*Study of Australia's Future Electricity Supply, Optimised for Cost, Reliability and Carbon Intensity*

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**Australia**

# Context

- Greenhouse Gas (GHG) Emissions must be reduced to limit global temperature rise to within 2 ºC average.

- **Australia's** GHG emission reduction target: **43% by 2030** (below 2005 levels)
  … translating to 83% of electricity from renewable energy.

- There are current **Federal and State legislative bans** on nuclear energy in Australia.

Roadmap

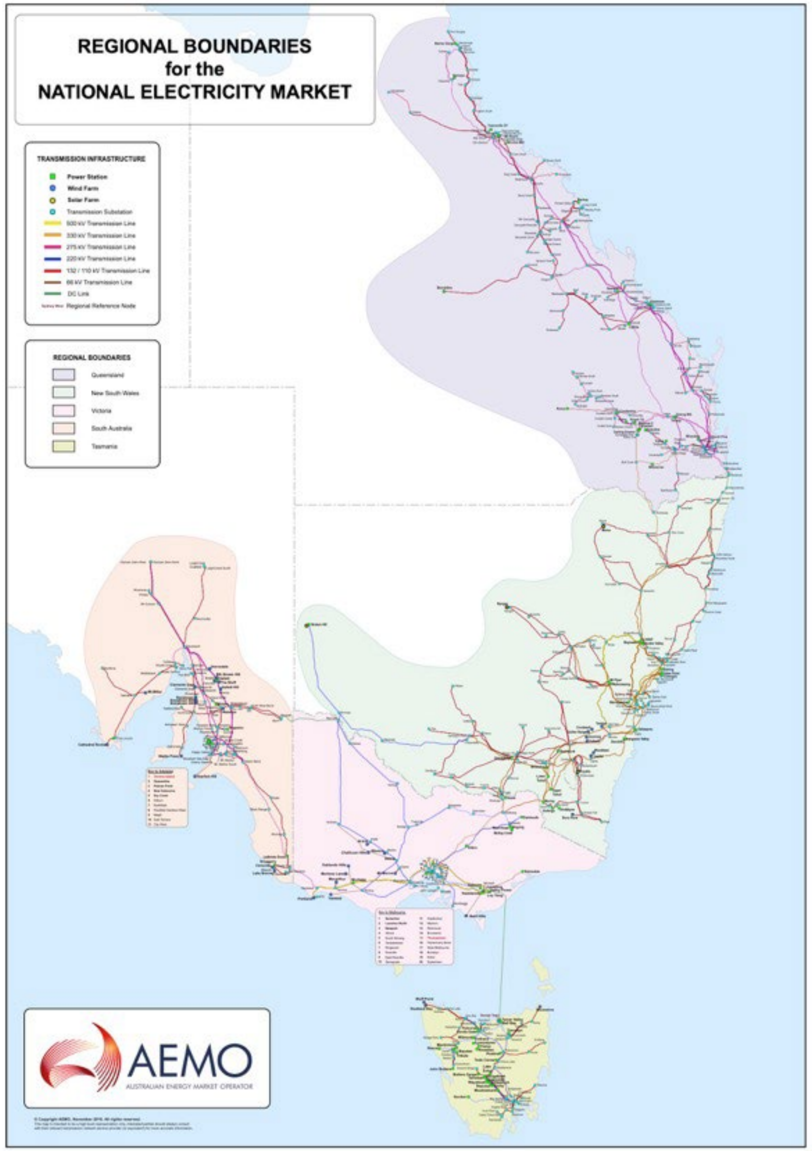
- **Power System models** are required to understand the **Opportunities, Challenges and Costs** of this clean energy transition**.**

- Some power system models focus on the long term investment implications (eg. Capacity planning models)

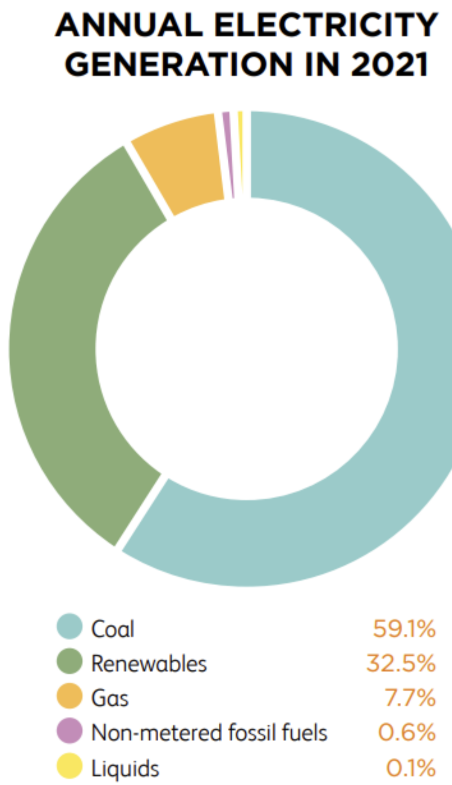
- Other power system models capture operational aspects of the system (eg. Unit commitment and dispatch models)

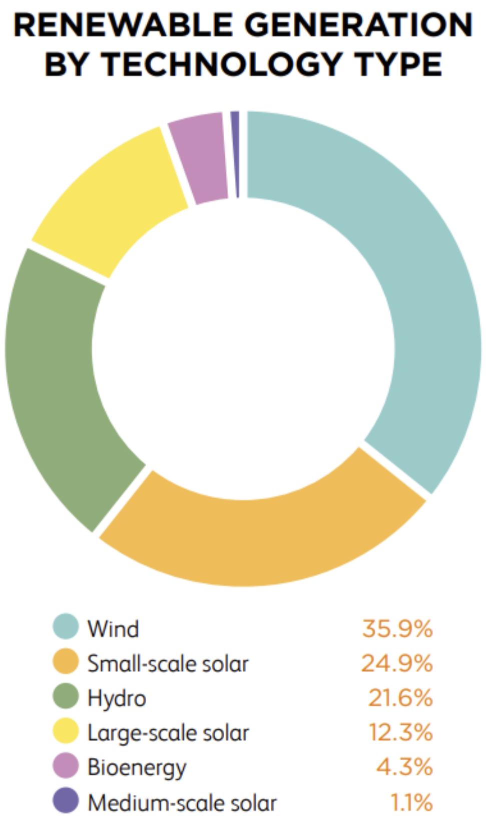
# Context

- The Australian National Electricity Market **(NEM)** is expected to undergo a **large** and **significant** transformation for **reducing greenhouse gas emissions (GHG)**.
- **Electrification** is a common strategy for decarbonising other sectors.
- It is a sector that must be **transformed** for achieving deep decarbonisation.
- The Challenge: deploy a **Low-carbon**, **Reliable** AND **Affordable** electricity system.



