# Agenda

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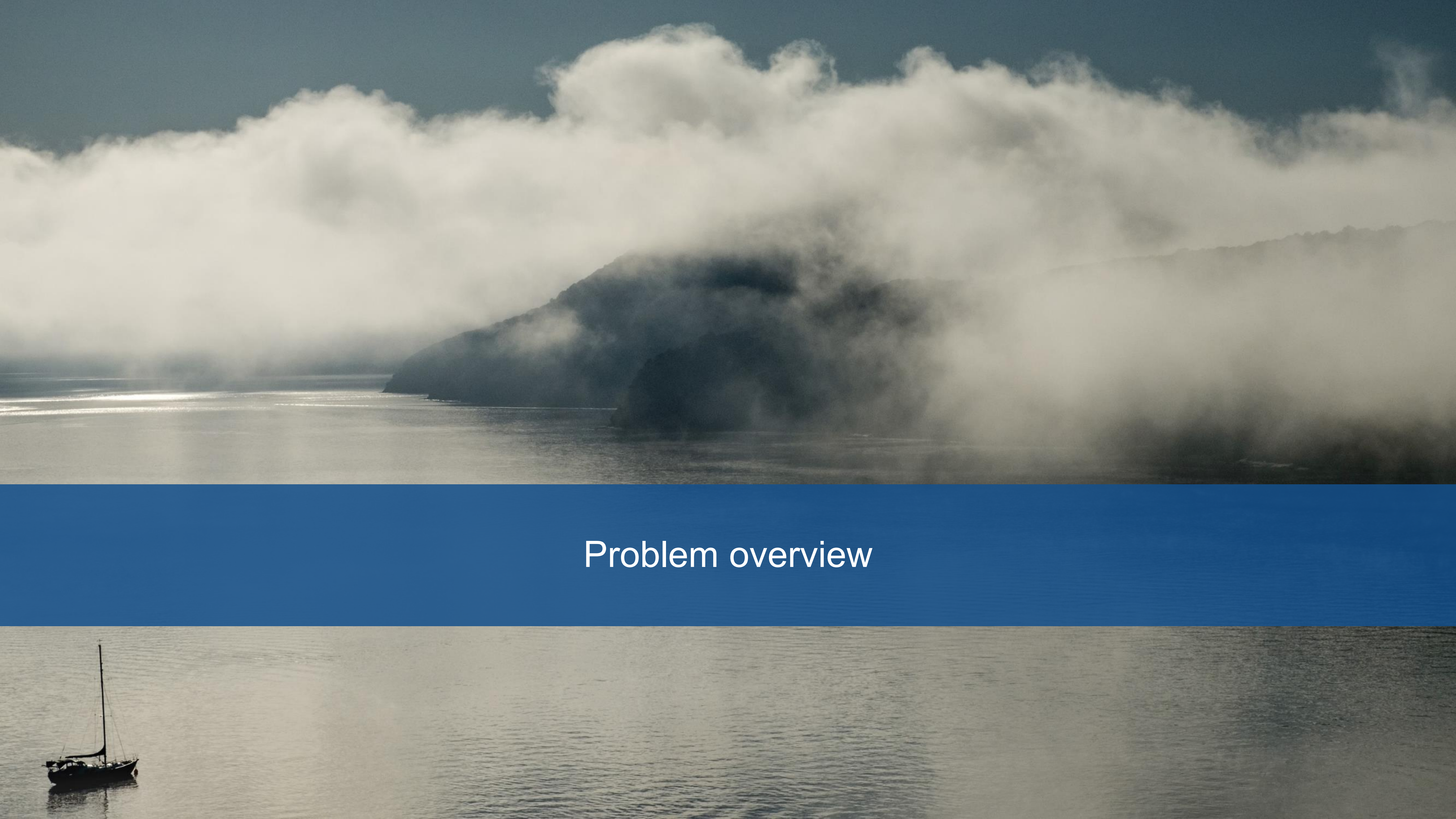
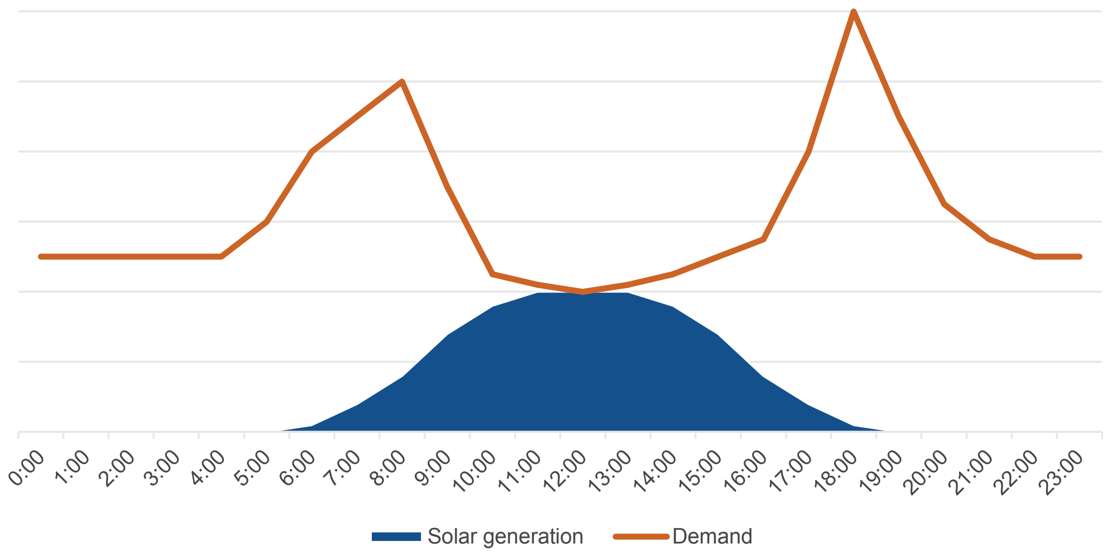


