Moving Ontario to a 100% renewable electricity grid: system operation for renewable integration

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Ontario Climate Symposium - long term energy policy panel

Objective

Gradually move Ontario from its current electricity configuration to a 100% renewable system

Challenge: integrating wind and solar resources with their variable nature

Focus on the electricity system design, from an operational perspective:

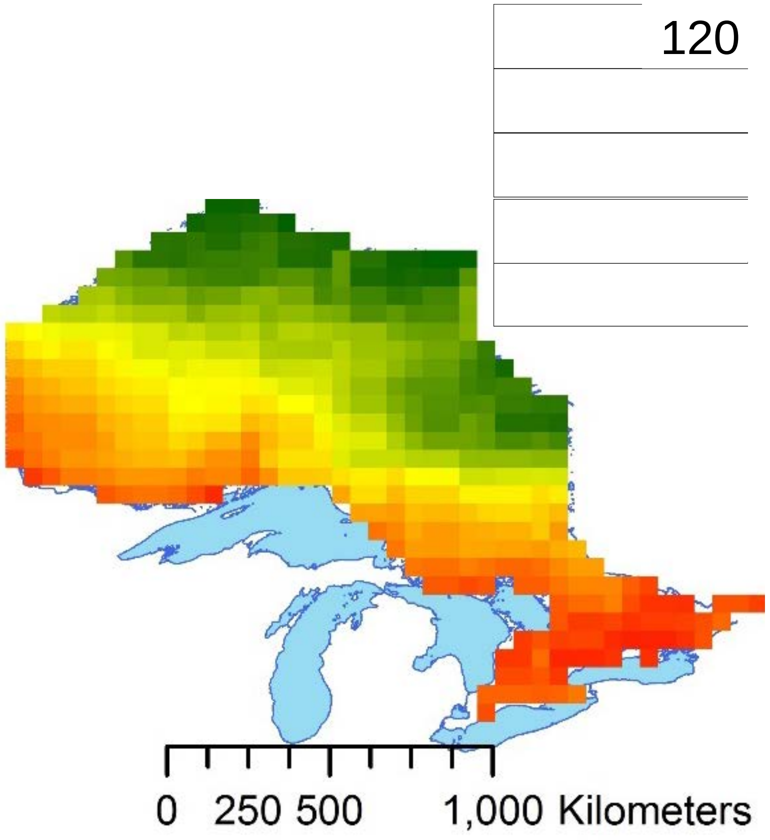
- Understand the interactions between flexibility resources:
  - Demand response (DR)
  - Storage assets (PHS)
  - Curtailment
- Quantify costs & GHG emissions
- Understand the implications of system design on system operation:
  - Baseload generation
  - Market design

The SILVER Model

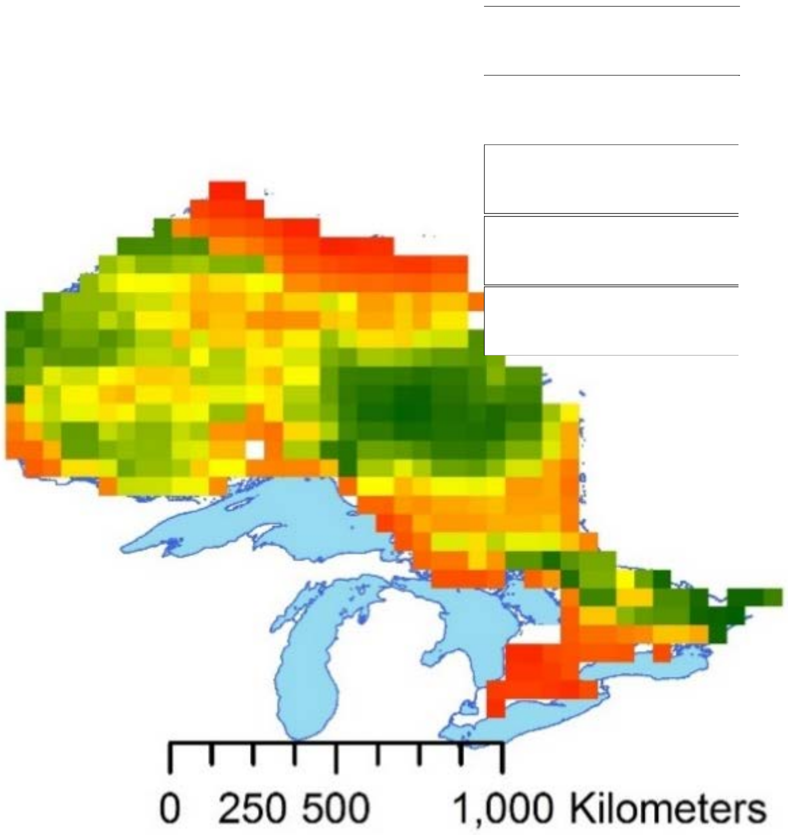
- Production cost model with mixed-integer linear formulation
  - Unit commitment, economic dispatch, and optimal power flow
- Grid operators scale
  - Spatially – Ontario's balancing area
  - Electricity only – other energy carriers can be indirectly quantified
  - Hourly temporal resolution
- Scenario design approach:
  - Test twelve scenarios – full Ontario system to 100% RE
- Analysis: annual electricity system dispatch
  - Flexibility requirements
  - Costs
  - GHG emissions

