**MSc Thesis**

Research Question:

1. Upper bound for inefficiencies of incomplete market in deep decarbonisation scenarios.
2. The impact of the degree of incompleteness in under-investments in LDES.

Specific Tasks:

1. Fully complete markets: Optimisation problem (central planner)
2. Fully incomplete markets: ADMM

Test System:

* The GB-greenfield test case will be employed, using a copper plate model (no transmission network – generators and consumers on a single-bus system).
* Ideally, use a dataset of 30–40 weather years. However, initially start with 2–3 weather years. Select extreme and/or typical years (as done in the AFRY report) to ensure adequate variability. Highlight certain years as extreme or typical. So based on what they highlight, we can choose some years to start our ‘toy’ simulations. (winter high demand: 2010 weather pattern, January week, high wind generation: January 2017 weather, weather year 2017, five historical years: 2012, 2014, 2015, 2017, 2018)
* Due to system complexity, reduce data resolution to monthly or quarterly intervals.
* Incorporate elastic demand to address price multiplicity issues, which commonly occur in inelastic demand scenarios. Elastic demand introduces quadratic objective functions. Degeneracy problem refers to the non-improvement of the objective function when changing a basic variable which has a value of zero – RHS=0, (see research by S. Wogrin).

Coding:

* Julia
* GitHub Repository

PSCC 2026:

* Goal: Submit a paper to PSCC 2026.
* Deadline for 1-page abstract: June 1, 2025.

Timeline:

1. GitHub Repository
2. Data analysis (cleaning, pre-processing, selecting representative years, reducing data resolution)
3. Julia optimisation models on generation capacity expansion (<https://github.com/Power-Systems-Optimization-Course/power-systems-optimization/tree/master?tab=readme-ov-file>)
4. Abstract for PSCC 2026
5. Fully complete markets (central planner)
6. Elastic demand
7. Fully incomplete markets (ADMM)
8. In parallel, continue thesis and logbook writing
9. Poster & Presentation after submitting the thesis

**Setup and Findings Questions:**

**1. What is the research question?**

Estimate the impact of lack of hedging instruments on LDES investments. By comparing the social welfare under two cases: a fully complete and a fully incomplete market, the results will provide an upper bound for the value of hedging instruments policymakers are considering, offering insights for market design and regulatory strategies to support LDES deployment.

**2. Key Performance Indicators (KPIs)?**

* Total Social Welfare (Objective Function Value): Represents the sum of consumer surplus and producer surplus net of investment costs. SWcomplete=Consumer Utility (or Surplus)−Total System Cost (CAPEX + OPEX)

SWincomplete​=Consumer Surplus+Generator Revenues−Generator Costs (CAPEX + OPEX)

* LDES Investment Levels: Energy capacity and Power capacity (E/P ratio not fixed).
* System costs: Total capital and operational costs of the system. This can help to quantify the inefficiencies because of sub-optimal investment decisions.
* Unserved Energy or Energy Not Stored: Due to our flexible demand this should not be a problem (the flexibility in our cases, should we take into account the load recovery period or is more abstract?)
* Shadow prices?

**3. How many weather years?**

For LDES technologies, I want to include hydrogen therefore our timeline is post-2035. Let’s aim for 2040-2045, which aligns with hydrogen deployment and is approaching net zero targets, so by that time we will be in deep decarbonization scenarios. Therefore, I plan to use 15-20 years of weather data to capture inter-annual variability and different stress events. ADMM with 15-20 years it should be okay with tractability. If not, we are going to use reduction techniques. So max 15-20 scenarios.

By modeling 2040-2045 with 15-20 different historical weather years, we capture inter-annual variability in system operation and revenues streams for these technologies.

**4. Where you could obtain the data?**

We have demand and weather data. The data for the different storage and generation technologies should represent the specific year 2040-2045. We will need to scale the demand for that year 2040-2045. The demand will increase due to: electrification (transport, heating, industry), population growth, economic growth. We can use just a scaling factor so we can preserve the shape of the load. What is happening with base demand (what we have right now) and new loads (EVs and HPs). All technologies, costs, policies, and infrastructure represent what you expect in 2040-2045. For 15-20 weather years: we should include typical years, low wind, high demand, winter peak, summer shortfall, stress events.