# Problem overview

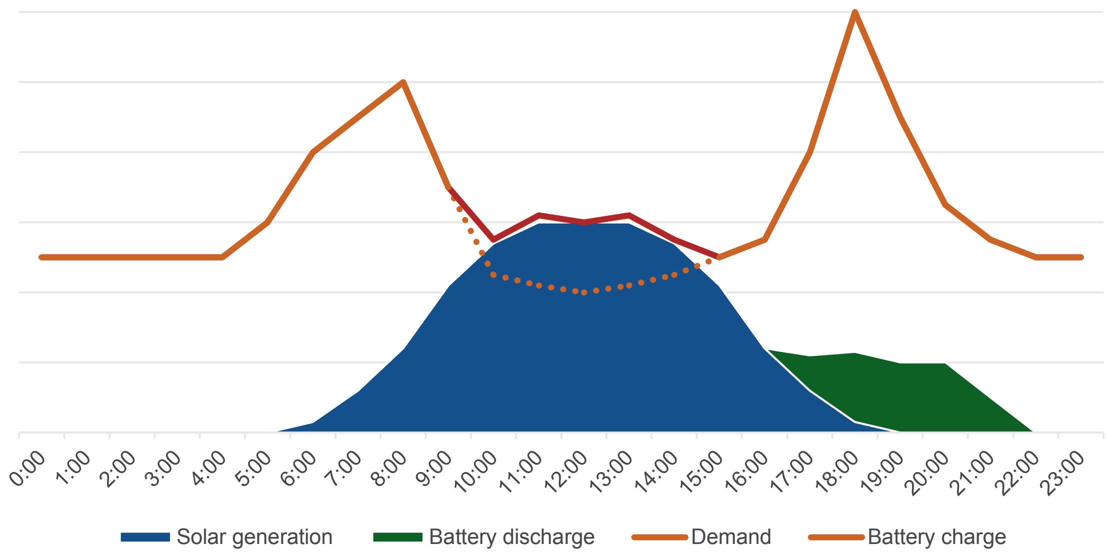
# Introducing batteries

## Without battery




- In Australia, grid electricity demand has a bath-tub shape (called the duck-curve) due to rooftop solar on homes and commercial properties reducing the amount of electricity needed during the middle of the day.
- Additional solar generation is therefore limited in its ability to meet demand, despite having low capital costs and no short-run marginal cost (no fuel – it is free to operate).

## With battery




- Batteries add energy demand when they charge, and then add to energy supply when they discharge.
- Energy storage technologies, such as batteries, are critical for the renewable energy transition due to their ability to shift energy to low sunlight/wind periods.
- Note the large solar capacity (compared to without battery) due to the battery 'unlocking more generation'. This displaces more expensive and high-emitting generation.

