Battery optimisation

MAST30034 Applied Data Science

Agenda

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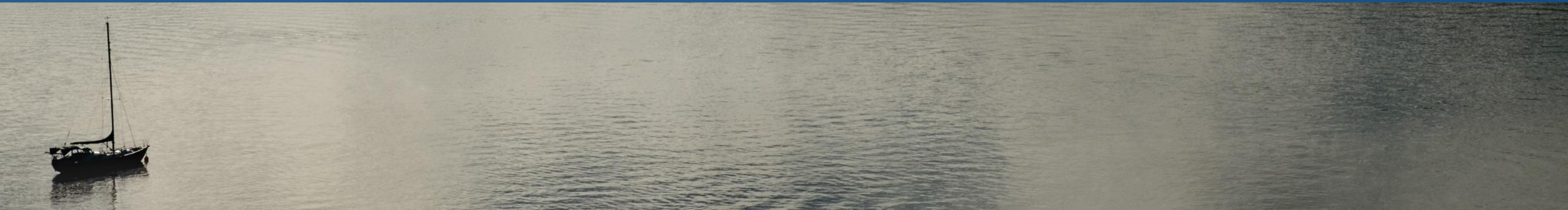
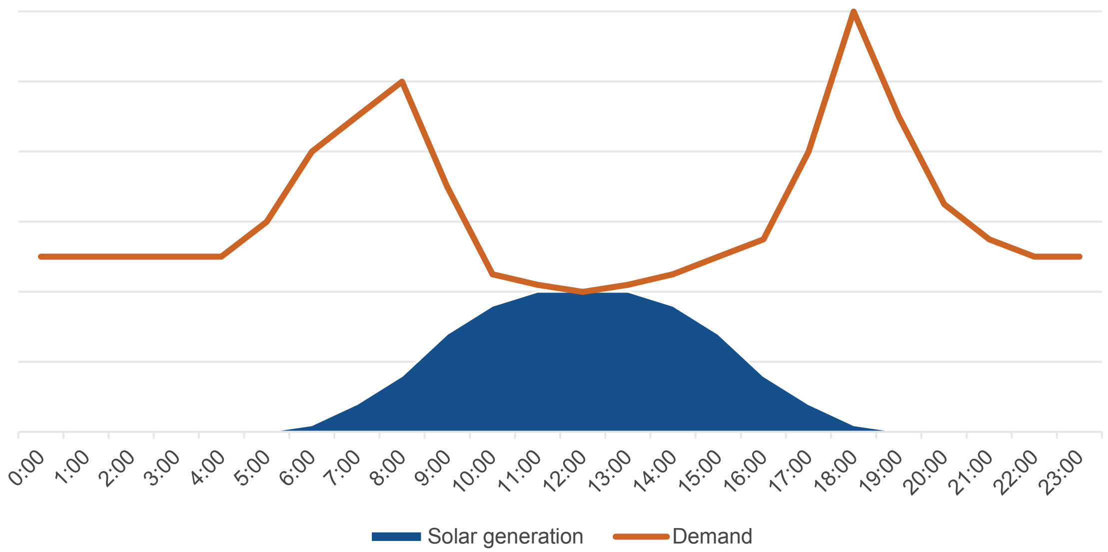
Problem overview