# The Australian NEM is changing



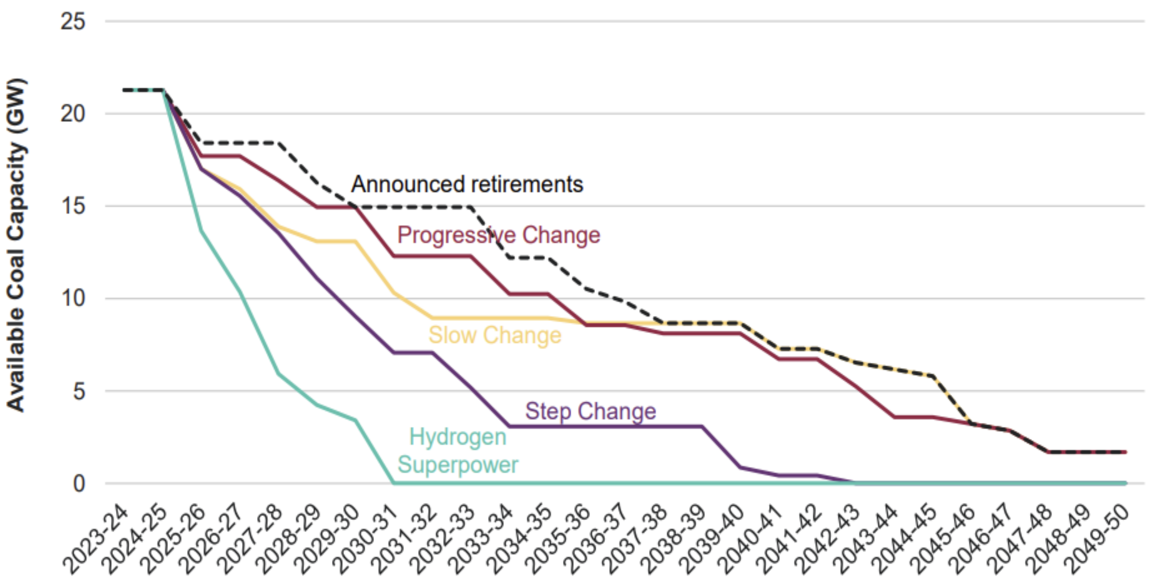

source: Clean Energy Australia Report, 2021

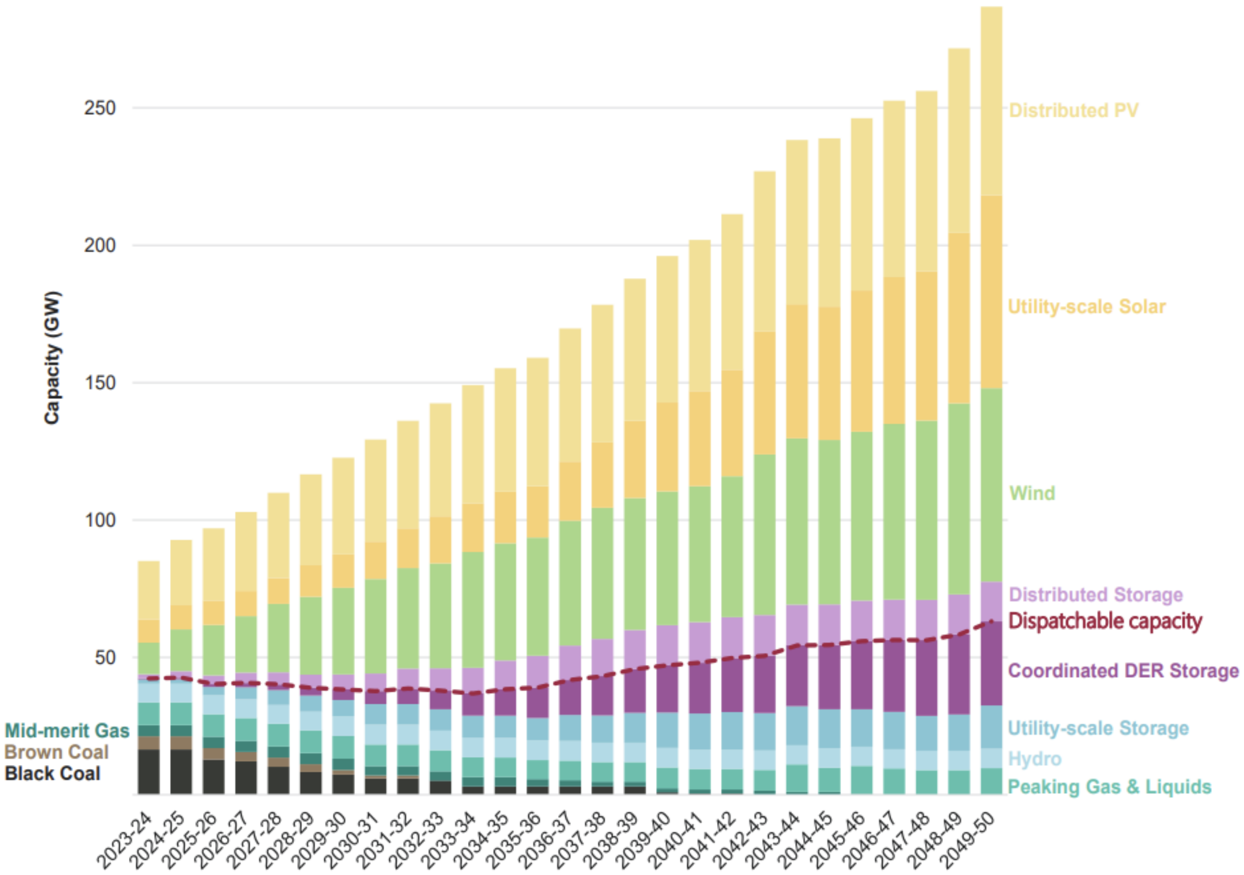
Main renewable and GHG targets by states in the NEM:

- **Queensland**: 70% renewable energy generation by 2032.
- **New South Wales**: 50% emission reduction target by 2030.
- **Victoria**: 50% renewable energy generation by 2030.
- **Tasmania:** 200% renewable energy production by 2040.
- **South Australia:** 100% renewable generation by 2030.

# The Australian NEM is changing: AEMO's official plan

### Forecast NEM Capacity by 2050. AEMO 2021 ISP Report



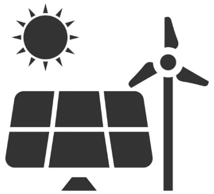

- Between **70%** and **100%** of existing **Coal** capacity is expected to **retire** in the coming decades.
- A small portion of **Gas** plants are expected to remain in the system.

**A significant amount of retiring capacity must be replaced**

# Considerations

Electricity systems are **Complex systems** with a range of technologies (each with different technical and economic parameters) operating together to **match electricity demand at ALL TIMES**.

Different technologies have different investment and operating costs, but they also pose a **different value to the system:**



**Solar PV and Wind** have **low costs (estimated LCOE ~$50 to $60 /MWh)**, but they are **variable and location specific**, thus they required additional support services and investment  (e.g., storage, backup, transmission, etc) to firm their generation.