# The problem

## Objective: Mandatory task

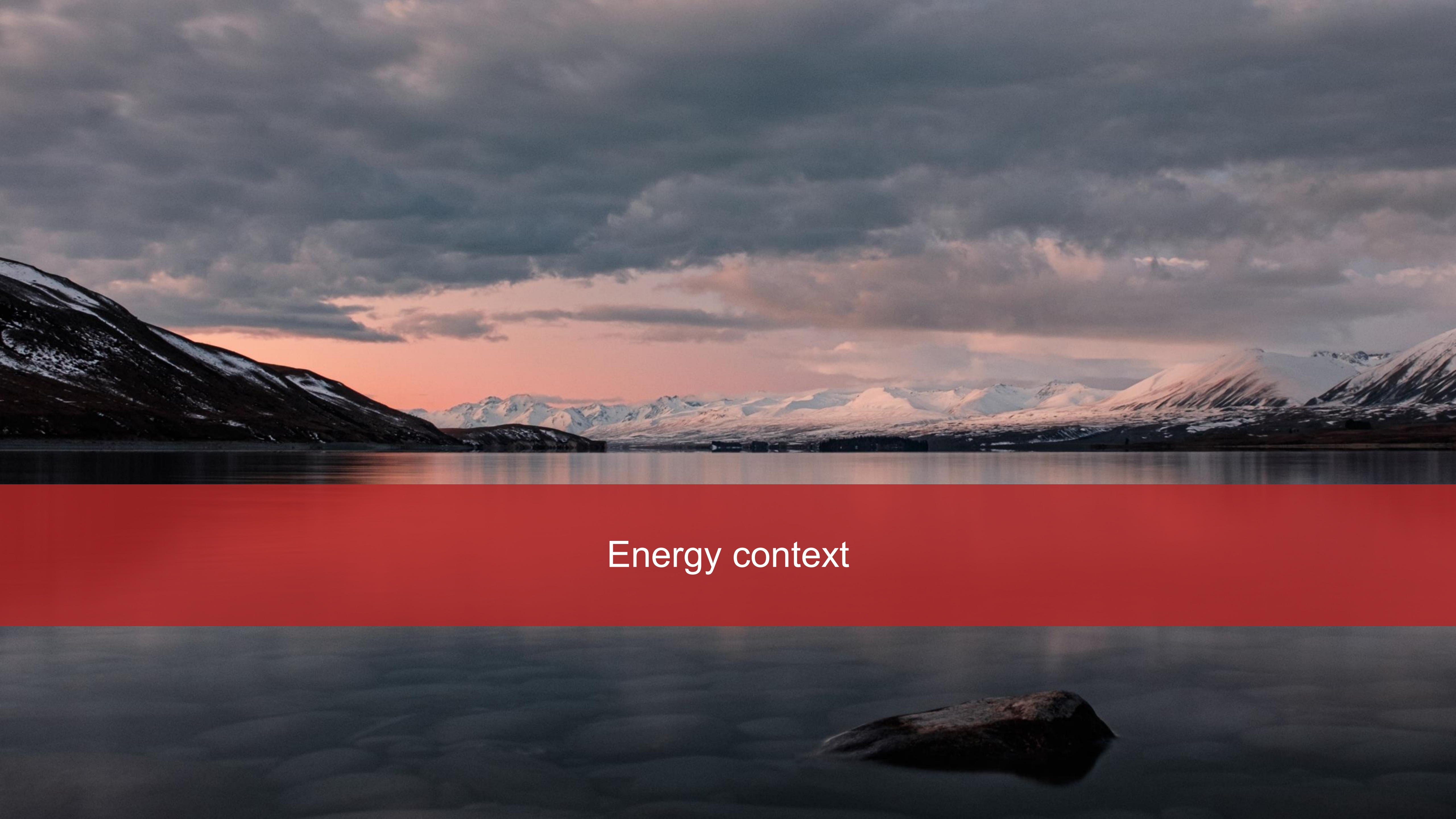
- Develop an algorithm that determines the optimal charge and discharge behavior of a battery based in Victoria.
- Maximise revenues by charging when electricity prices are low and discharging when prices are high.

## Objective: Bonus task

- Inform current charging behavior without using future prices.

## Industry purpose: Revenue maximisation for…

- Stand-alone grid batteries
- Residential battery aggregators (Virtual Power Plants)
- Renewable energy developers



# Energy context

# National Electricity Market (NEM)

## Overview of NEM

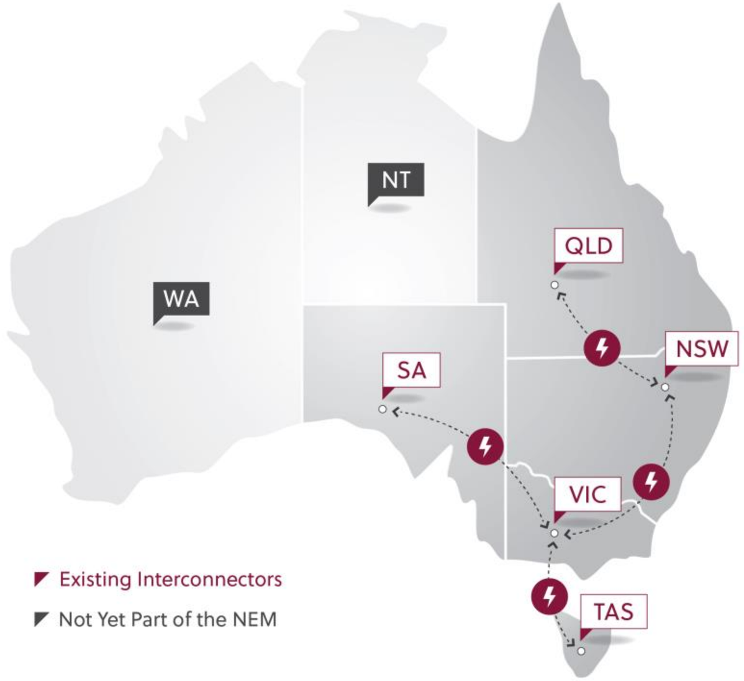
- Comprises 5 states (ACT is considered to be a part of NSW)
- Interconnectors between the states allow for the sharing and trading of electricity (up to certain specified limits)

## Price setting

- Prices are set every 30 minutes based on prevailing supply and demand (called the spot price)
- Each state has its own price

## Generation

- Every generator is registered to a single state
- Dispatchable generators include coal, gas, biomass and hydro
- Intermittent generators include wind and solar
- Storage technology includes pumped hydro and batteries



# Price setting in the NEM: 30-minute spot price

As an illustrative example, consider a closed system with a 10MW (pronounced megawatt) coal generator, a 10MW solar farm, and a 10MW gas generator.