Ontario's resources and existing assets

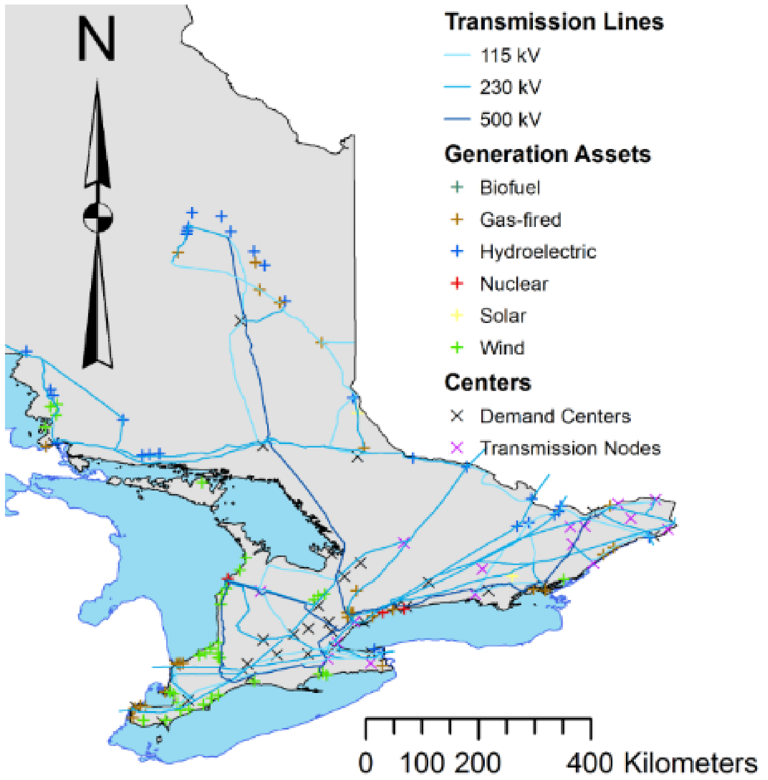
Average (annual) solar irradiance [W/m2]



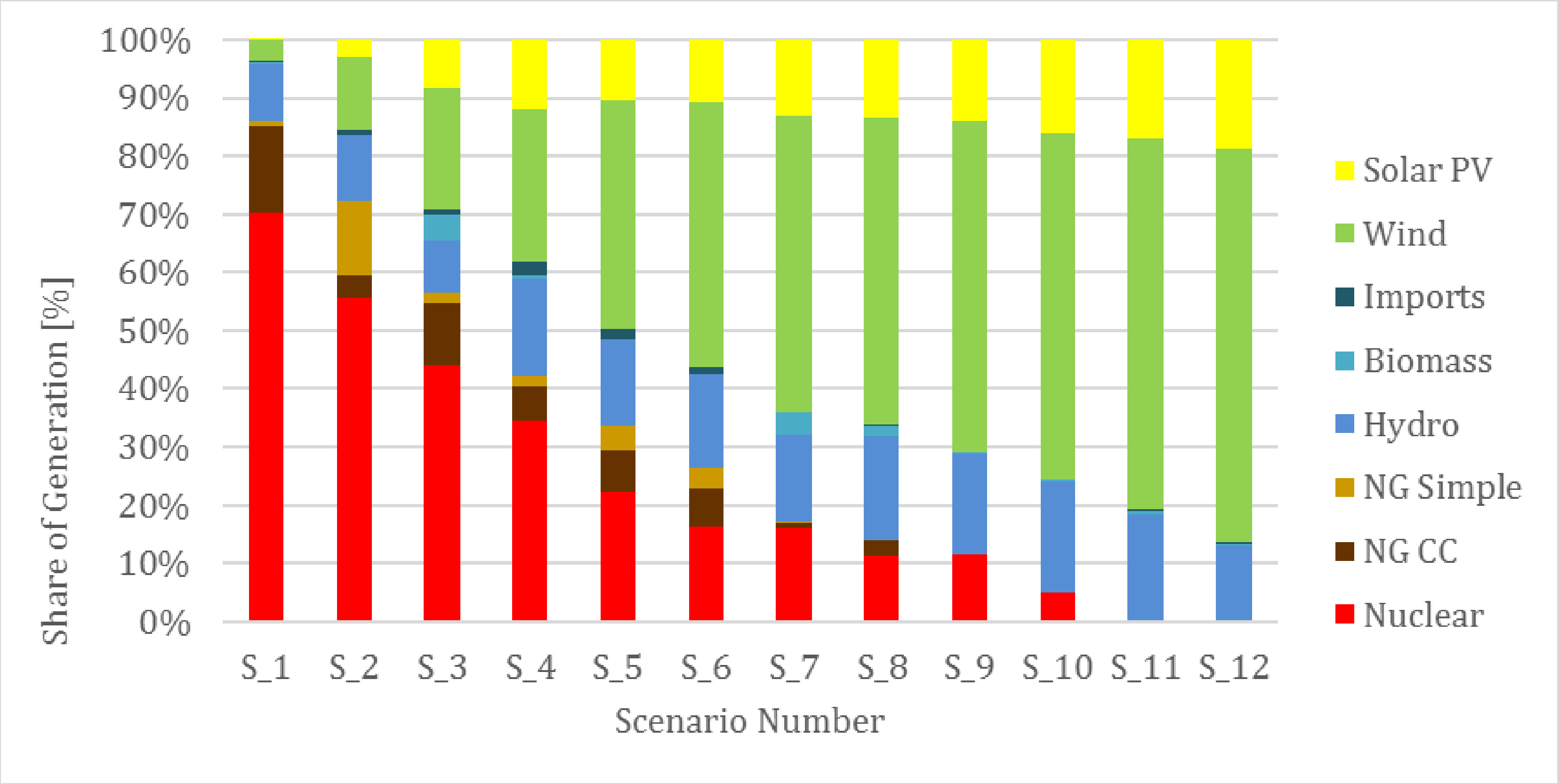
Average (annual) wind speed [m/s]