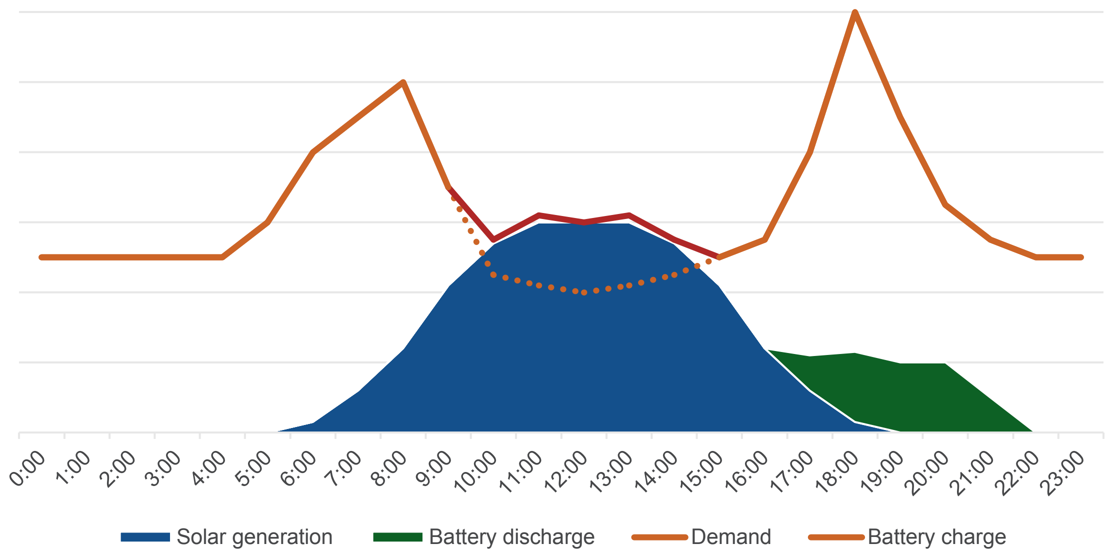
Introducing batteries

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

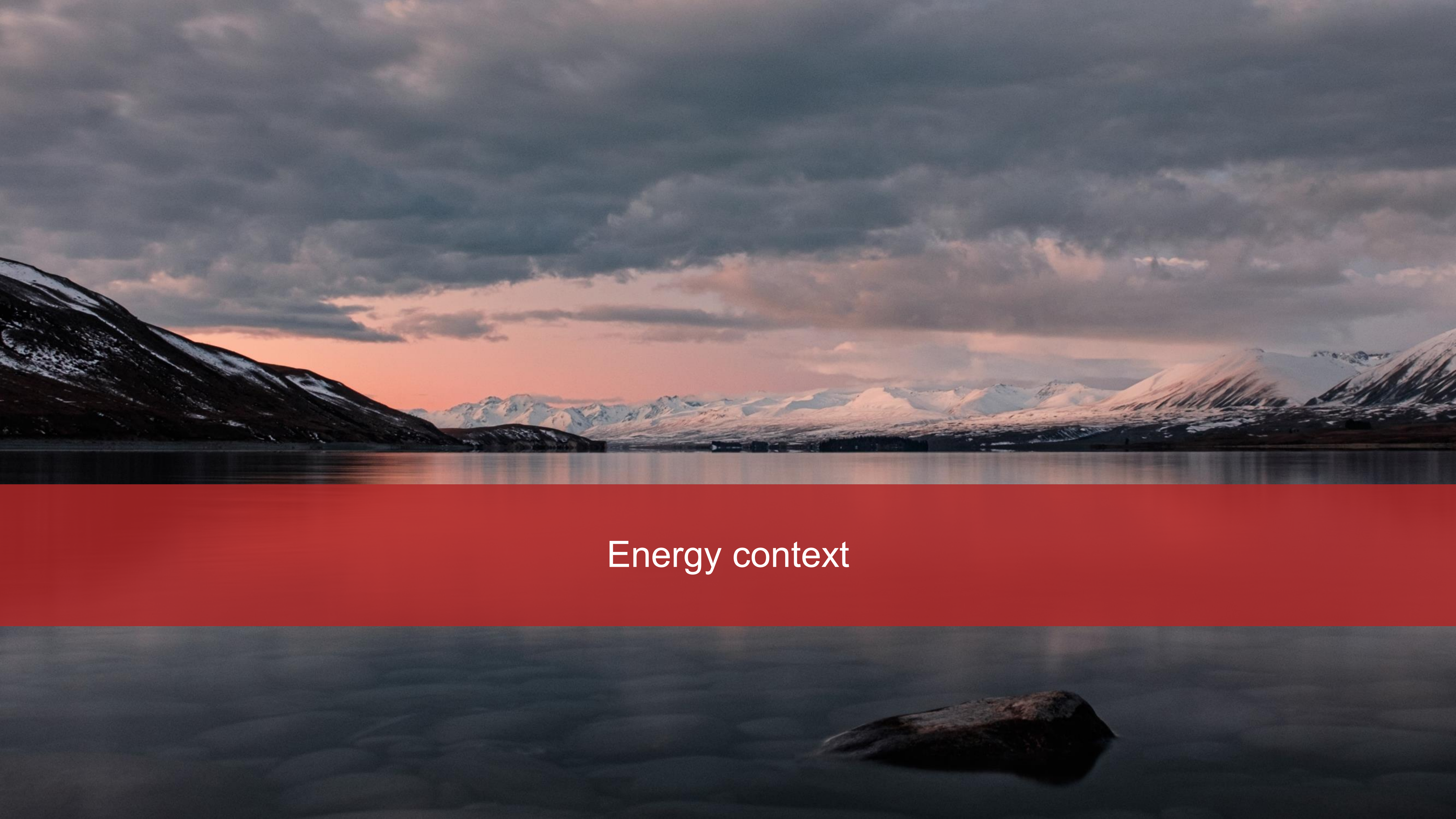
- Develop an algorithm that determines the optimal charge and discharge behavior of a battery based in Victoria.
- Maximise revenues by charging when electricity prices are low and discharging when prices are high.