Dispatchable low carbon electricity generation technologies (as nuclear and hydro) have **higher costs (estimated LCOE for NuclearSMR ~$100/MWh)**, but they can **provide firm dispatchable generation**.

# Modelling Approach

- For capturing the whole system implications of decarbonising the NEM, we need to **simultaneously capture, 1) investment** and, **2) operation** dimensions of the system.
- This will allow to determine the **full system impacts** and the **most cost-effective approach** for achieving **deep decarbonisation**.
- For this, we developed a **long-term electricity capacity planning model with an embedded short-term operational/unit-commitment formulation.**
- The model is applied to the whole NEM, and different runs were conducted for **different GHG limits** and capital costs (CAPEX)

**Main features of our Investment and Operations Electricity system model:**

| MILP Least-Cost Optimisation | Investment & operations | 2040/ hourly | Renewables, coal, gas, hydro, among others | Nuclear SMR |
| --- | --- | --- | --- | --- |
| Model type | System dimensions captured | Time horizon & Time resolution | Generation technologies | Additional case evaluated |

# Model Definition – which time domains does our model address?

**system investment** *simultaneously optimised*
*over five regions with* **24x365 = 8760 hourly dispatch**

One millisecond | One second | One minute | One Hour | One Day | One Week | One Month | One Quarter | One Year | One Decade | One Century

**instantaneous & near-real-time CAPACITY, system strength and stability issues**

**UNIT COMMITMENT MODELS**

- **SRMC: Short-Run Marginal Costs**
- **Operational constraints and costs**
  - **Fixed and variable O&M**
  - **Fuel costs**
  - **Ramping and cycling costs**
  - **Unit commitment constraints**
  - **…etc.**

**..but usually long-term investments and divestments are not captured**

**CAPACITY PLANNING MODELS**

- **LRMC: Long-Run Marginal Costs**
  - **Capacity mix**
  - **Investment**
  - **Divestments**
  - **Storage, transmission capacity and investment, etc**

**..but usually these models lack the resolution to capture operational constraints**

**<u>Approach of this study</u>: Long-term capacity planning model with operational constraints captured through an embedded unit commitment formulation and inter-region transmission**

# Model overview

***Model Objective Function*** *- Minimize Total System Costs:*

$$Min\ Z = \sum_{p,r} C_{p,r}^{inv} + \sum_{p,r} C_{p,r}^{fix\ O\&M} + \sum_{p,t,r} C_{p,t,r}^{var\ O\&M} + \sum_{p,t,r} C_{p,t,r}^{fuel} + \sum_{p,t,r} C_{p,t,r}^{start.up} + \sum_{sto,r} C_{s,r}^{sto} + \sum_{r,rr} C_{r,rr}^{trans} + \sum_{p,t,r} C_{p,t,r}^{carbon}$$

*CAPEX new plants* | *Fixed O&M costs* | *Variable costs* | *Fuel costs* | *Start-up costs* | *Storage costs (CAPEX and OPEX)* | *Transmission costs* | *Carbon costs (if a carbon tax is levied)*

*Subject to a set of CONSTRAINTS on:*

**CAPACITY :**
- Supply = demand at every hour
- Generation < Capacity (or committed capacity for thermal plants)
- Generation > min stable generation for thermal plants
- VRE and Hydro generation < resource availability

**STORAGE :**
- Storage level (min max)
- In and outflows
- Round trip efficiencies

**TRANSMISSION :**
- Interconnector capacities
- Flow less than capacity

**THERMAL :**
- Heat rates and fuel use (dependent on output)
- Ramping up and down limits
- Min UP and DOWN times
- Min Stable Generation
- Emission limits
- Maintenance requirements

**UNIT COMMITMENT (with individual units grouped in clusters):**
- Committed capacity < installed capacity minus units in maintenance
- Committed capacity increases with capacity coming online and decreases with capacity turned off, among others..

# Main Inputs

| Technology | CAPEX Low | CAPEX Central | VOM ($/MWh) | FOM ($/kW yr) | Fuel Price ($/GJ) | Start up Costs ($/MW Start up) |
|---|---|---|---|---|---|---|
| Brown Coal VIC | Limited to Existing Capacity | | $5.50 | $131.5 | $0.7 | $120 |
| Black Coal QLD | | | $4.30 | $53.9 | $3.0 | $120 |
| Black Coal NSW | | | $4.30 | $53.9 | $3.0 | $120 |
| OCGT | $1,407 | $1,407 | $4.10 | $12.6 | $10.0 | $100 |
| CCGT | $1,675 | $1,675 | $3.70 | $10.9 | $10.0 | $25 |
| SolarPV | $569 | $778 | $0.00 | $17.0 | $0.0 | $0 |
| Wind | $1,492 | $1,732 | $2.90 | $25.0 | $0.0 | $0 |
| Hydro reservoir | Limited to Existing Capacity | | $0.00 | $51.3 | $0.0 | $0 |
| Biomass | | | $8.40 | $131.0 | $0.0 | $0 |
| CST | $4,449 | $5,234 | $0 | $86.10 | $0.00 | $0 |
| Pump Hydro | $214 | $214 | $0 | $18.5 | | |
| Batteries li-Ion 2h | $194 | $253 | $0 | $8.1 | | |

| CASE | NuclearSMR CAPEX ($/MW) |
|---|---|
| NUC_LOW | $4,698,000 |
| NUC_CENTRAL | $6,641,000 |
| NUC_HIGH | $7,955,000 |
| NUC_VERY_HIGH | $9,912,000 |

| NuclearSMR Operational parameters | Value |
|---|---|
| FOM (A$/MW yr) | $100,000 |
| VOM (A$/MWh) | $5.3 |
| Fuel cost (A$/GJ) | $0.60 |
| Efficiency (%) | 33% |
| Ramp rate (%  per hour) | 40% |
| Min Stable Gen (%) | 30% |
| Min up and Down times (hr) | 12 |
| Start up costs ($/MW start up) | $350 |

source: *GenCost (2021).* CSIRO & AEMO report for Central and Low 2040 Costs projection