Existing electricity infrastructure

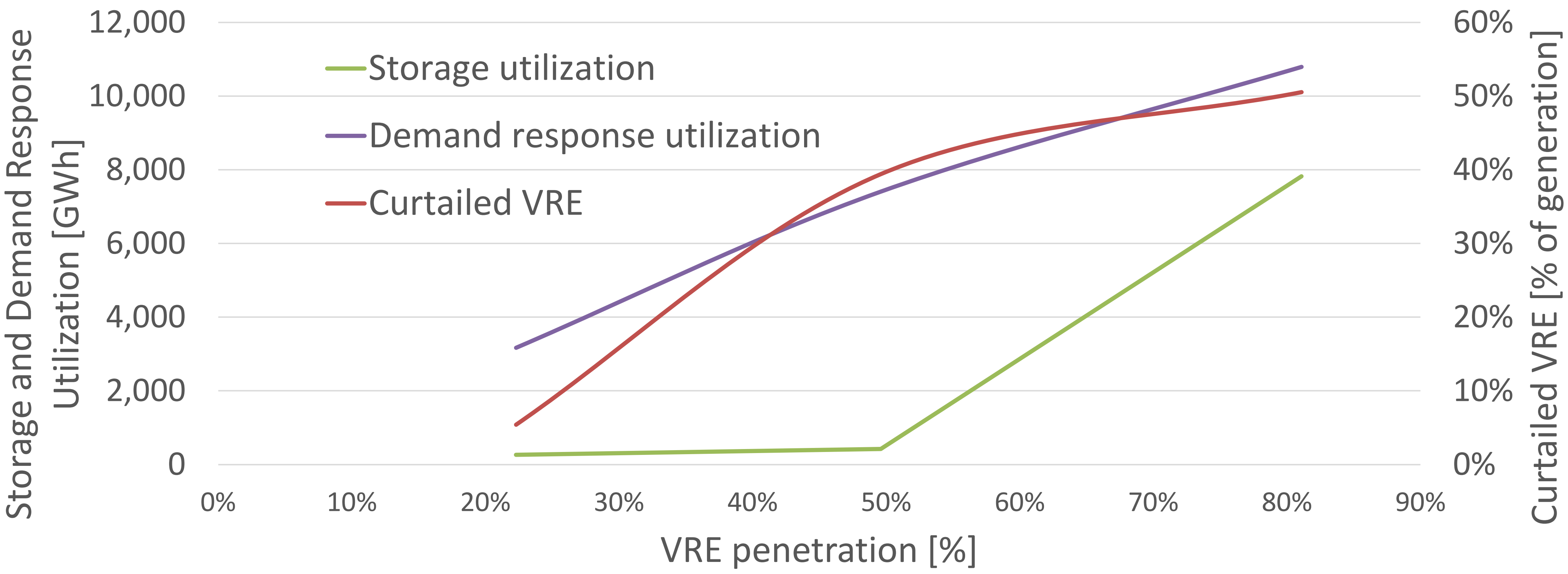


Ontario transformation: twelve scenarios



- Phase out natural gas and nuclear
- Phase in wind, solar PV, biomass, hydro
  - pumped hydro storage, electric vehicles, demand response, and curtailment

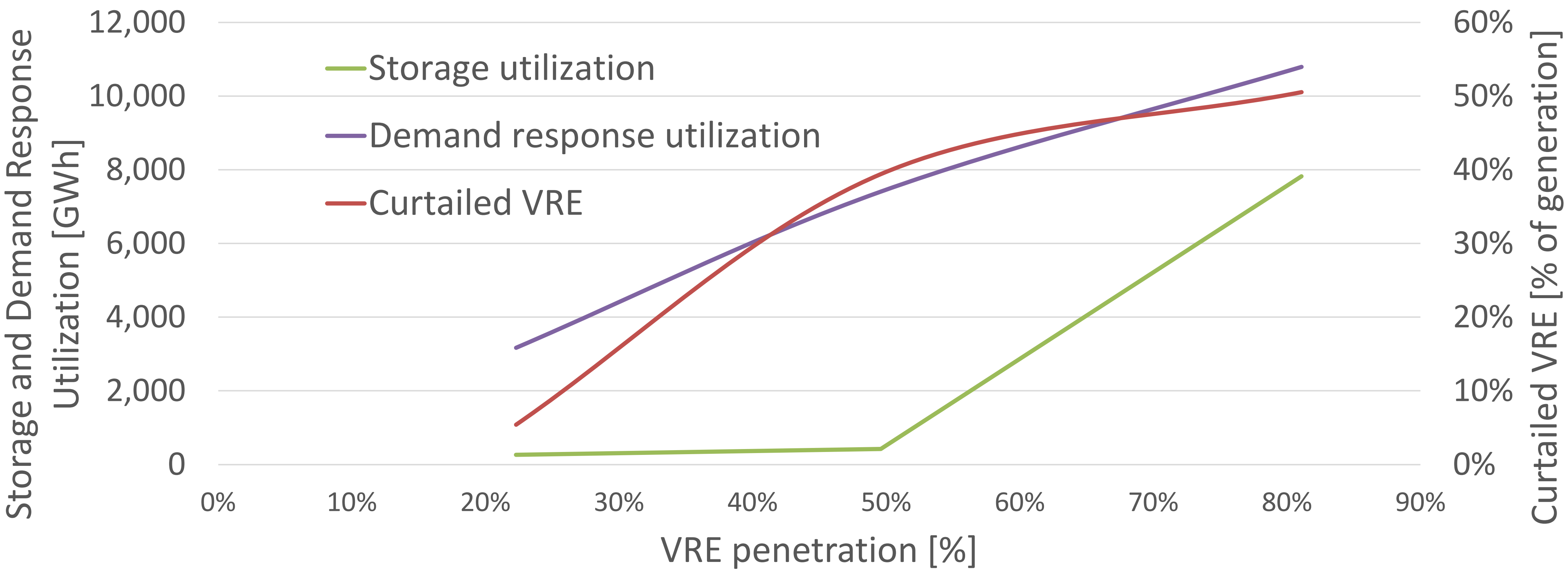
Flexibility resource utilization & curtailment rates



Demand response utilization rates

- Increase relatively consistent increase with VRE penetration
- Reaching maximum utilization rates at about 70% VRE penetration