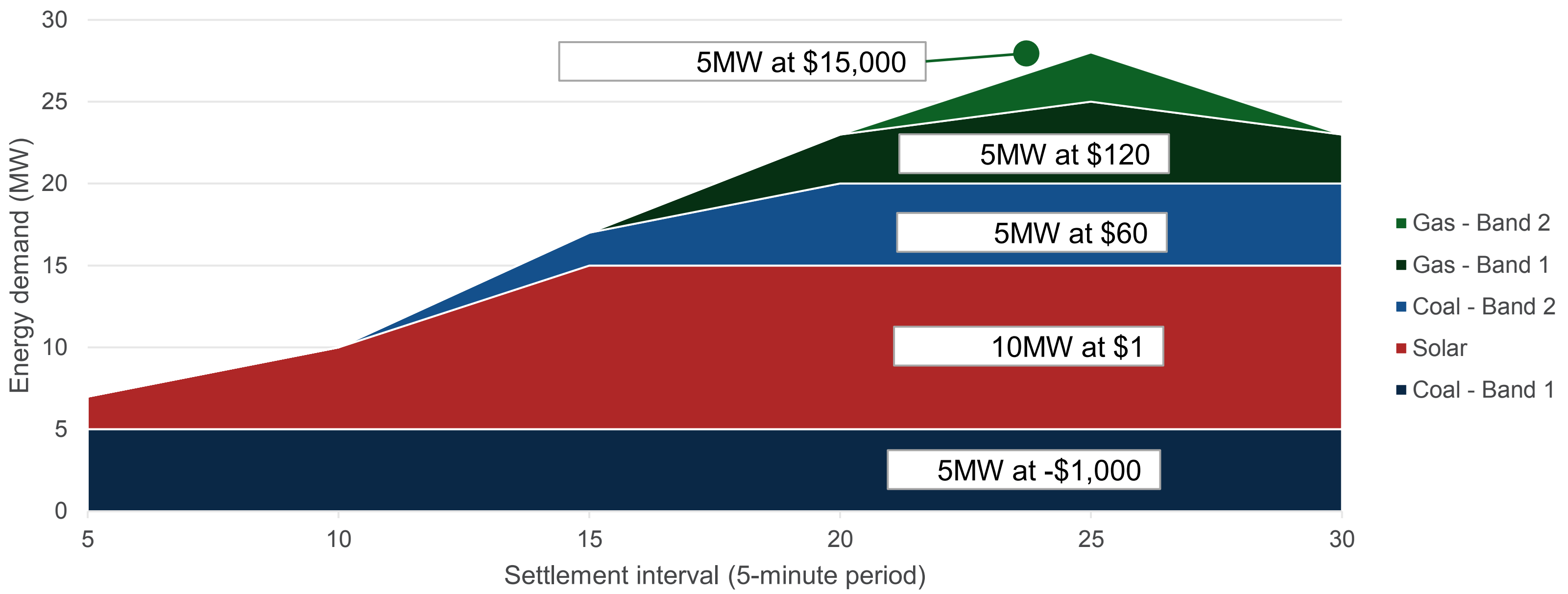
**The coal generator bids 5MW at -$1,000:** It is prohibitively expensive to restart a coal turbine and causes significant wear-and-tear to run it discontinuously, so coal generators tend to put their minimum stable volume at the market floor price to guarantee dispatch.

**The coal generator bids its remaining 5MW at $60:** The short-run marginal cost for coal is currently around $30-$50 per MW so this ensures profitability for ramping above minimum stable levels.

**The solar farm bids all its 10MW at $1:** Solar is a price-taker and has no short-run marginal cost to operate (no fuel required).

**The gas generator bids 5MW at $120:** The short-run marginal cost for gas is currently around $80-$120 per MW and so this price ensures it switches on when profitable. Unlike coal, some gas turbines can switch on and off.

**The gas generator bids its remaining 5MW at $15,000:** When demand reaches extreme levels, there is no competition and so generators can bid at the market-cap.




In this simplified example, the following settlements occur:

- In the 5-minute and 10-minute periods, demand is low and is serviced by the lowest cost generation. The price is $1 in both periods and this is received by both solar and coal for their respective volumes dispatched.
- In the 15-minute period, demand rises and coal ramps up to meet this. The price is set at $60 which is received by both coal and solar for their respective volumes dispatched.
- In the 20-minute and 30-minute periods, demand is near its peak and gas switches on to ensure adequate supply. The price is set at $120 and this is received by all generators for the respective volumes dispatched.
- In the 25-minute period, demand momentarily reaches its peak. The price is set at $15,000 and all generators receive this price for their respective generation.

