolyzer / P2G	BEV	PHEV / REEV
Hydro power	(Multivalent) CHP system	Cooling process	Boiler	(Hybrid) Electric truck
Condensing Plant	Power-to-Heat	(Hybrid) Heat pump	Solar thermal	Geothermal

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(Multireservoir) hydropower systems are an essential part of the future decarbonised system and need adequate representation in the model

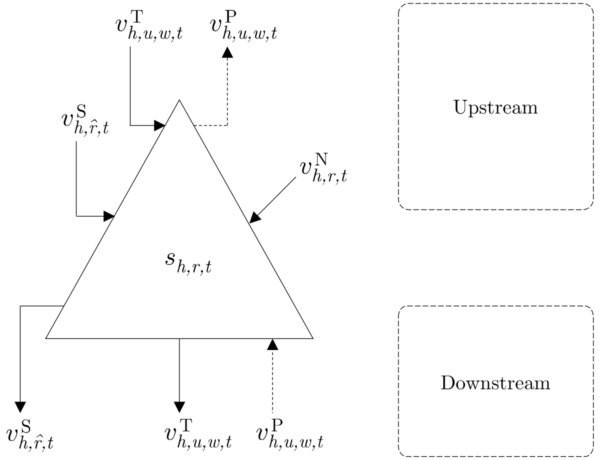
Detailed model and data representing European (multi-reservoir) hydropower systems

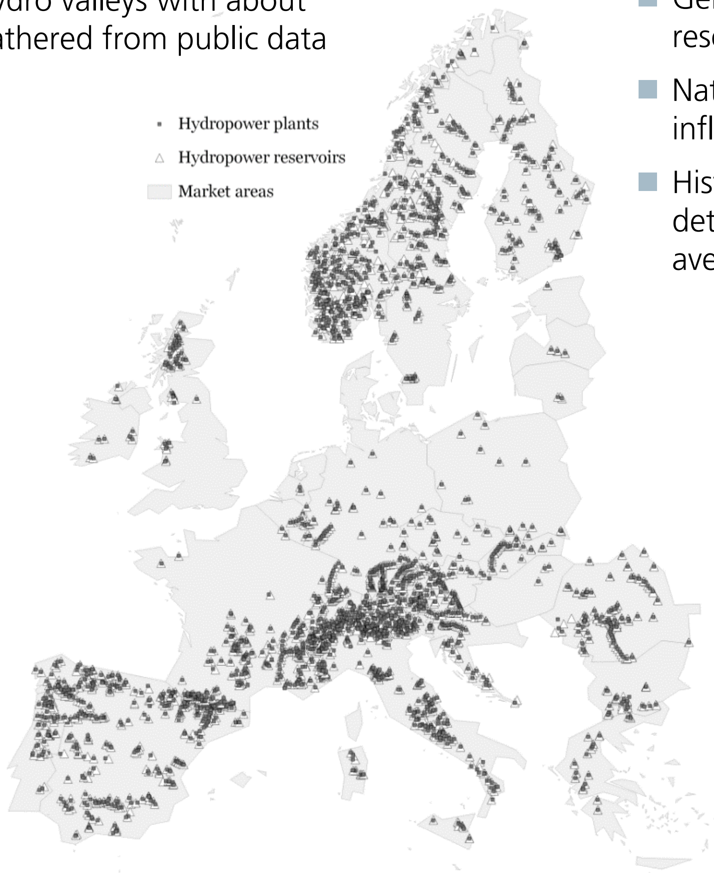
Data base

- Hydropower plants and reservoir parameters of over 849 hydro valleys with about than 3000 single hydro plants and 3700 hydro reservoirs gathered from public data
- Includes complex hydraulic connections and coupling
- Cross-border hydropower units are captured

Model formulation

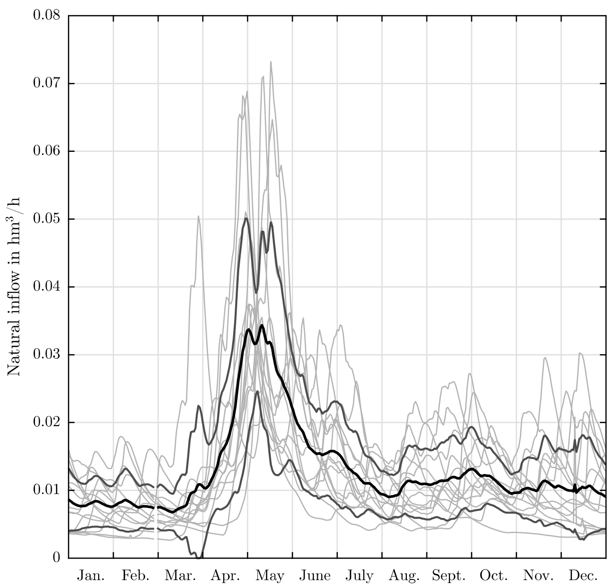
- Deterministic, linear, continuous reservoir model
- Plants with their turbine and pump capacity, efficiencies
- Reservoirs with their storage capacities, inflows, spillage





Inflow model

- Generic approach which can be applied to all hydro reservoirs across Europe
- Natural inflow based on ERA-Interim-Data for historical inflow years 2000-2017 (switch to ERA5 data is planned)
- Historical runoff profiles and their variations used to determine hydro inflows for energy production (based on average output of single units)



Härtel, Philipp; Korpås, Magnus (2017): Aggregation Methods for Modelling Hydropower and Its Implications for a Highly Decarbonised Energy System in Europe. In Energies 10 (11), p. 1841. DOI: 10.3390/en10111841.