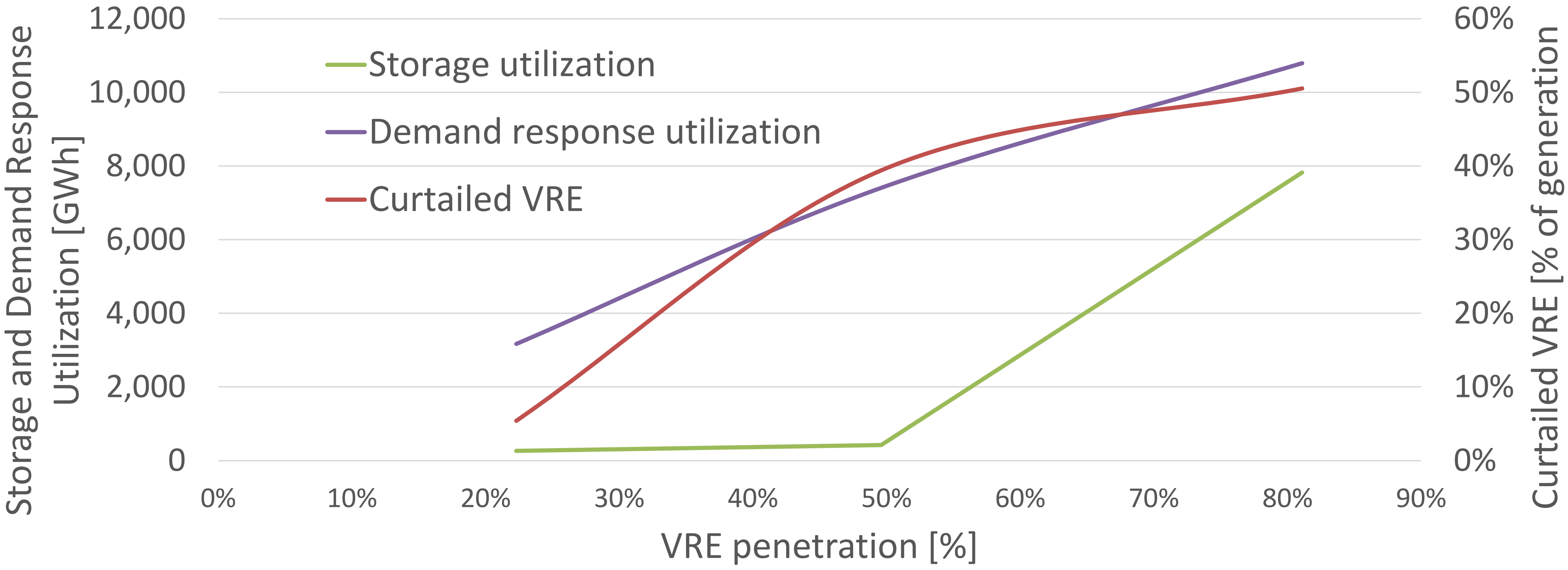
Flexibility resource utilization & curtailment rates



Storage utilization rates:

- Lower than demand response utilization rates at all VRE penetrations
- Near-zero for VRE penetrations < 50%
- Catches up at higher VRE penetrations, drawing down curtailment

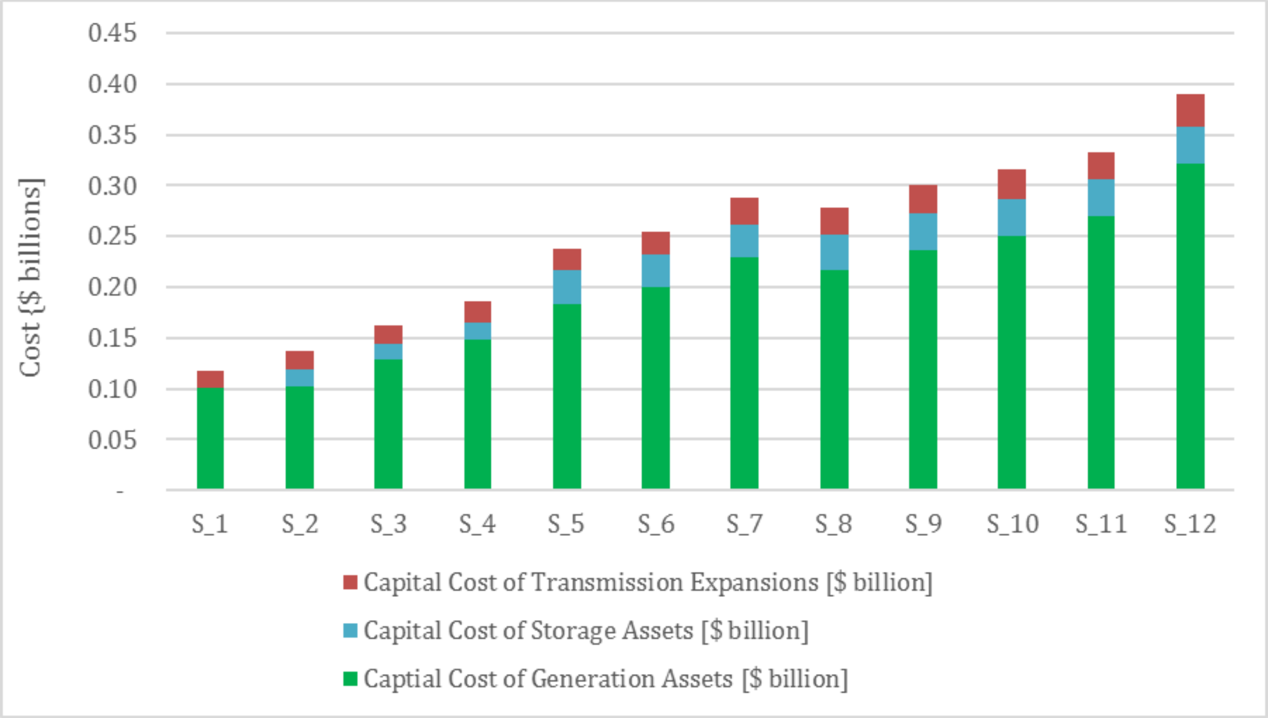
Flexibility resource utilization & curtailment rates