**The price for the 30-minute period is set at the average of the 6 periods = ~$2,550/MWh. All generators receive this price for their generation output during the 30-minute period.**

# A note on units

**Power**
in Megawatts (MW)

×

**Time**
in hours (h)

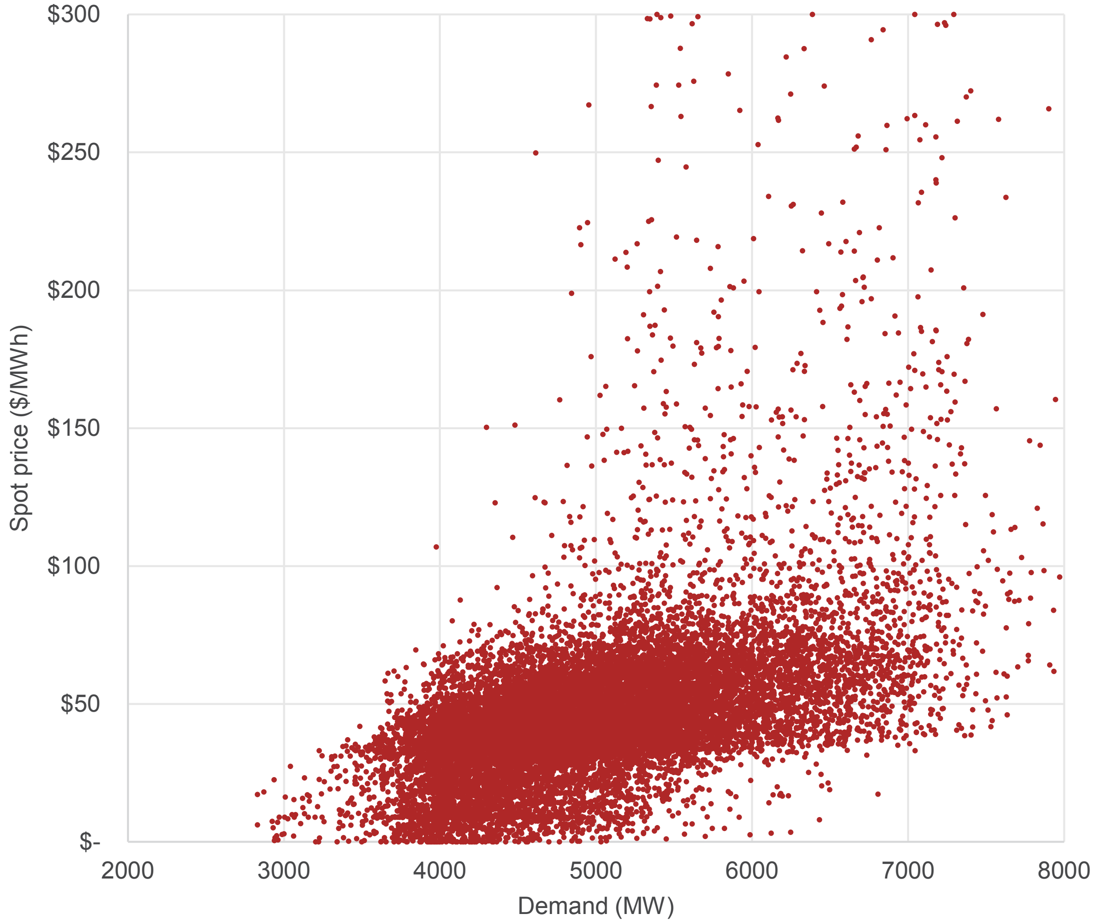
=

**Generation/ consumption**
in Megawatt-hours (MWh)

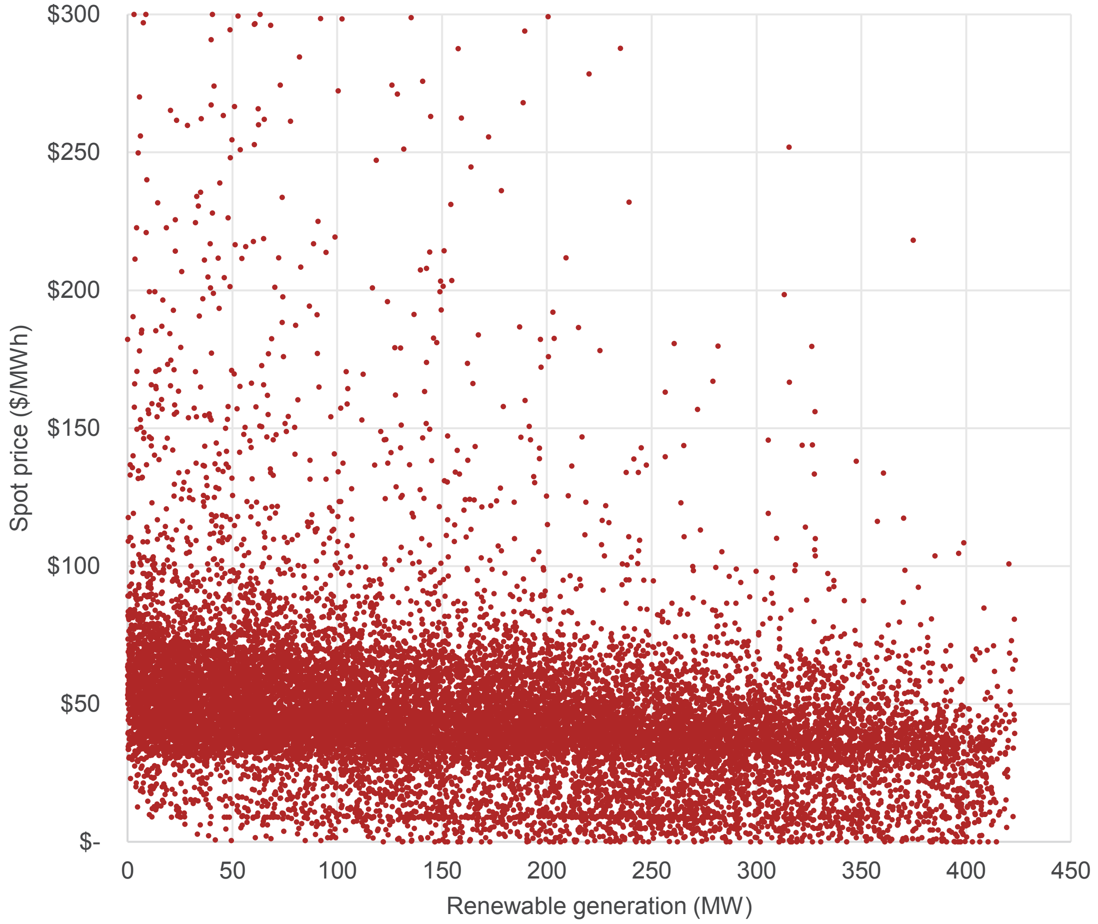
| | | |
|---|---|---|
| 12 MW | 1 hour | 12 MWh |
| 12 MW | 30 minutes | 6 MWh |
| 12 MW | 5 minutes | 1 MWh |
| 60 MW | 1 hour | 60 MWh |
| 60 MW | 30 minutes | 30 MWh |
| 60 MW | 5 minutes | 5 MWh |