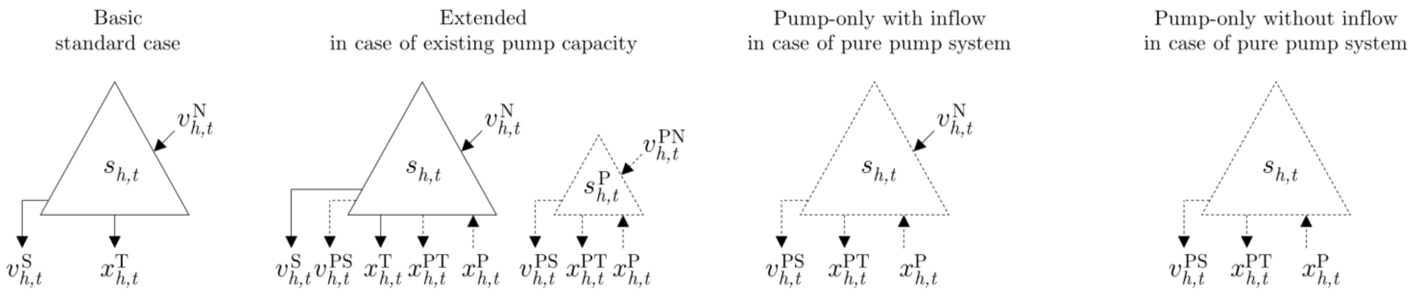
Two aggregated hydropower formulations were developed for overcoming computational challenges in large-scale power and energy system model instances

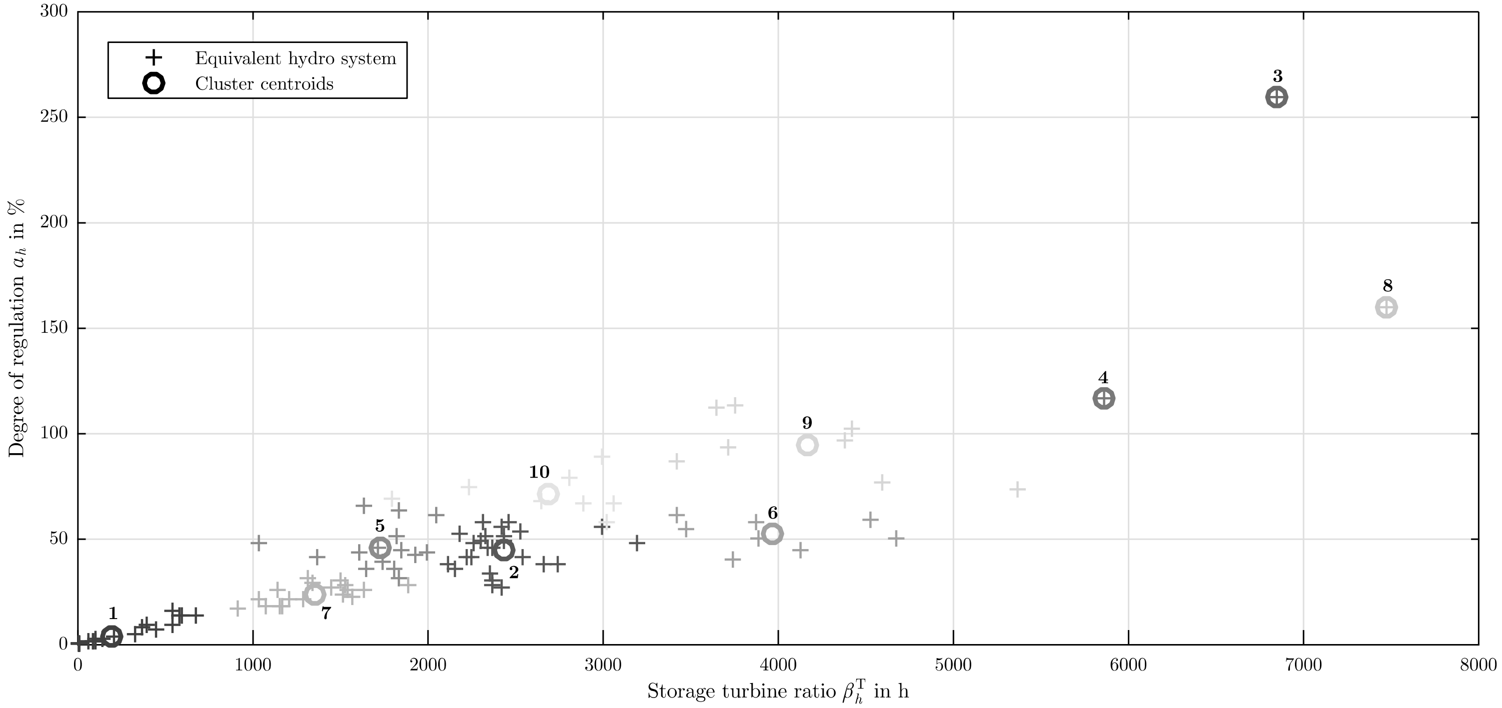
Equivalent hydro system model

- **Equivalent one-dam representations** are determined **by solving ex-ante optimisation problems** for each detailed hydropower system
- **Possibility to include pumping behaviour** in multireservoir systems through a "synthetic" reservoir to not overestimate the flexibility

Clustered equivalent hydro system model

- Using **clustering methods** (e.g., k-means) to identify similar equivalent hydro system models
- Criteria include **storage turbine ratio** and **degree of regulation** (see figure)
- **Sub-categories** of **conventional and pumped hydro storage** systems helpful when clustering
- **Clusters of units are** then **merged** into clustered equivalent hydro system models
- **Spatial differentiation at country level** – further distinction e.g. in bidding zones of NOR and SWE could be easily done