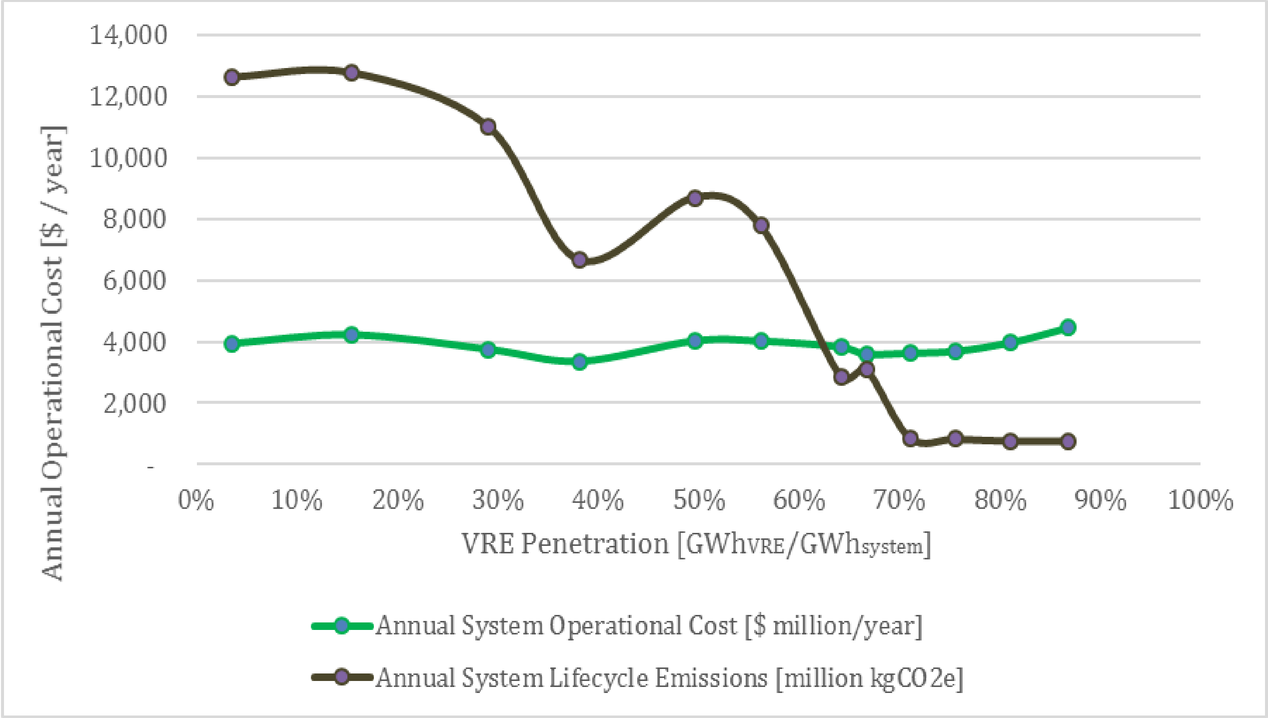
Curtailment rates

- Increase consistently with VRE penetration to ~50% VRE penetration
- Plateau for VRE penetrations > 50% when storage utilization increases

System costs & GHG emissions



Capital costs of generation assets, storage assets, and transmission expansions for each Scenario



System annual operational cost and lifecycle emissions as a function of VRE penetration

*Non-smooth decrease in GHG emissions is a red-flag for specific grid configurations

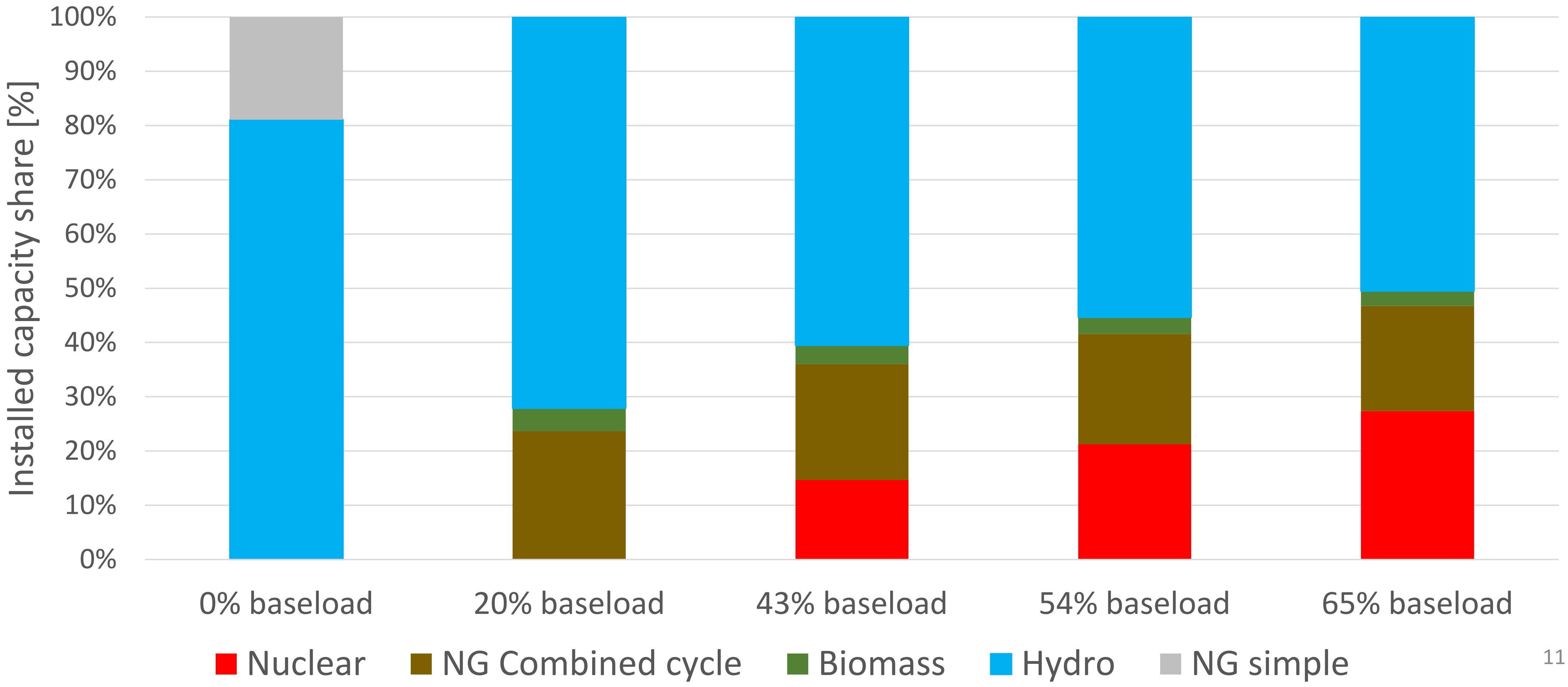
Follow-up exploration:

How should we design the electricity system to effectively accommodate high penetrations of renewable resources?