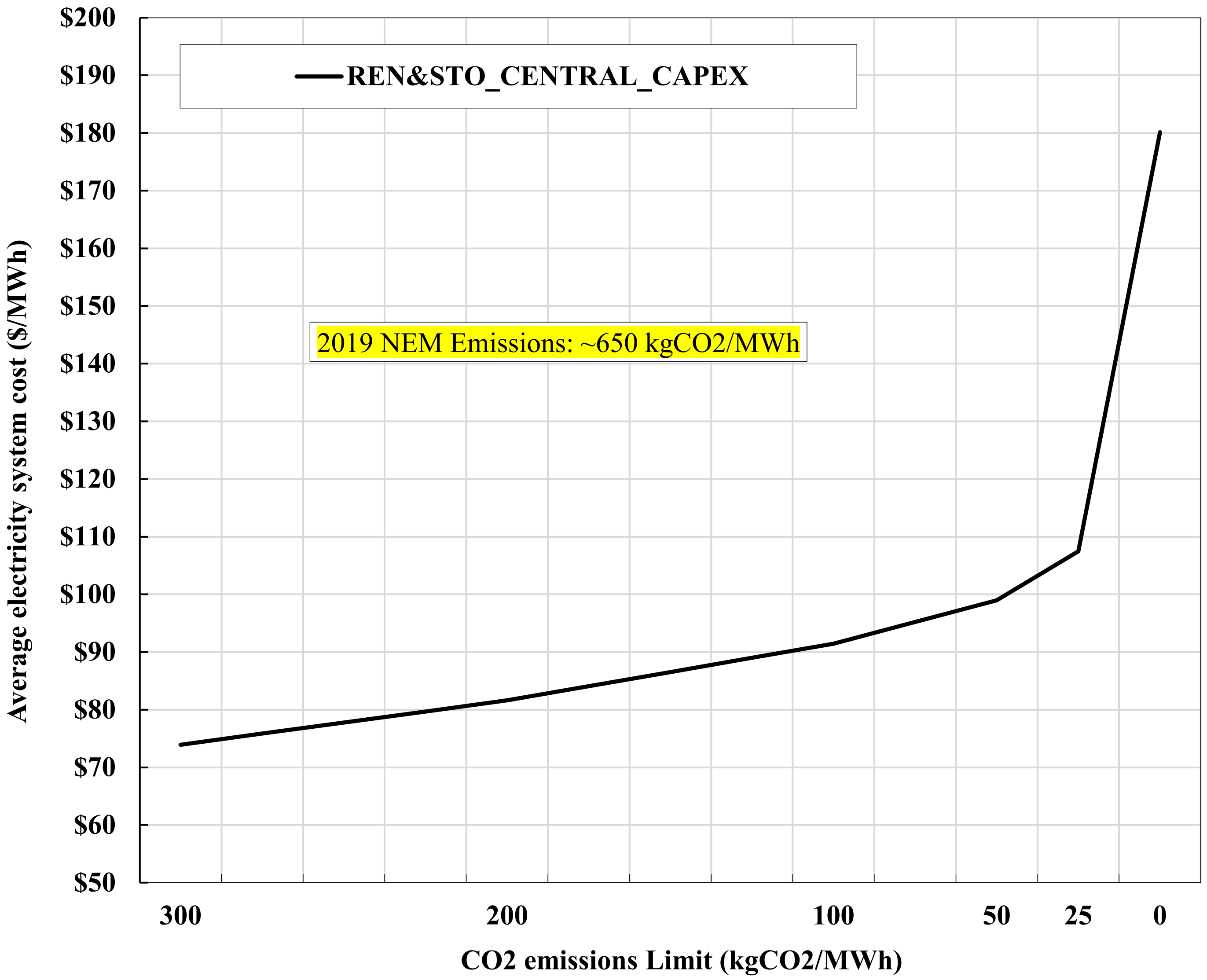
source: *What would be required for nuclear energy plants to be operating in Australia from the 2030s.* Stephen Wilson. The University of Queensland

# Model Outputs

- The model capture **Long-term capacity** planning decisions of the system (that occur at an yearly time resolution), but also the **technical/operation constraints** that occur at an **hourly time resolution**

- **Long-Term economic aspects:**
  - **Total System costs** to reach a certain GHG or renewable target.
  - **Resulting Generation** (Capacity Mix) in the system.
  - **Resulting Storage Mix** in the system (batteries, Pumped Hydro, Solar Thermal, Hydrogen?).
  - **Investment in transmission Lines**, etc. -> Only considering additional interstate connections at the moment.
- **Short-term operational aspects the model can capture:**
  - **Dispatch decisions**: how much to dispatch and what technology to meet hour-to-hour demand.
  - **Ramping, start up, min stable generation** limitations of the plants in the system.
  - **How technologies behave** in the system: Base load operation, level of flexibility, peaking plants etc.
  - **Requirements of firming** Low-Carbon generation sources, etc.