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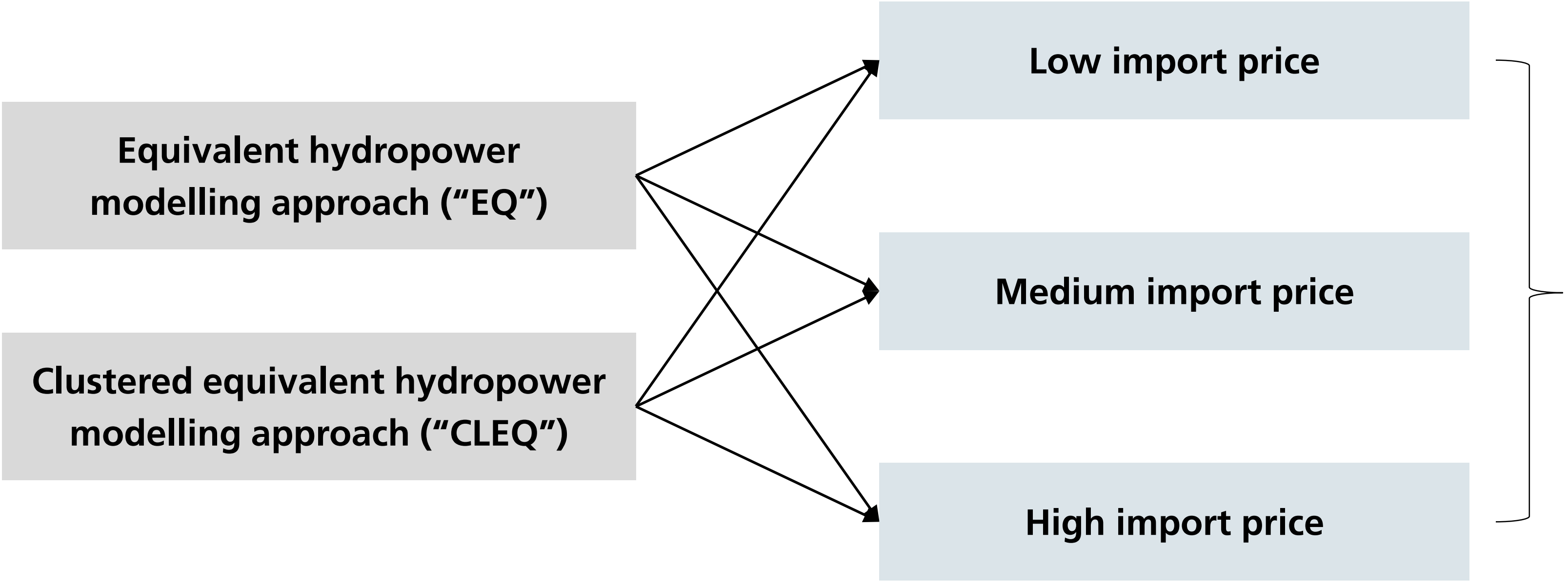
Chapter 02

Case study

Case study setup and results

The case study setup combines two different hydropower modelling variants with three different sets of energy carrier import prices, resulting in six different scenario variants



Six different scenario variants

- LowEQ
- LowCLEQ
- MedEQ
- MedCLEQ
- HighEQ
- HighCLEQ

Import prices in 2050 in EUR	Low	Medium	High
Green hydrogen	72.50	85.00	97.50
Renewable methane	95.43	106.33	134.50
Renewable liquid fuels	111.89	124.40	136.90

The clustered equivalent modelling approach (CLEQ) leads to substantial reductions in solution time while maintaining good accuracy for the considered case study

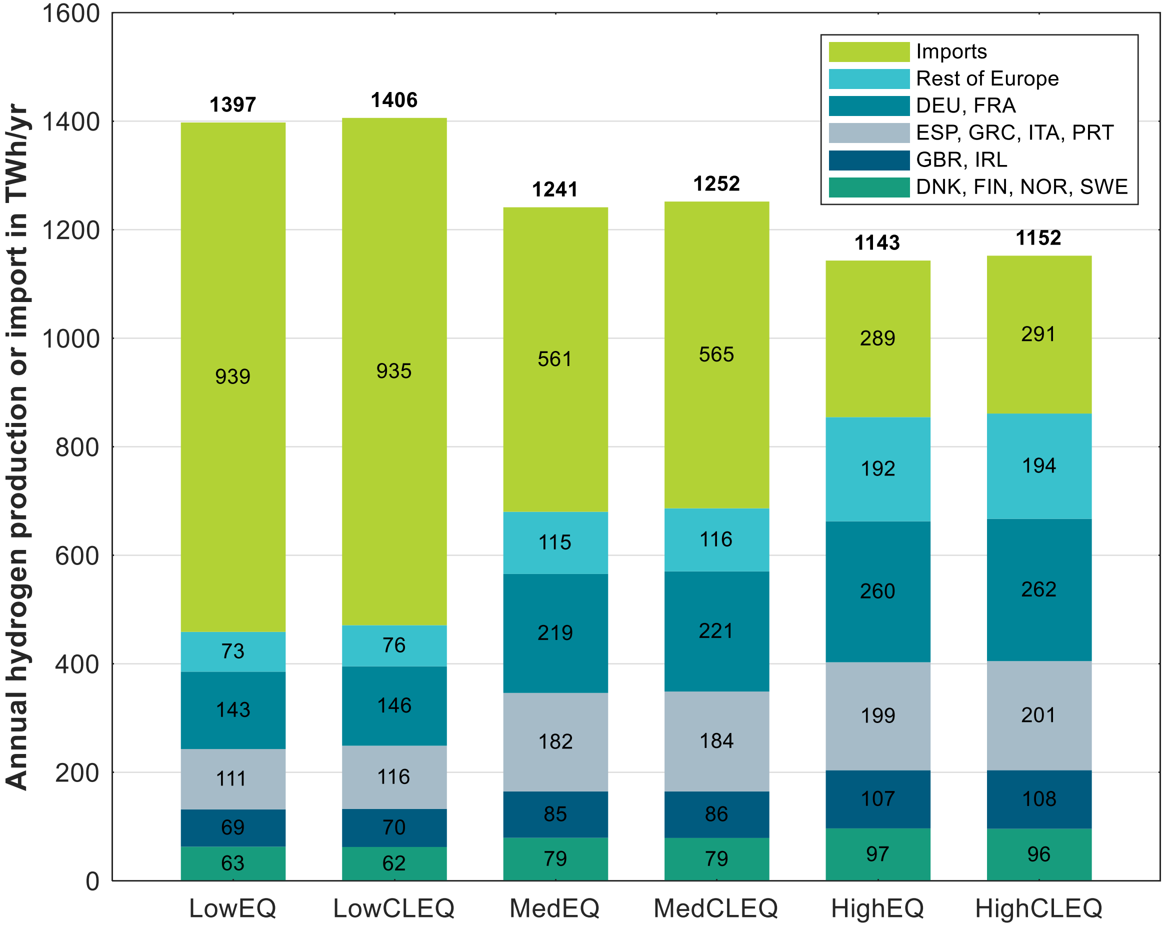
Computational | European energy system | Hydropower