- System configuration design: flexibility
- Electricity market design: remuneration mechanisms for storage assets

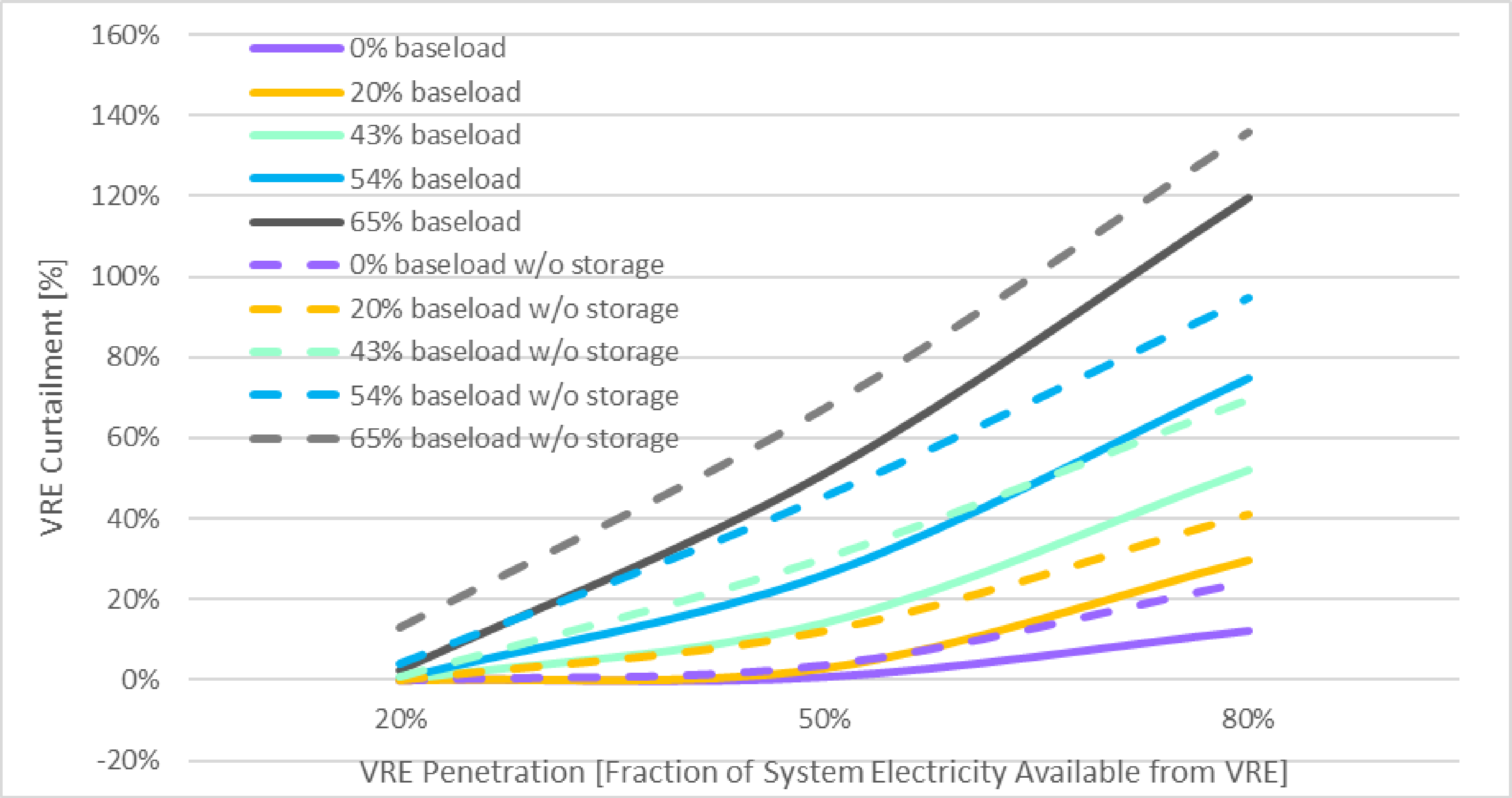
System flexibility

- ***Percentage of must-run baseload generation***
- ***High start-up costs plus long minimum off times >> must-run baseload***