**5. Do you expect the model to be computationally tractable with these assumptions?**

Yes, we have techniques to make it tractable if there is a problem (monthly or quarterly resolution or weekly/daily). CPLEX should be fine, ADMM is better at scaling than KKT/MCP/PATH but I will also try that if we have a problem.

**6. Do you need scenario or timestep reduction (reduction techniques, year to select time resolution)?**

We will choose 15-20 from 40 weather years so we reduce our dataset by 50%. If we have performance issues then we will try to move to daily or weekly and scale up accordingly. Maybe some chronological clustering for each year. The goal is to simulate hourly data. Within each weather year to preserve key temporal features such as seasonal storage cycles, and Dunkelflaute events.

**7. What technologies you should include?**

CCGT, PV, WIND, NUCLEAR, LDES. The data for these must represent 2040-2045. And for LDES should we split it to PHS, CAES, H2 or keep it as LDES. If we keep it as LDES how are we going to define their C\_v, C\_inv, WACC etc? Our goal however is not to compare between different LDES. Better to aggregate and have one LDES technology. We can use weighted average between 3-4 techs.

**8. What future year or horizon are you modelling?**

A year between 2040-2045, deeply decarbonized power system, it aligns with policy (strategies to significantly reduce emissions by 2040-2045), far enough to assume mature deployment of all included technologies (hydrogen technology readiness level), system maturity (lots of VREs by that time).

**9. Is the greenfield expansion approach appropriate?**

Greenfield (no existing assets), Brownfield (existing assets). So yes it is appropriate because we will compare the investments decisions between complete and incomplete. If you include existing assets you will bias the decision of the system. We are quantifying the impact of risk trading not how we are going to develop form 2025 to 2040. By modeling a greenfield system, we ensure that observed differences in investment — particularly in LDES — result from market design (based on hedging and risk trading), not historical assets.

**10. How valid is this setup for the system/regulator you want to support?**

It is a future system where we have high VRE shares, electrification, and need for LDES which are highly relevant to regulators. We analyze market design and policy. We are not forecasting exact investments, but we want to provide an upper bound for the value of hedging. Using this work, regulators can define contracts, evaluate market completeness, and policy gaps for LDES.

**11. How to specifically model LDES?**

More discharge duration e.g. more than 6 hours if you have nominal power, less efficiency than BESS, non zero operation costs per MWh charged or discharged in order to limit frequent cycling. We need to allow LDES to carry energy for days or weeks or months. +++

**12. How will you ensure that the mix will be high VREs?**

We can enforce a minimum level of VRE capacity, for example 70% of demand must be met by RES and LDES or the capacity of VREs should be x% from the total but this is more complicate due to capacity credit (for example 40 GW wind can replace 4GW gas).

We can add emissions cap or CO2 price but then we will do the same as Emil’s.

We can play with technology parameters (cheap RES, fossil fuel more expensive)

**13. Should you include other uncertainties (besides weather)?**

With demand scaling you include also limited demand uncertainty. We will not have uncertainties in costs, technology availability, or policies because we want to see the effect of market incompleteness. If you add too many things, it will be hard to explain the outcomes. Electricity prices and market volatility is the outcome of the model (ADMM market clearing) so no need to define anything for that. For technology costs we will estimate their values based on some assumptions about 2040-2045 (no need for uncertainties here). WACC (keep it as fixed point but differentiate among different technologies). We can change the WACC for sensitivity analysis but we will not model it as stochastic. We are using a copper plate model so no need for uncertainty regarding interconnection, import-export, transmission. Operational uncertainty (e.g. outages, we do not really care as we model long term capacity expansion planning). LDES availability constraints (this is not uncertainty is how you model LDES, of course there will be some uncertainty because we will model it as LDES rather than H2 or PHS but there is no need to use stochasticity here).

We want to isolate and measure the impact of market incompleteness. If we introduce many other uncertainties would make everything more complex and not easy to explain. We will capture the most relevant sources of uncertainty:

* Renewable production,
* Load patterns,
* Storage utilization,
* Investment value of LDES.

Deadline:

29/08/2025