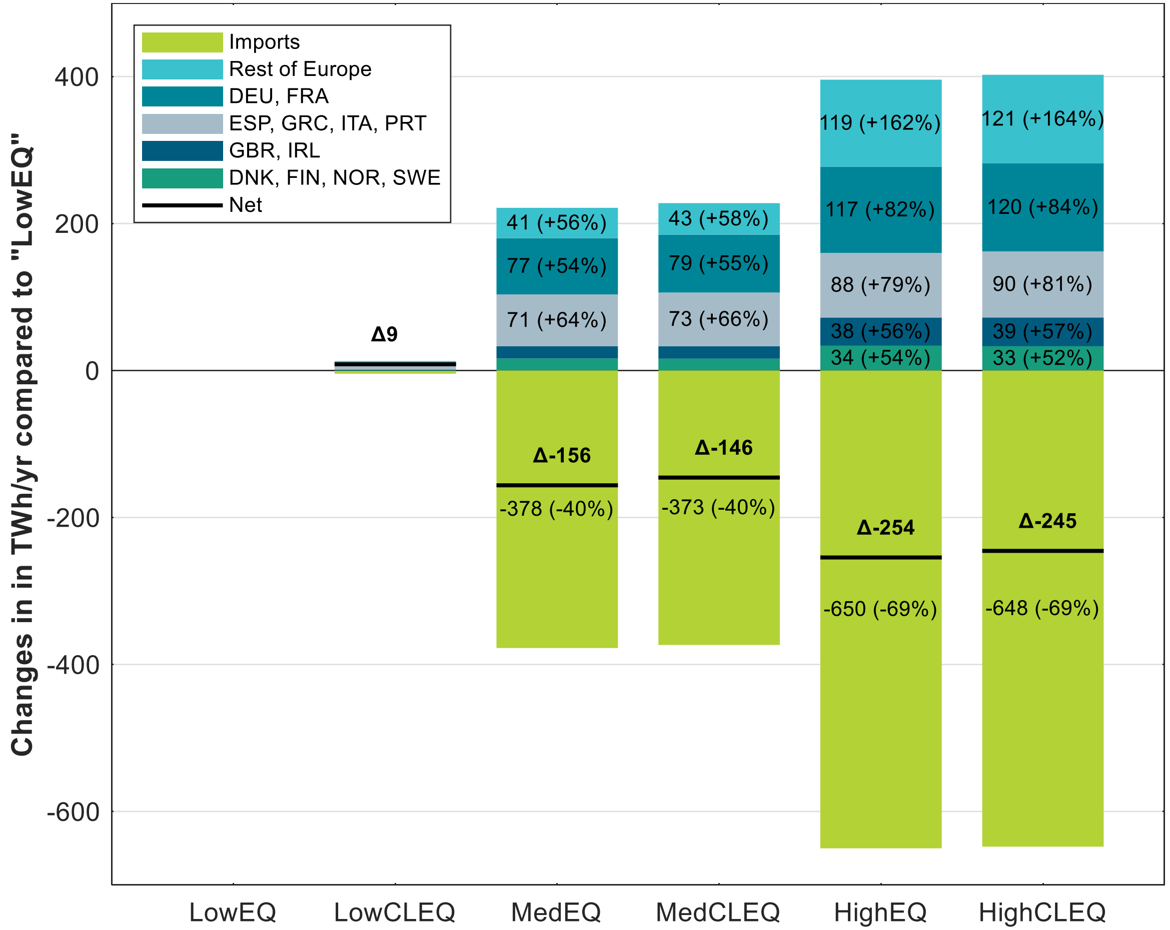
	Low		Medium		High	
	EQ	**CLEQ**	**EQ**	**CLEQ**	**EQ**	**CLEQ**
Objective function in billion EUR	466.7	465.8 (-0.2%)	476.7	475.8 (-0.2%)	483.0	482.1 (-0.2%)
Number of columns in millions	67.4	48.3 (-28%)	67.4	48.3 (-28%)	67.4	48.3 (-28%)
Number of rows in millions	54.1	48.0 (-11%)	54.1	48.0 (-11%)	54.1	48.0 (-11%)
Computing time in hours	235	28 (-88%)	217	31 (-86%)	270	36 (-87%)
CPLEX® Ticks in millions	1143	115 (-90%)	1046	132 (-87%)	1311	155 (-88%)

Note that relative comparisons use the corresponding EQ as a reference.
Hydropower modelling approaches: Equivalent (EQ), Clustered Equivalent (CLEQ)