System flexibility

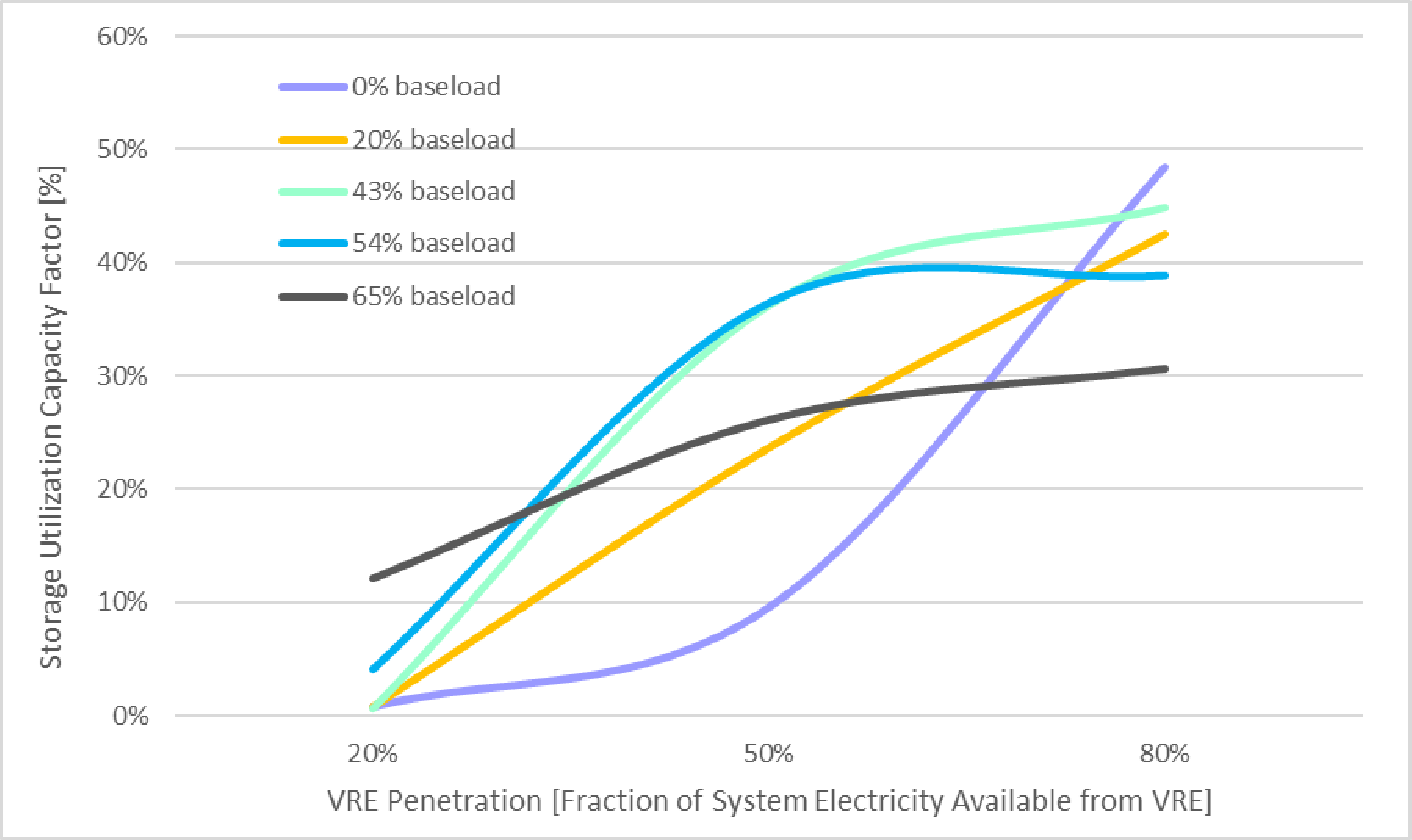
- ***Impact on curtailment > system with and without storage***



- Storage assets draw down curtailment to some extent
- System flexibility has a larger impact
- Curtailment increase non-linearly as flexibility decreases

System flexibility

What about utilizing storage to add flexibility?



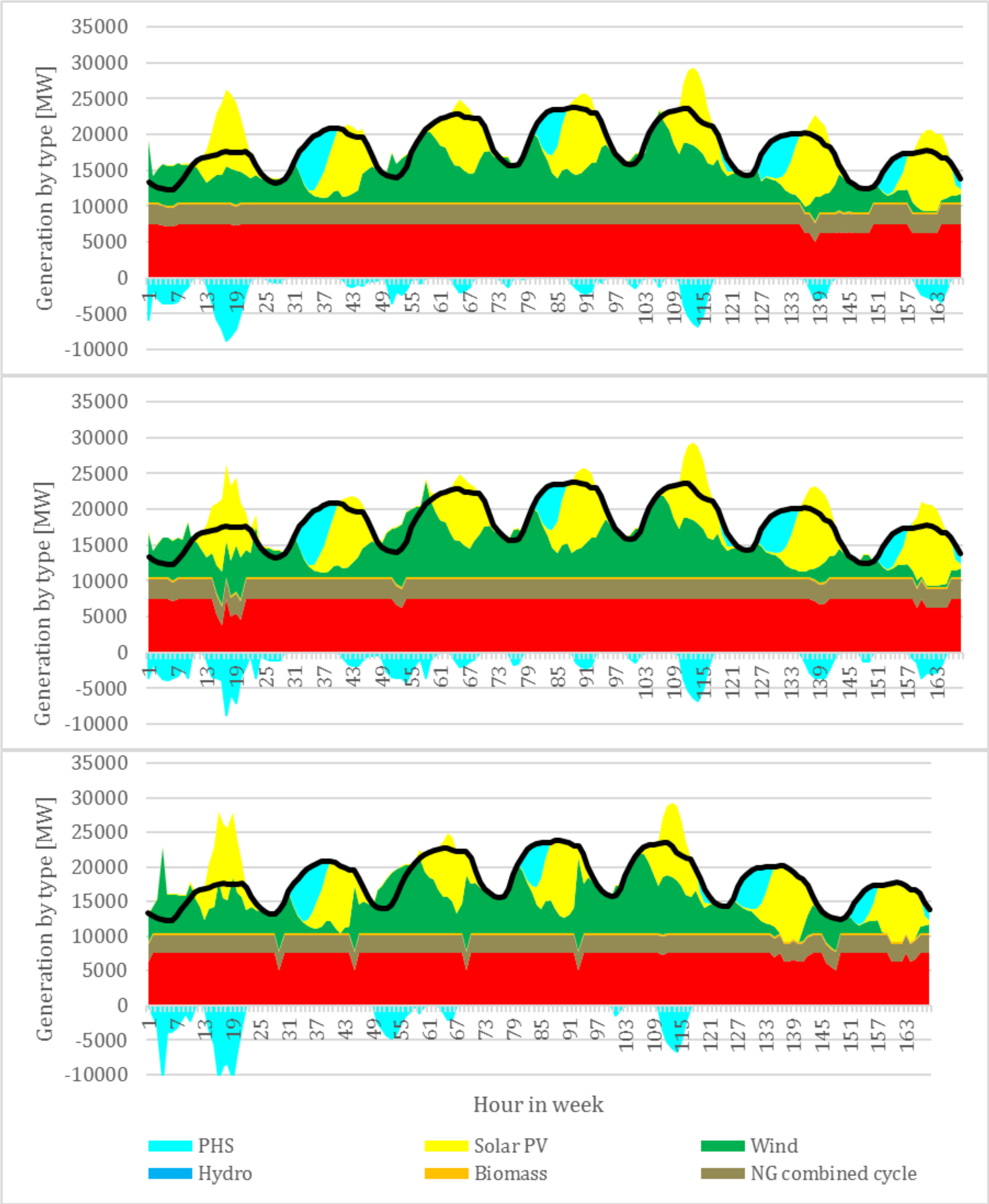
Storage is limited in is ability to add flexibility to a high-VRE, high-baseload system

- Flexible system: storage is utilized a lot to mitigate VRE variability
- Inflexible systems: storage utilization plateaus for higher VRE penetrations
  - Energy perspective: PHS Storage assets can't mitigate annual over-generation
  - Cost perspective: Storage can't reduce costs by dispatching low-marginal cost (VRE generation) because of high-marginal cost assets are must-run

Remuneration mechanism:

How are storage assets remunerated by the electricity market?