# Electricity price trends: Victorian spot price (2020)

## Spot price vs. demand




## Spot price vs. renewable generation



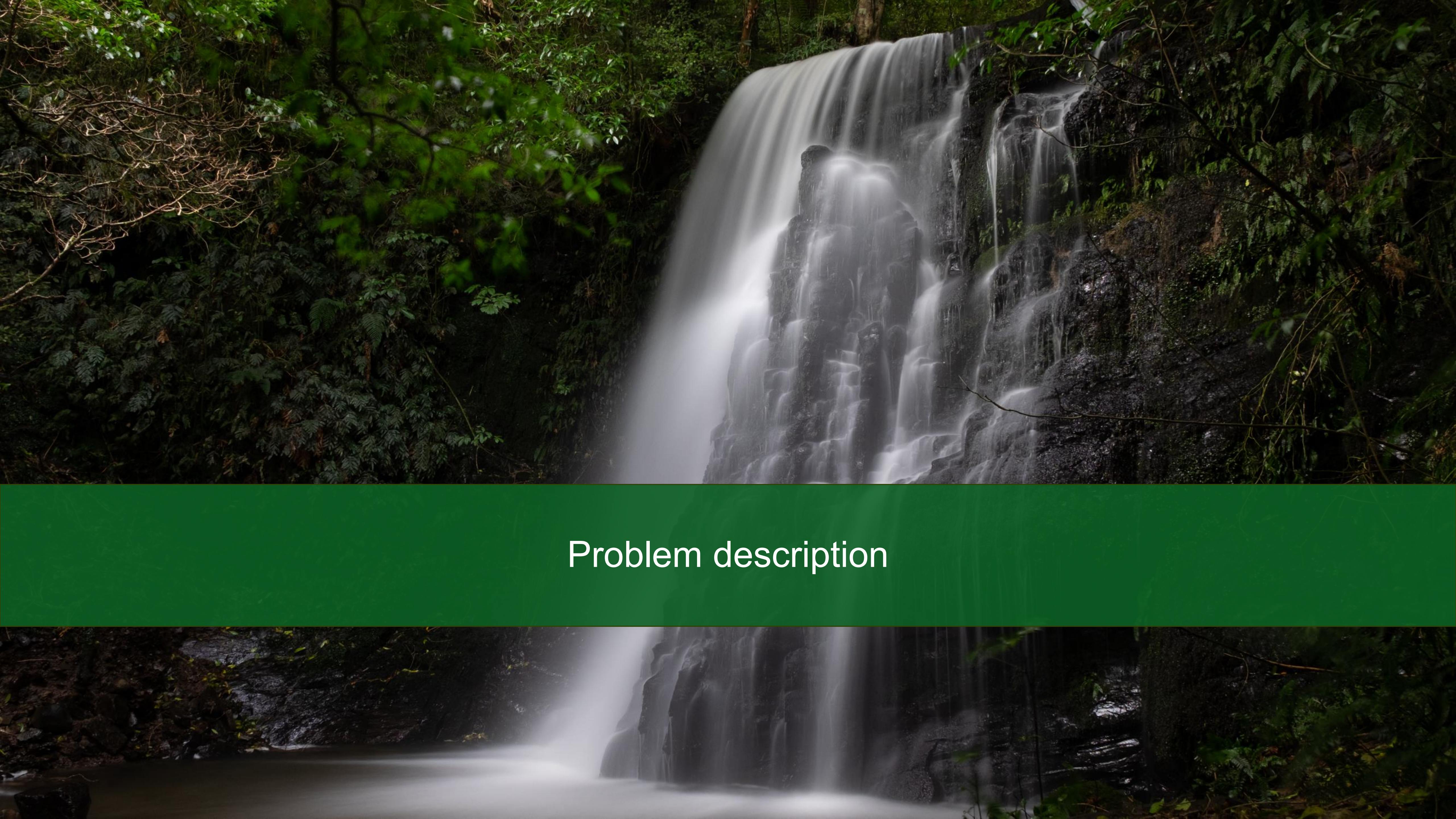
# How batteries function

Battery starts with no stored charge.

The battery charges by consuming power from the grid

The battery stores energy up to but not exceeding its capacity.

The battery can discharge and supply power to the grid



# Problem description

# Problem objective

## Mandatory task: The perfect but impractical battery

- Develop an algorithm to maximise the revenues of a grid connected battery assuming perfect future price visibility. VIC price is the only variable required for this optimisation.