# Results: 1) Decarbonising with renewables and Storage



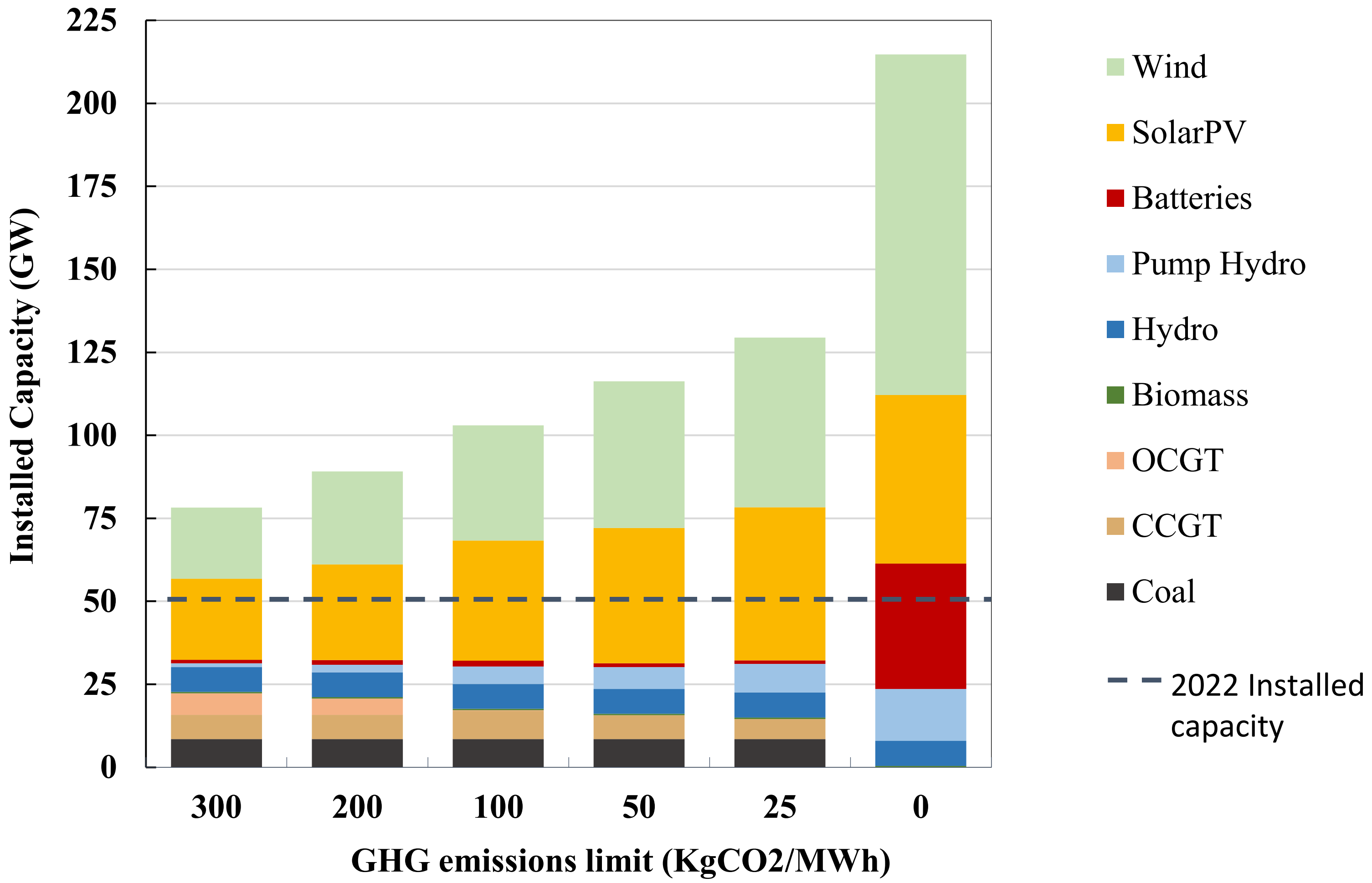

**1st Scenario**
**Seeking to decarbonise the NEM only with Renewables and Storage (ie. pump hydro and batteries).**

Electricity System **costs increase** as decarbonisation limits get **more stringent**.

**Sharp increase** seen as a fully decarbonised electricity system is approached **(0 kgCO2/MWh**).

Electricity system costs increases **~2.5 times** from a **300 GHG limit** (which represents around 50% decarbonsiation) **to a fully decarbonised system.**

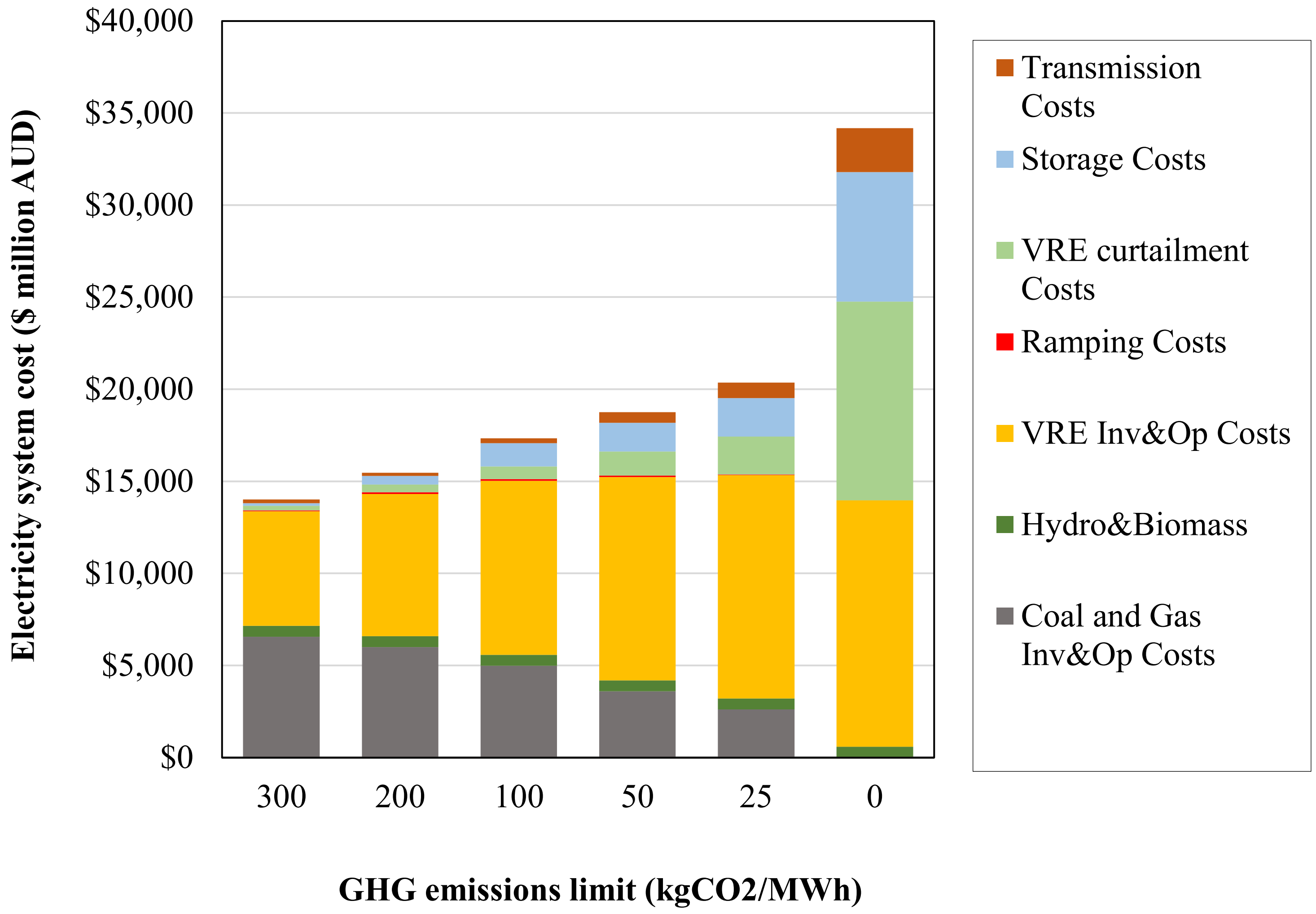
# Results: 1) Decarbonising with renewables and Storage