High import prices of green hydrogen reduce import volumes and increase the expansion of electrolysers across all parts of Europe

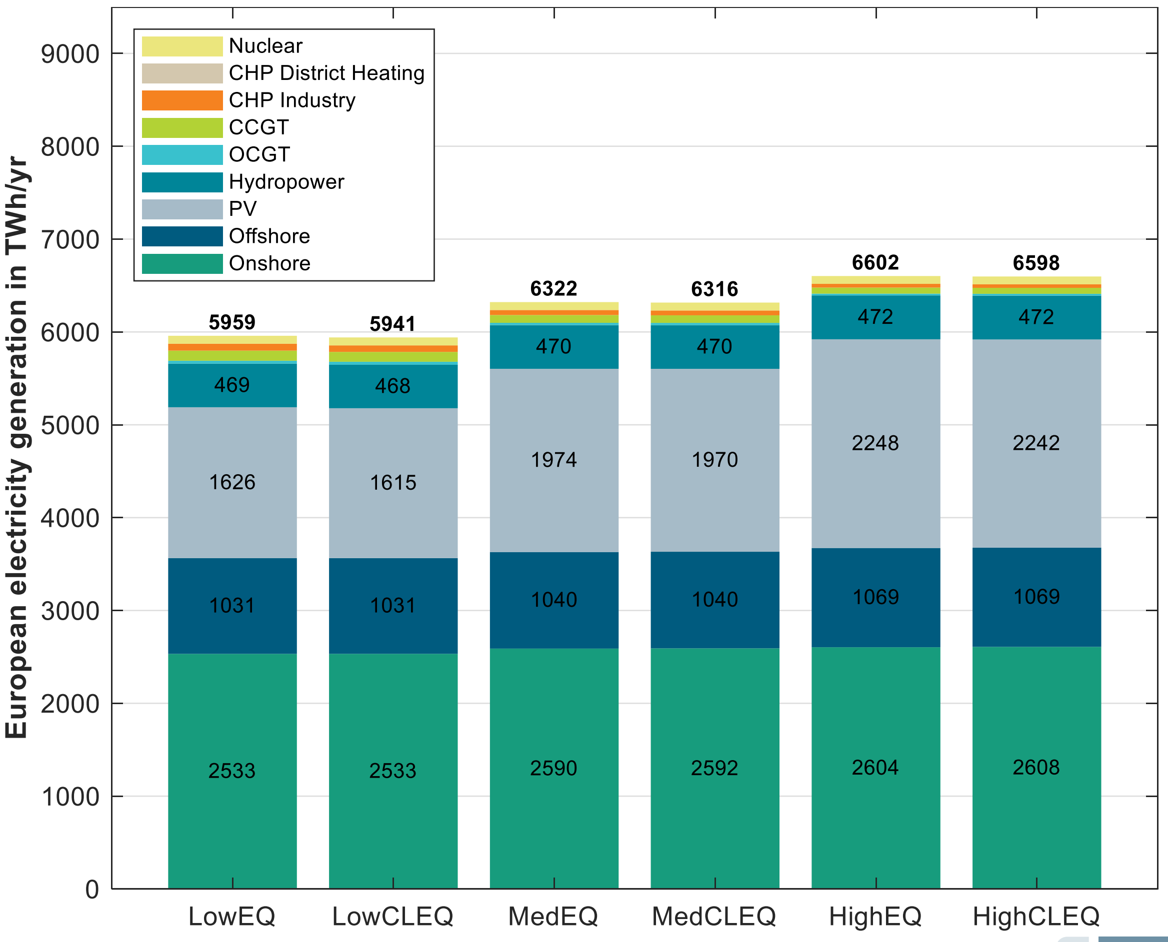
Computational | **European energy system** | Hydropower