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

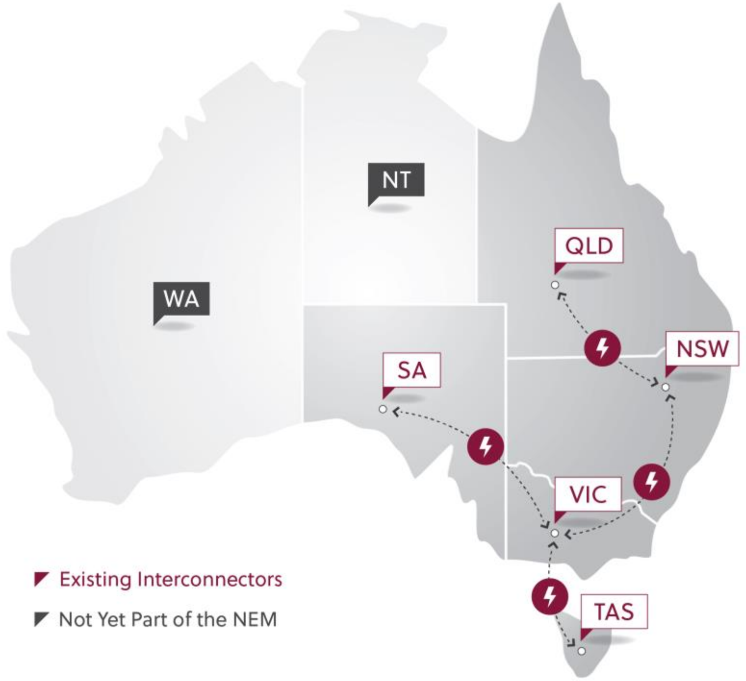
- Comprises 5 states (ACT is considered to be a part of NSW)
- Interconnectors between the states allow for the sharing and trading of electricity (up to certain specified limits)

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.

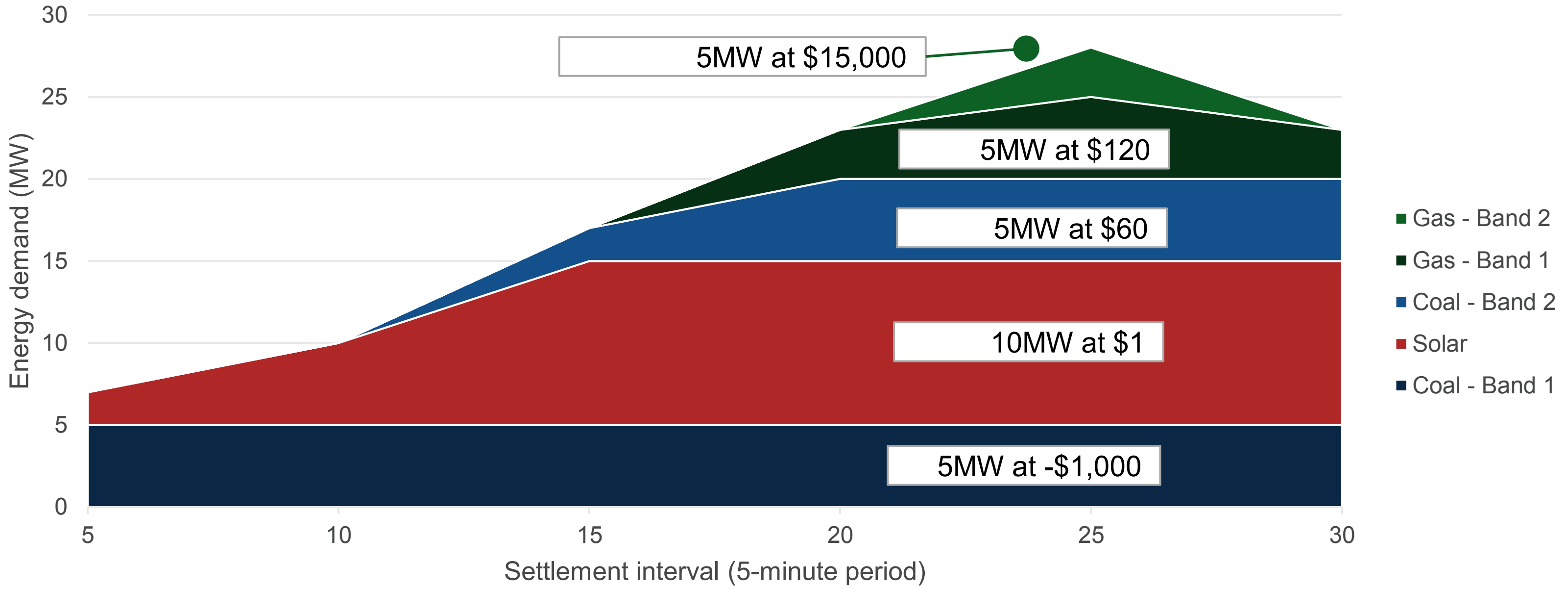
The coal generator bids 5MW at -$1,000: It is prohibitively expensive to restart a coal turbine and causes significant wear-and-tear to run it discontinuously, so coal generators tend to put their minimum stable volume at the market floor price to guarantee dispatch.