## Bonus task: The practical but imperfect battery

- Develop another algorithm to maximise the revenues of a grid connected battery assuming no future visibility of price. The usage of renewables and demand data available at each period is allowed given the ability to forecast these.

## Requirements for both tasks

- Ensure all technical and operational criteria are met.
- Use the assigned Training and Cross-Validation periods to develop the algorithm(s).
- Output revenues and battery dispatch from the Test period for comparison with other groups.

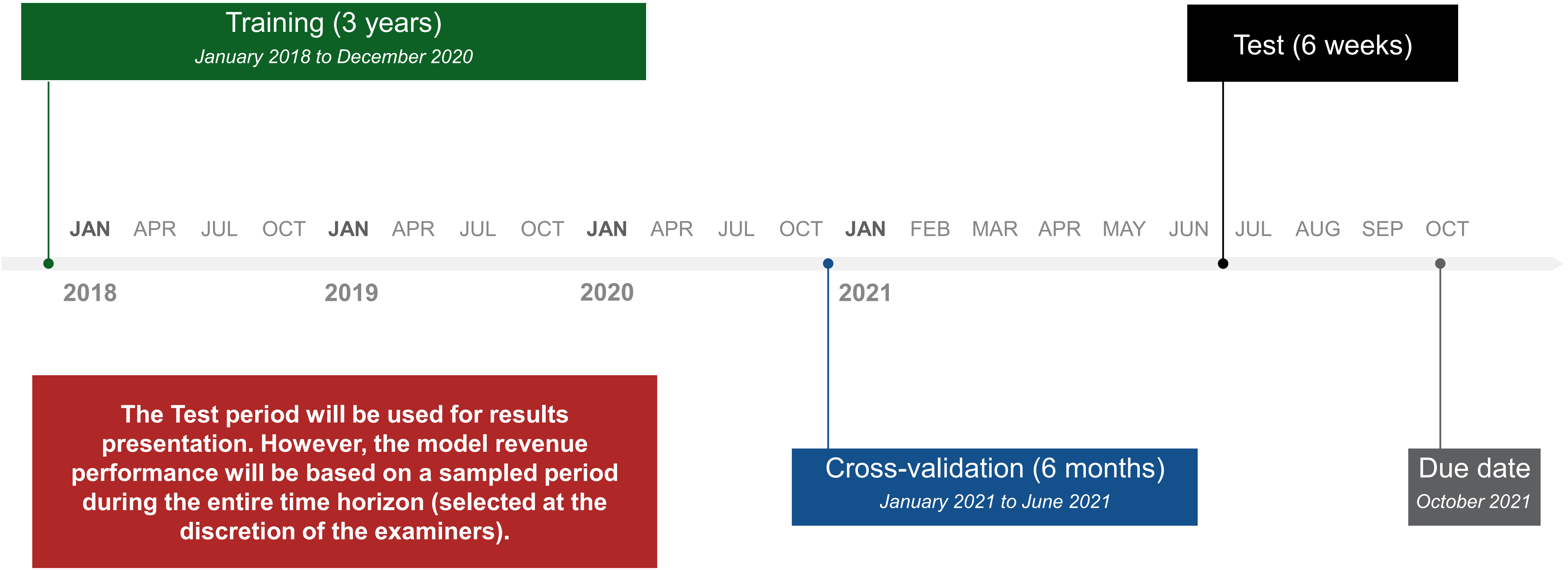
# Data points enabled for use at time t in the models