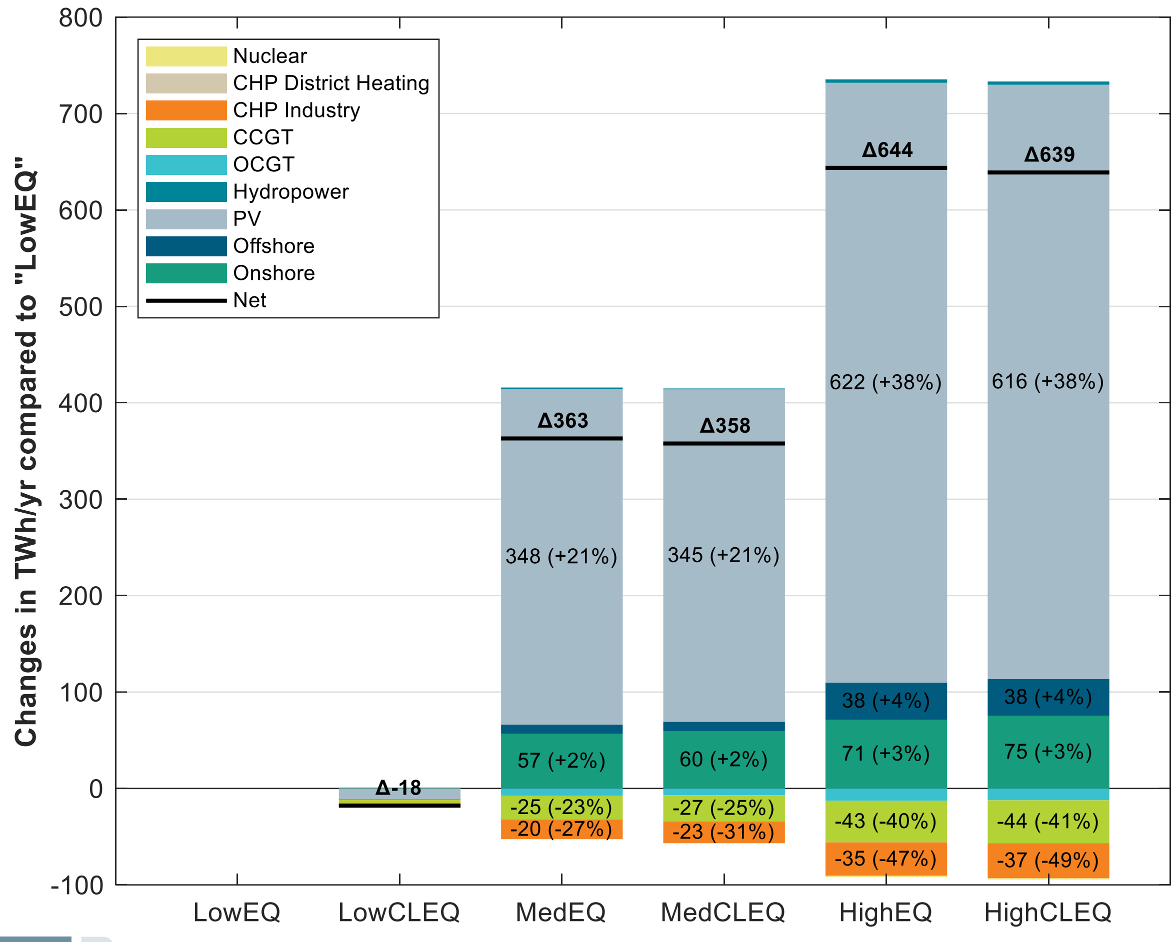




Note that relative comparisons use LowEQ as a reference.
Hydropower modelling approaches: Equivalent (EQ), Clustered Equivalent (CLEQ)

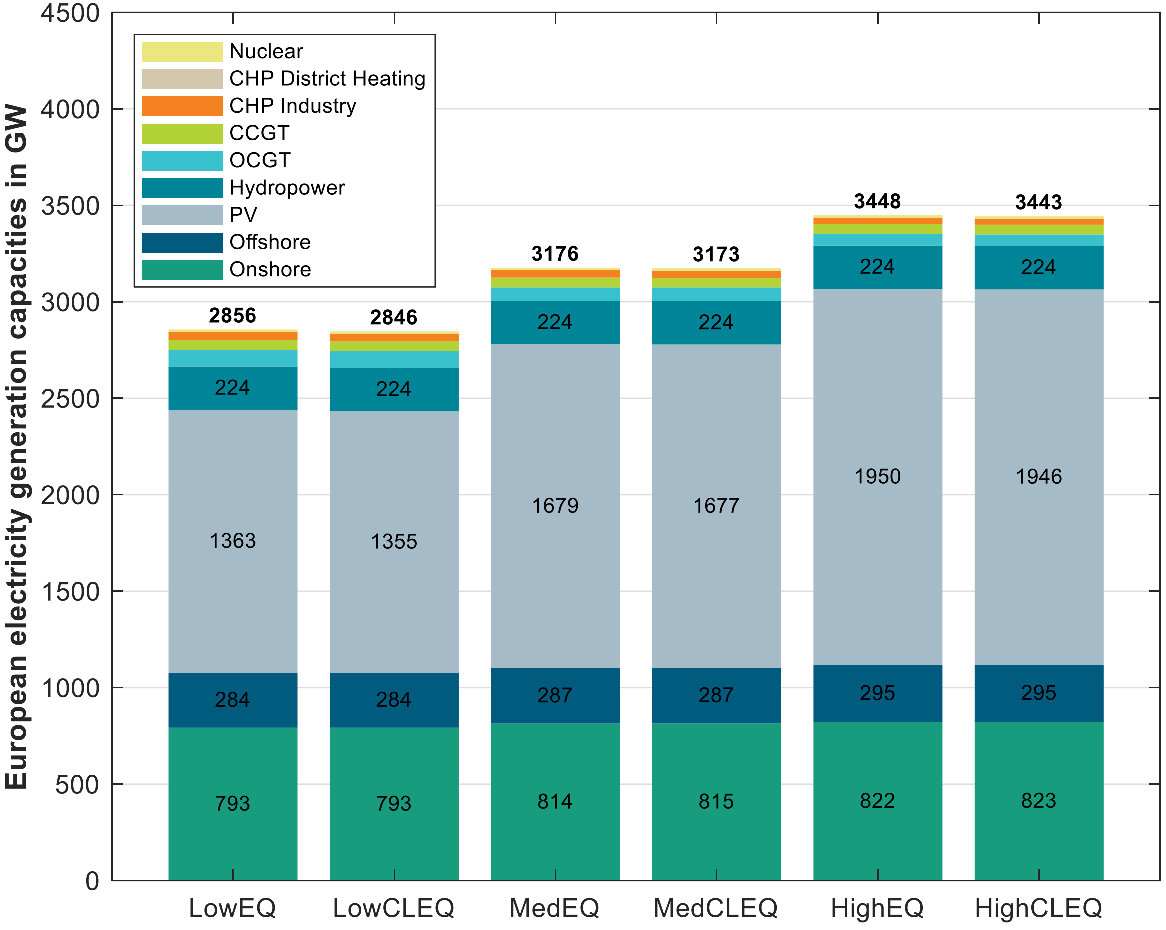
Higher import prices of green hydrogen cause additional electricity generation from domestic wind, PV and hydropower, while the share of conventional power plants decreases