**System size increases ~1.5 times** when comparing the 300 GHG system versus the current installed capacity.

**System size increases ~4 times** when comparing the fully decarbonised system versus the current installed capacity.

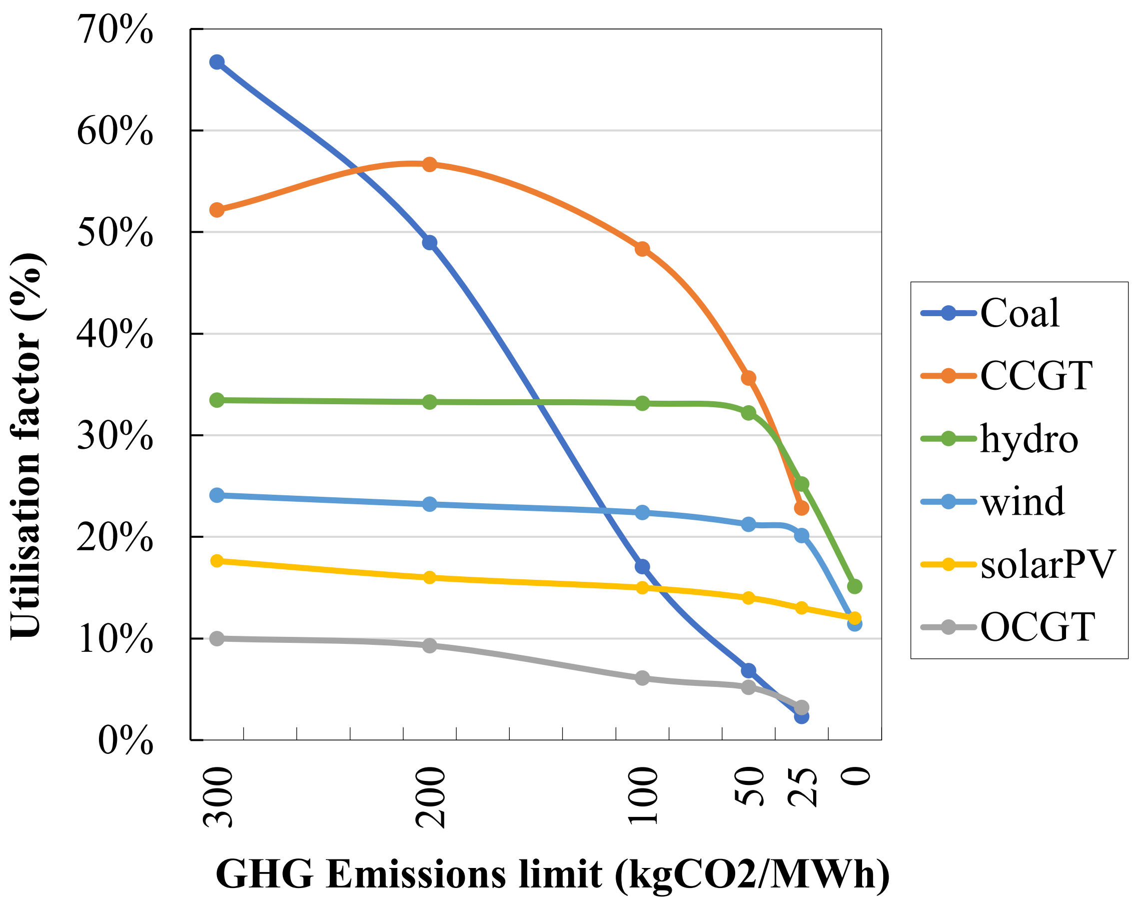
# Results: 1) Decarbonising with renewables and Storage




A considerable **increase in Storage, Transmission and VRE curtailment costs** is seen as the fully decarbonised system is approached.

For fully decarbonised system - **around 50% of total system costs** are incurred to **accommodate VRE variability and location-specificity**.

# Results: 1) Decarbonising with renewables and Storage




**Utilisation factor decreases drastically for all units as decarbonisation is fully realised.**

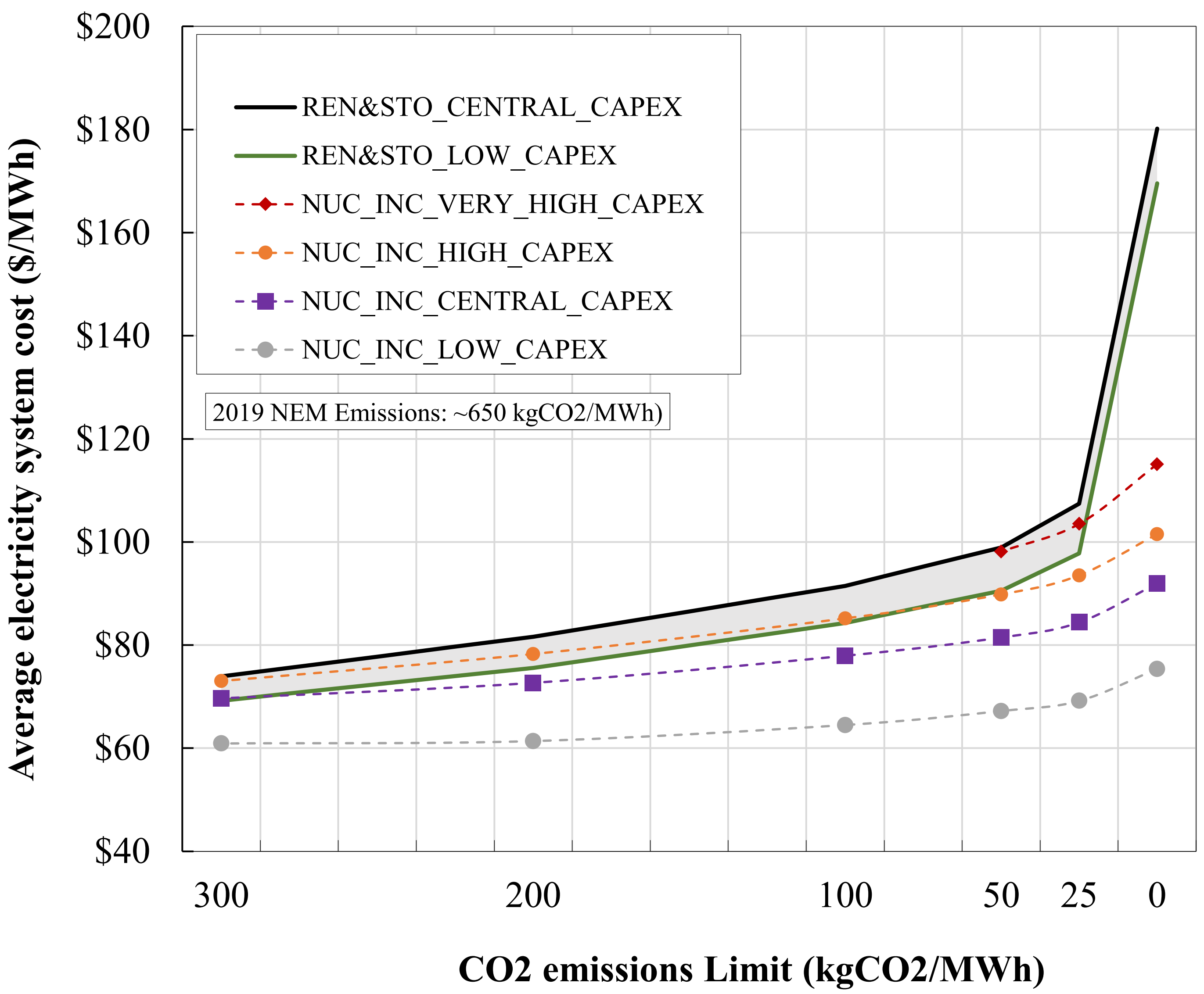
Reduced utilisation have a direct impact on capital utilisation, and specific capital costs.

For instance: **at the 50 kgCO2/MWh**, the **long-term generation cost estimated for Coal and CCGT is $232/MWh and $157/MWh respectively.**

At the **Zero carbon emission limit**, long-term generation cost of **SolarPV is $98/MWh and for Wind is $186/MWh.**

In a market based system, these technologies will need to recover that costs to remain in business.