Impact on dispatch



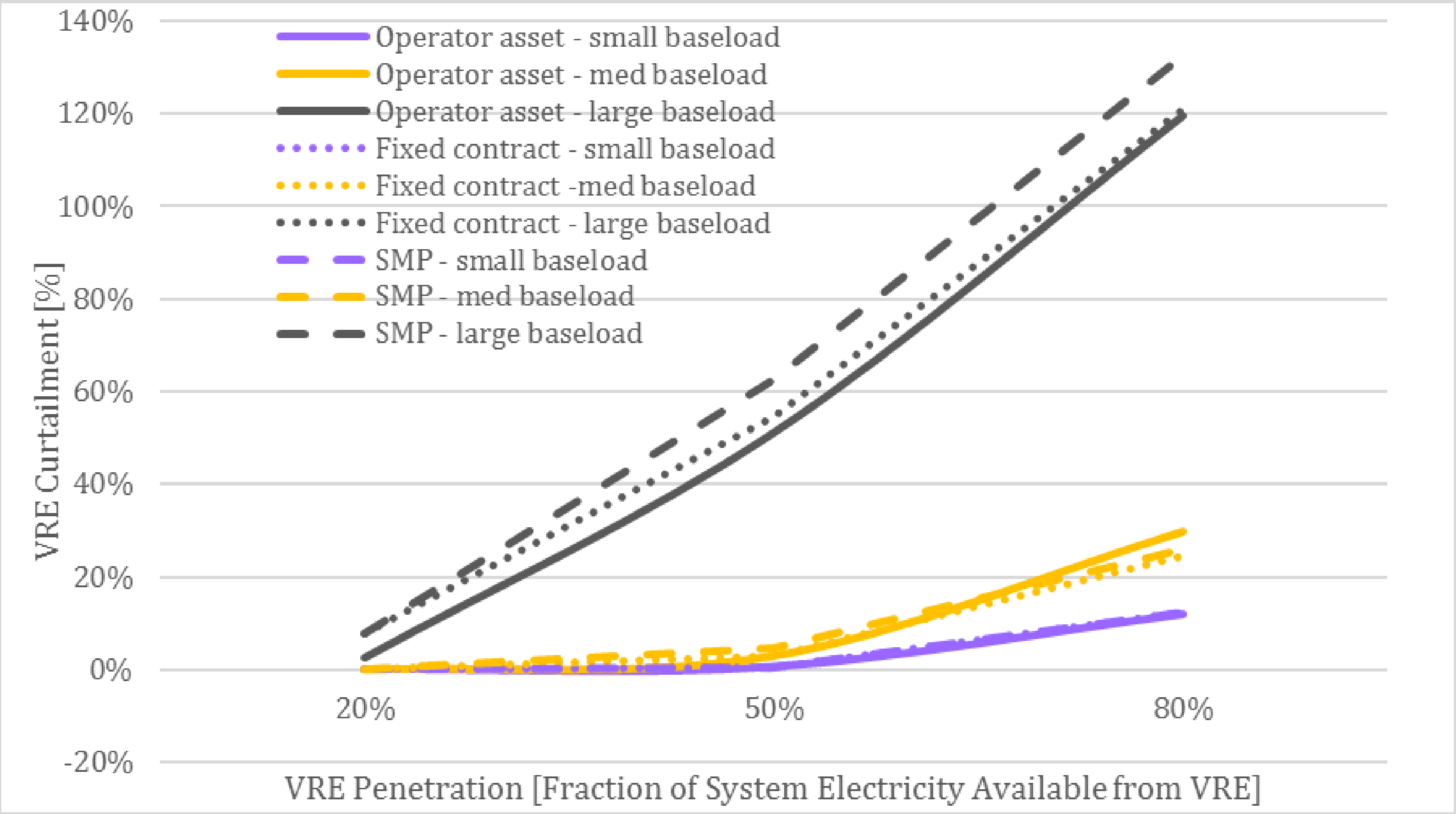
<u>Operator asset:</u> no explicit pumping or generating cost

<u>Fixed contract payments:</u> generation from storage asset is paid fix price (like a FIT)

<u>Spot market prices:</u> storage asset pays hourly market price for pumping

Market design: Storage remuneration mechanism

- ***Impact on curtailment***



- Depend strongly on system flexibility
- Remuneration mechanism has larger impact in inflexible system

Modelling conclusions:

- The 100% renewable electricity system operates
- High utilization rates of demand response and storage assets
  - For VRE penetrations greater than 50% storage utilization increases rapidly
- DR and storage assets ‘compete’ to draw down curtailment
  - Storage utilization increases when DR resources are reaching their limit
- GHG emissions local maxima under increasing VRE penetrations
  - Natural gas replaces nuclear, and in doing so increasing GHG emissions

Policy implications moving forward

- Electricity system design:
  - System flexibility plays a large role in both curtailment rates and flexibility utilization rates
  - **Phasing in wind and solar needs to be accompanied by phasing out inflexible generators**

  - The relative balance of nuclear, gas, and renewable (not just renewable penetration) impacts GHG-emissions
  - **Perform operational modelling of proposed grid configurations before committing to capital investments**

  - **Need to be strategic about the electricity grid configuration to make renewable integration effective**

- Market design:
  - Competition between DR, PHS, and EV depend on respective remuneration mechanism
    - Net load curve variability drives assets with fixed price remuneration
    - System marginal price variability drives assets performing price arbitrage
  - **Future policies should account for this competition and sensitivity to remuneration mechanism**

  - A longer dispatch planning horizon will encourage better utilization of flexibility resources

  - **Prioritize effective strategies for including novel flexibilities on the electricity market**

Thank you!

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