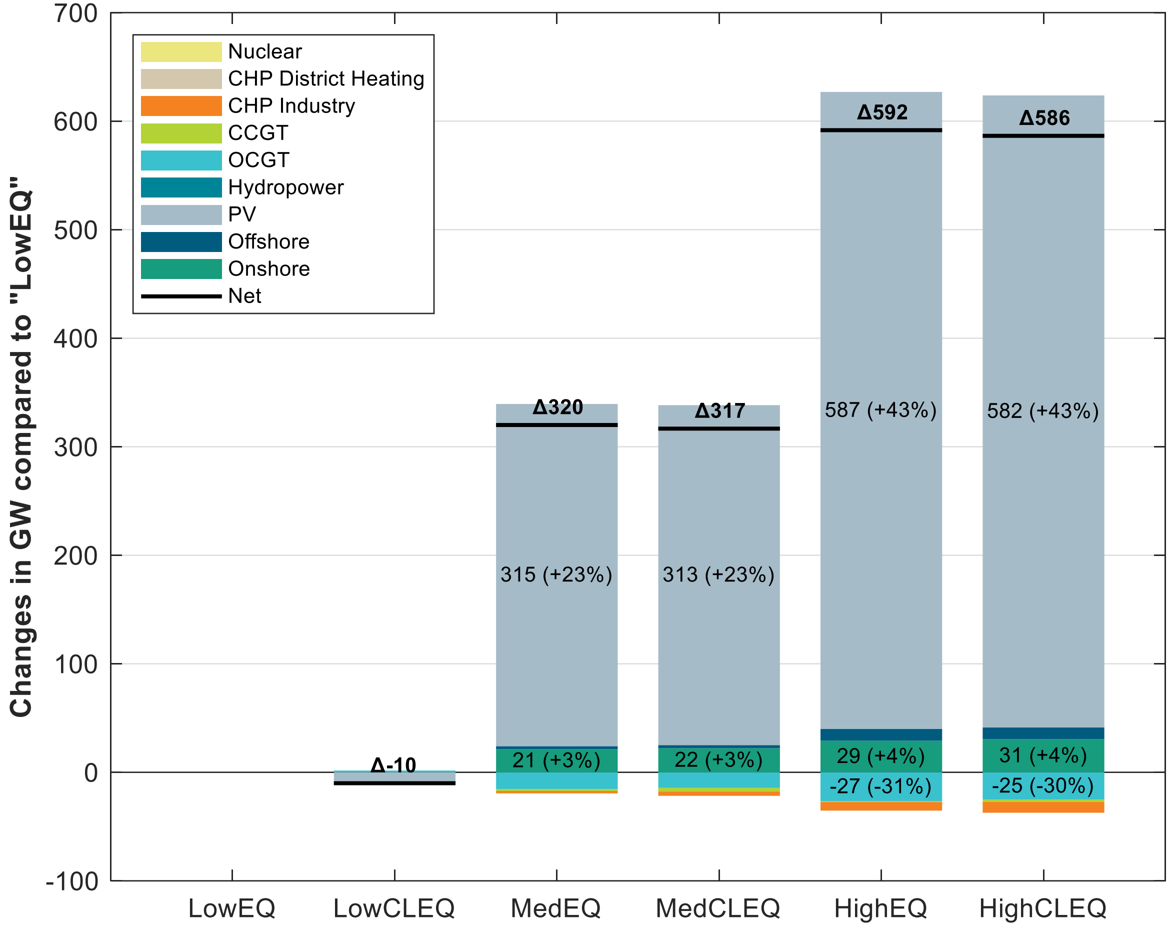




Note that relative comparisons use LowEQ as a reference.
Hydropower modelling approaches: Equivalent (EQ), Clustered Equivalent (CLEQ)

The capacities of the hydropower plants are exogenously given in all scenarios. There are hardly any differences between the clustered and non-clustered variants





Note that relative comparisons use LowEQ as a reference.
Hydropower modelling approaches: Equivalent (EQ), Clustered Equivalent (CLEQ)