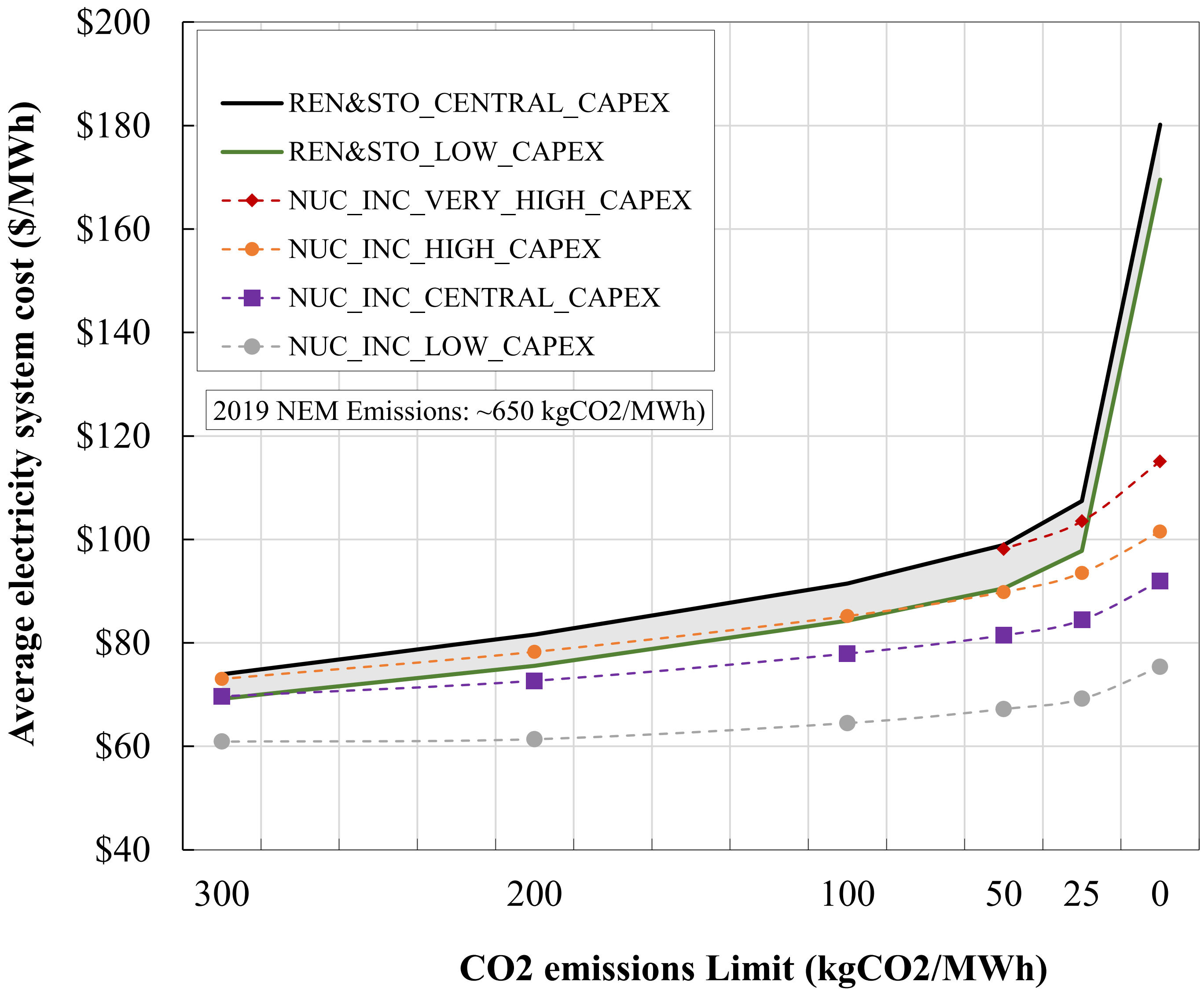
# Results: 2) Decarbonising with Nuclear SMR as an option




**Allowing Nuclear SMR in the Mix**

**Nuclear SMR High and VERY High CAPEX cases.**

# Results: 2) Decarbonising with Nuclear SMR as an option

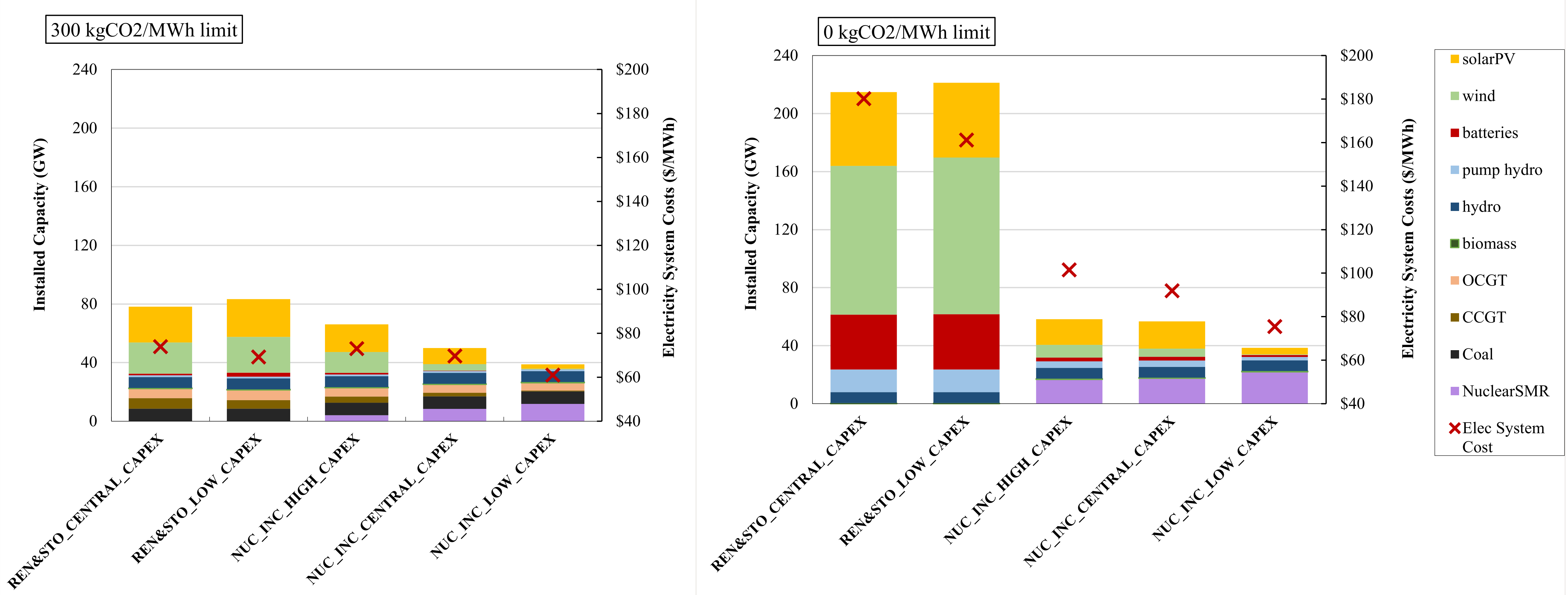



Across most of the cases the model chooses to **deploy NuclearSMR, as it results in a lower electricity system cost.**