| Data point | Examples | Mandatory task | Bonus task |
|---|---|---|---|
| Prices before current period | $Price_{t-n}$ | Allowed | Allowed |
| Price during current period | $Price_{t}$ | Allowed | Allowed |
| Price after current period | $Price_{t+n}$ | Allowed | Not allowed |
| Demand/supply before current period | $Variable_{t-n}$ | Allowed but not required | Allowed |
| Demand/supply during current period | $Variable_{t}$ | Allowed but not required | Allowed |
| Demand/supply after current period | $Variable_{t+n}$ | Allowed but not required | Allowed |

n is an element of [1, 48] half-hour periods

# Data timeline for battery calibration

To ensure comparable outcomes across the groups, identical time periods should be used for Training, CV and Testing.



# Interim deliverables (check-points)

| Week | Week starting | Deliverable | Objective |
|---|---|---|---|
| 1 | 30 August | How much energy is consumed in 10 minutes at 90MW? | Demonstrate an understanding of electricity fundamentals. |
| 2 | 6 September | What is the VIC spot price on 01/07/2020 15:00? | Demonstrate an understanding of the electricity data provided. |
| 3 | 13 September | What is the maximum revenue a battery can make on 17/07/2020 assuming it starts the day discharged and can only discharge 580MWh (the battery has a single charge cycle for this test)? | Demonstrate an understanding of battery revenue maximisation. |
| 4 | 20 September | Midsemester break | |
| 5 | 27 September | Provide a proposed approach on how you will optimise revenues with your final algorithm (200 words) | Demonstrate that you are able to meet the final deadline. Students may elect to use a different approach for final solution. |
| 6 | 04 October | None | |

# Battery technical and commercial properties

| Variable | Unit | Value | Description | Data source |
|---|---|---|---|---|
| State | Text | VIC | The regional node determines the spot market pricing. | - |
| Battery power | MW | 300 | Maximum instantaneous rate of energy release or energy charging. | Proposed battery for Deer Park, Melbourne[1]. |
| Battery capacity | MWh | 580 | Maximum energy that can be stored in the battery at full charge. | Proposed battery for Deer Park, Melbourne[1]. |
| Charge efficiency | % | 90 | Electricity to chemical conversion rate into stored battery capacity. | Australian Energy Market Operator[2] |
| Discharge efficiency | % | 90 | Chemical to electrical conversion rate into grid dispatched energy. | Australian Energy Market Operator[2] |
| Marginal Loss Factor | # | 0.991 | Losses associated with energy transmission. | Laverton North as shadow connection. |
| Capital cost | $ | 0 | Assume all development and procurement capital is sunk. | - |
| Fixed O&M | $/kW/year | 8.10 | Costs associated with fixed operations and maintenance. | Australian Energy Market Operator[3] |
| Variable O&M | $/MWh | 0.00 | Costs associated with variable operations and maintenance. | Australian Energy Market Operator[3] |

1. https://www.afr.com/companies/energy/transgrid-to-install-big-battery-for-melbourne-20210705-p586wv
2. https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/Inputs-Assumptions-Methodologies/2019/2019-Projections-for-Small-Scale-Embedded-Technologies-Report-by-CSIRO.pdf
3. https://aemo.com.au/en/energy-systems/major-publications/integrated-system-plan-isp/2022-integrated-system-plan-isp/current-inputs-assumptions-and-scenarios

# Illustrative algorithms for consideration

| Algorithm | Description | Revenue maximisation | Practicality (for Bonus task) |
|---|---|---|---|
| Fixed charge/discharge levels<br>*(Provided as illustrative example 1)* | A battery that charges below a set price level, and discharges above a set price level. | Poor | High |
| Time of day charge/discharge<br>*(Provided as illustrative example 2)* | A battery that charges and discharges at fixed periods in the day. Can be adjusted to have different periods based on season/month/day-of week etc. | Poor | High |
| Look ahead charge/discharge<br>*(Provided as illustrative example 3)* | A battery that compares current prices to future observed prices to determine whether to charge or discharge. | Moderate | Poor |

# Data sources for problem (all sourced from AEMO)

## Mandatory task

- Spot price data for Victoria
  Training and CV period (01/01/2018-30/06/2021)
  Illustrative example provided with problem
- Spot price data for Victoria
  Test period (01/07/2021-11/08/2021) – More data provided for t+n functions
  https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/data-nem/aggregated-data

## Bonus task

- Operational demand data for all 5 states
- Available dispatchable generation for all 5 states
- Available intermittent (renewable) generation for all 5 states
- Interconnector limits between all 5 states