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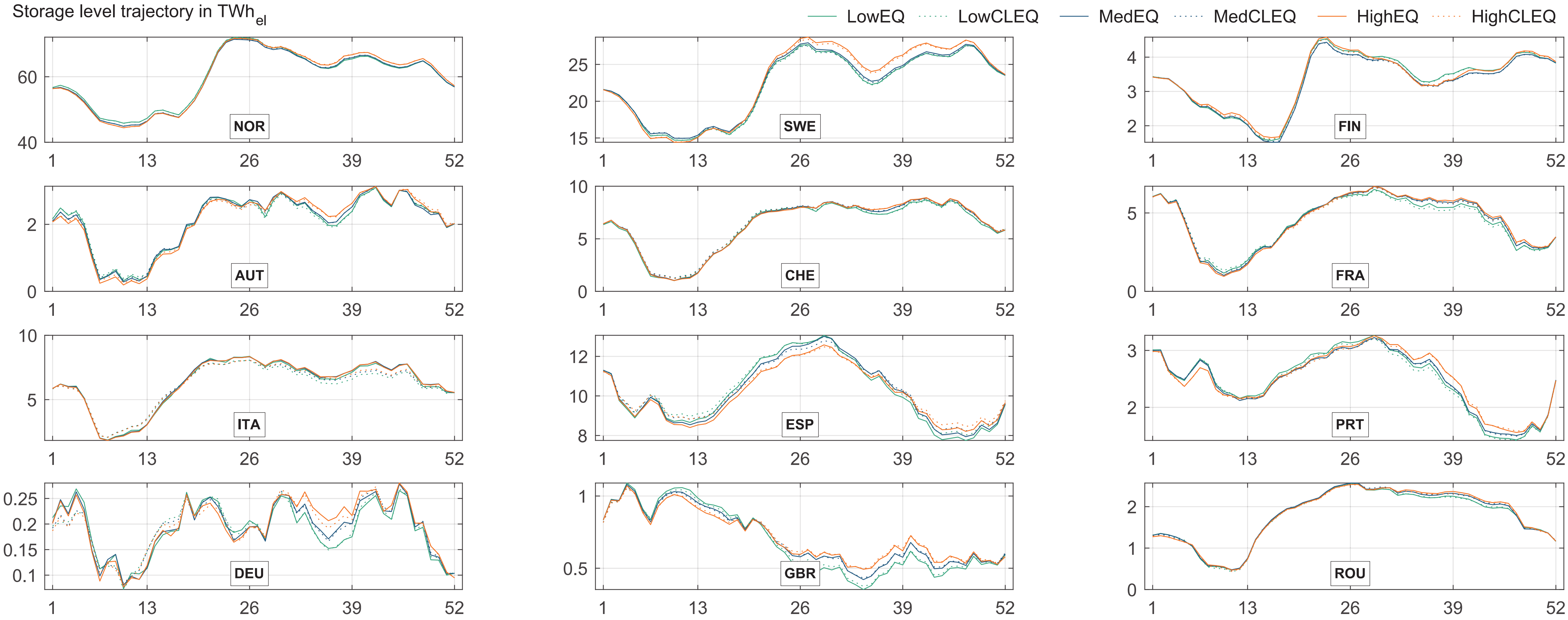
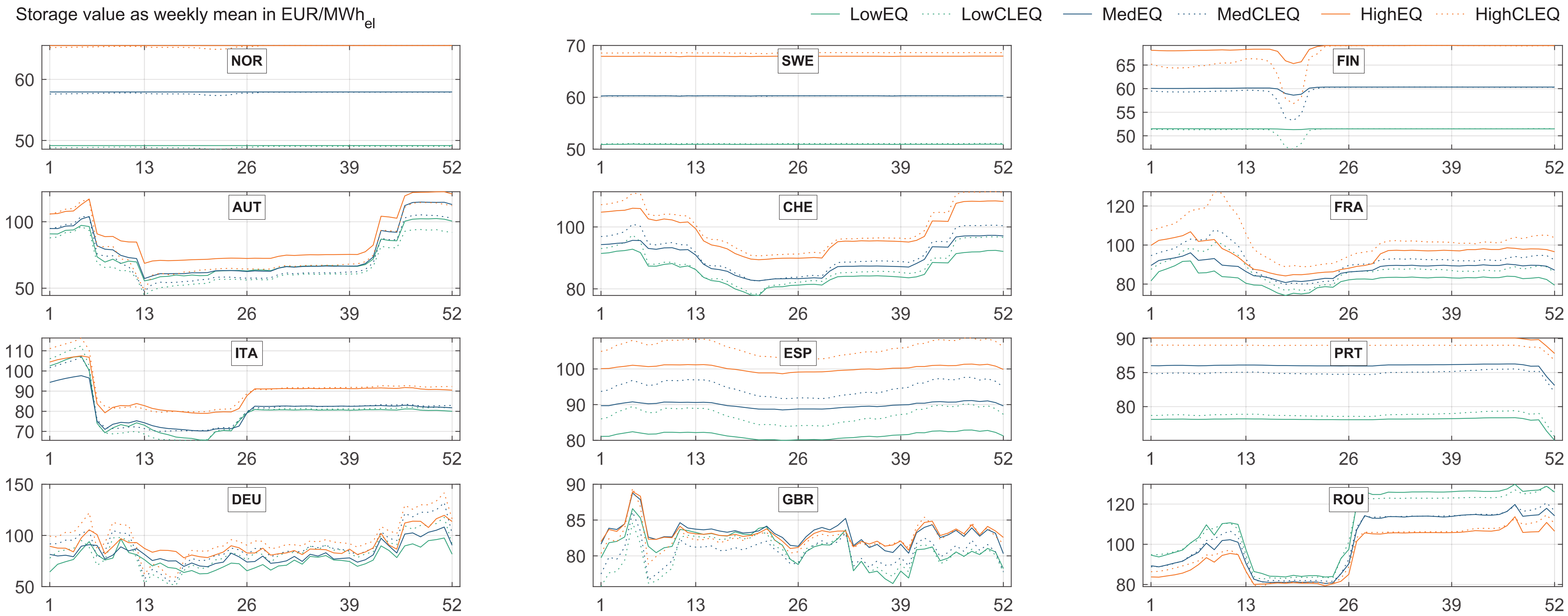
High H_2 import prices push hydropower storage more to their limits, especially in market areas with large storage capacities – only minor effects of different modelling approaches



Note that storage levels are aggregate figures from several hydropower systems in each market area.
Hydropower modelling approaches: Equivalent (EQ), Clustered Equivalent (CLEQ)

Aggregate storage values show direct influence of import prices and very different patterns and levels across Europe – hydropower modelling choice affects some areas more than others

Computational | European energy system | **Hydropower**



Note that storage values are aggregate figures (weighted mean of dual variable information) from several hydropower systems in each market area.
Hydropower modelling approaches: Equivalent (EQ), Clustered Equivalent (CLEQ)

Chapter 03

Conclusion

Summary and some take-away messages

Summary and conclusion

- The case study uses the pan-European cross-sectoral capacity expansion planning framework **SCOPE SD** to gain insights into the future **net-neutral energy system in Europe with a special focus on hydropower**

- **Import prices** for green hydrogen and renewable fuels have a **notable impact on European electricity production** capacities (up to +20%) and electricity production volumes (up to +11%)

- Clear **dependency of electrolyser production** (471-854 TWh/yr) and hydrogen import volumes (289-939 TWh/yr) on **import prices**

- **Large computational savings** (up to 90%) with **only limited effects on modelling accuracy** (0.2%) when using a clustered modelling approach for European hydropower

Aggregated modelling approaches for European hydropower **exhibit a fair trade-off** between computational efficiency and modelling accuracy (however, country-specific improvement potentials)

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Thank you very much for your attention!

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