As GHG limit approaches zero →
**Average electricity system cost is between 60%-240% higher without nuclear.**

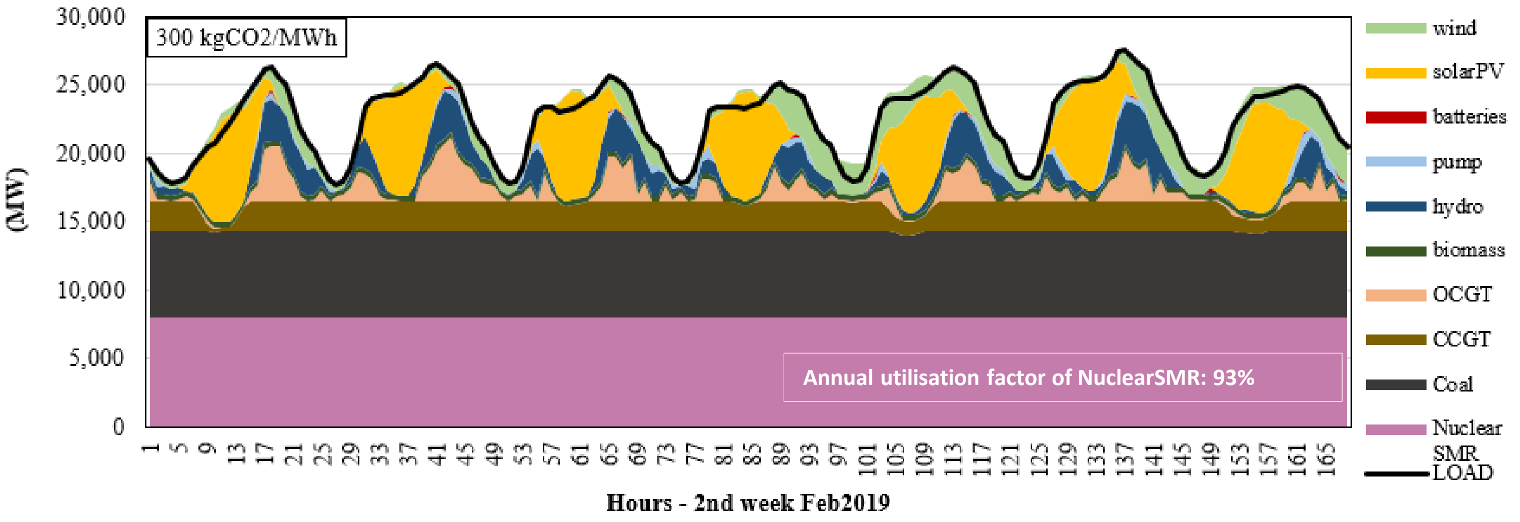
SMRs can play a **KEY role in containing** the **sharp increase** in cost as the grid approaches **full decarbonisation**.

# Results: 2) Decarbonising with Nuclear SMR as an option




- When carbon emission limit is reduced (from 300 to 0 kgCO2/MWh), **a significant increase in total installed capacity (GW) is seen** for the **case without nuclear in the energy mix**(**increasing between 2 and 2.5 times**).
- The system **with nuclear** in the mix, **reduces the need to overbuild solarPV, wind and storage.**

# Results: 2) Decarbonising with Nuclear SMR as an option

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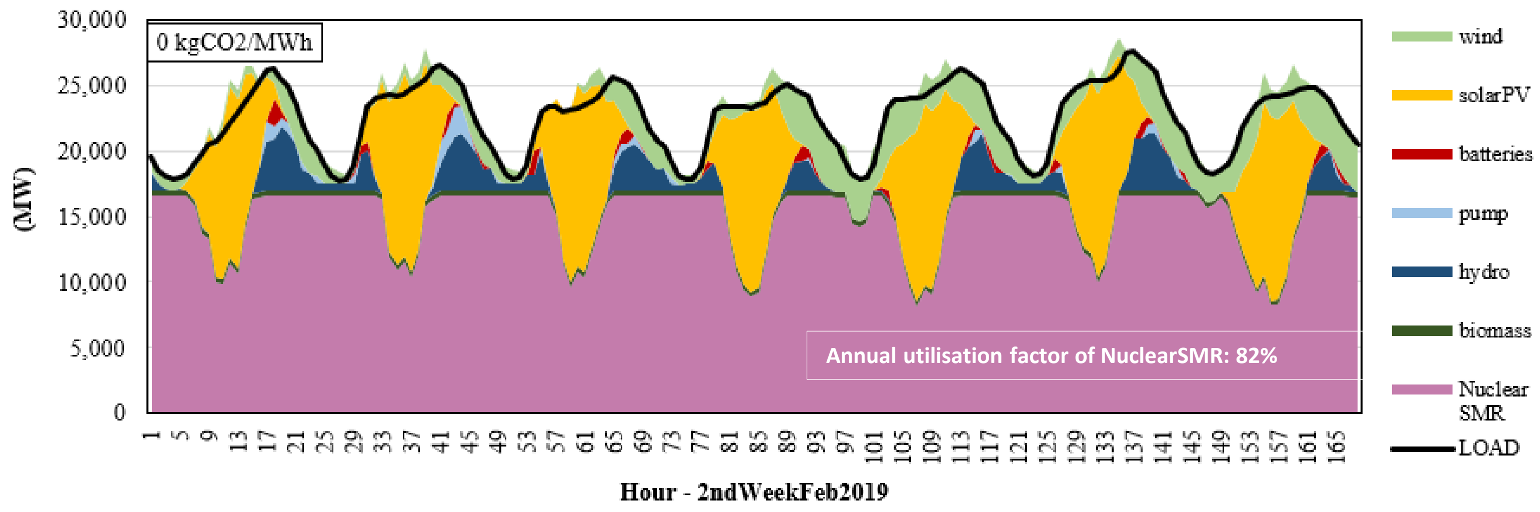


As the emission limits become more stringent, **SMRs adopt a peaking role to smooth out the variability of VRE resources**.

Most SMR ramping events occur during the day when solar PV is generating.

SMR can operate flexibly **to firm VREs and stabilize transmission grid frequency .**

# Conclusions

As suggested in this model …

1. How we model the NEM is **crucial to ‘see’ total system costs** and not overlook (some of) them

2. If we try to decarbonise only with renewables and storage, **total system costs will become very high**

3. Allowing SMR nuclear in the mix **can reduce the cost of a fully decarbonised system**

**Thank you for your attention!**