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)

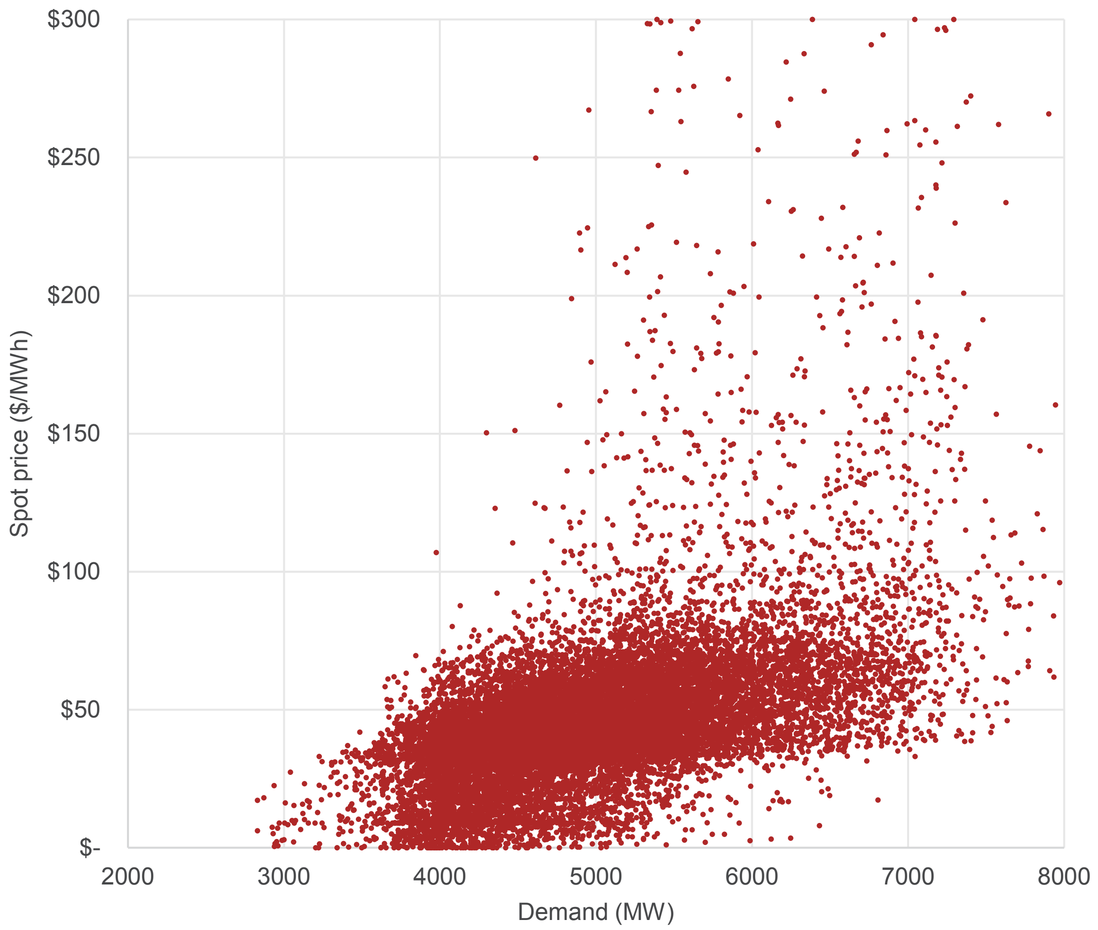
=

Generation/ consumption
in Megawatt-hours (MWh)

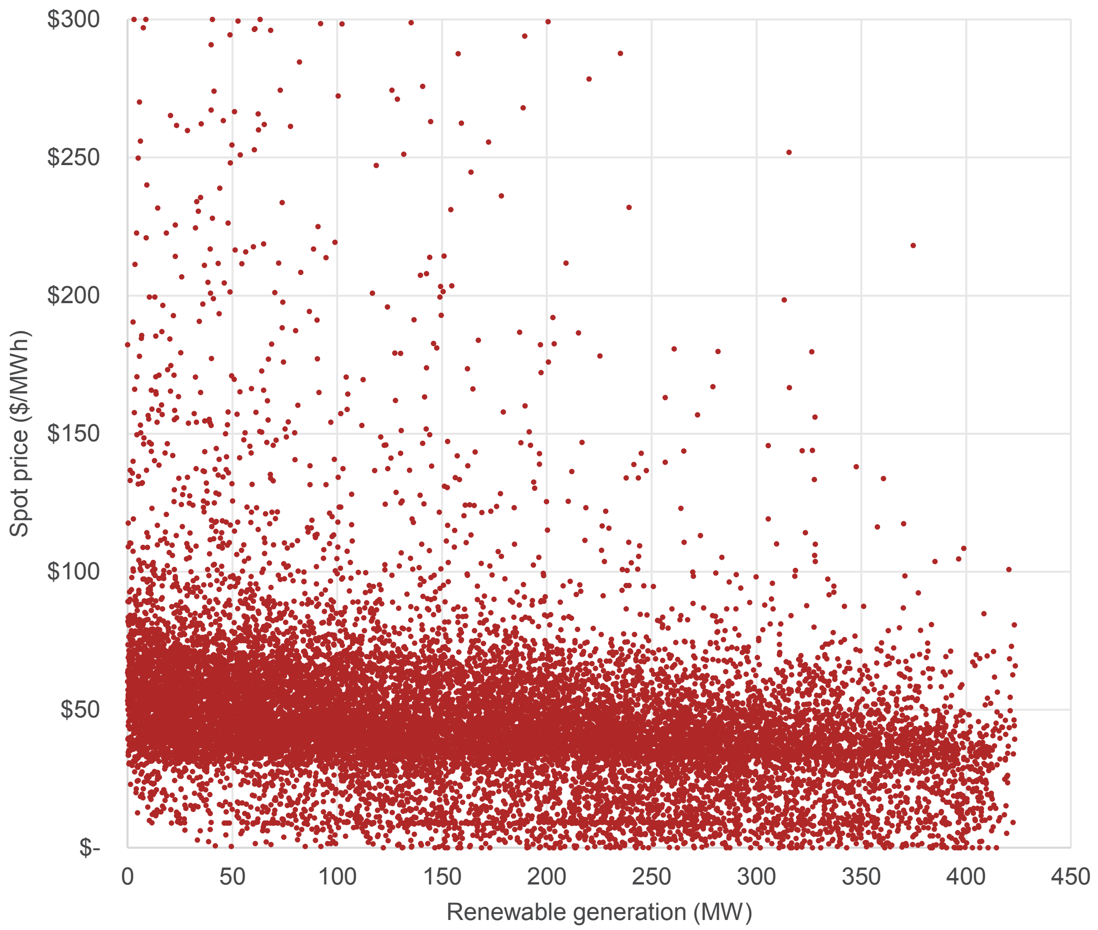
12 MW	1 hour	12 MWh
12 MW	30 minutes	6 MWh
12 MW	5 minutes	1 MWh
60 MW	1 hour	60 MWh
60 MW	30 minutes	30 MWh
60 MW	5 minutes	5 MWh

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.

→

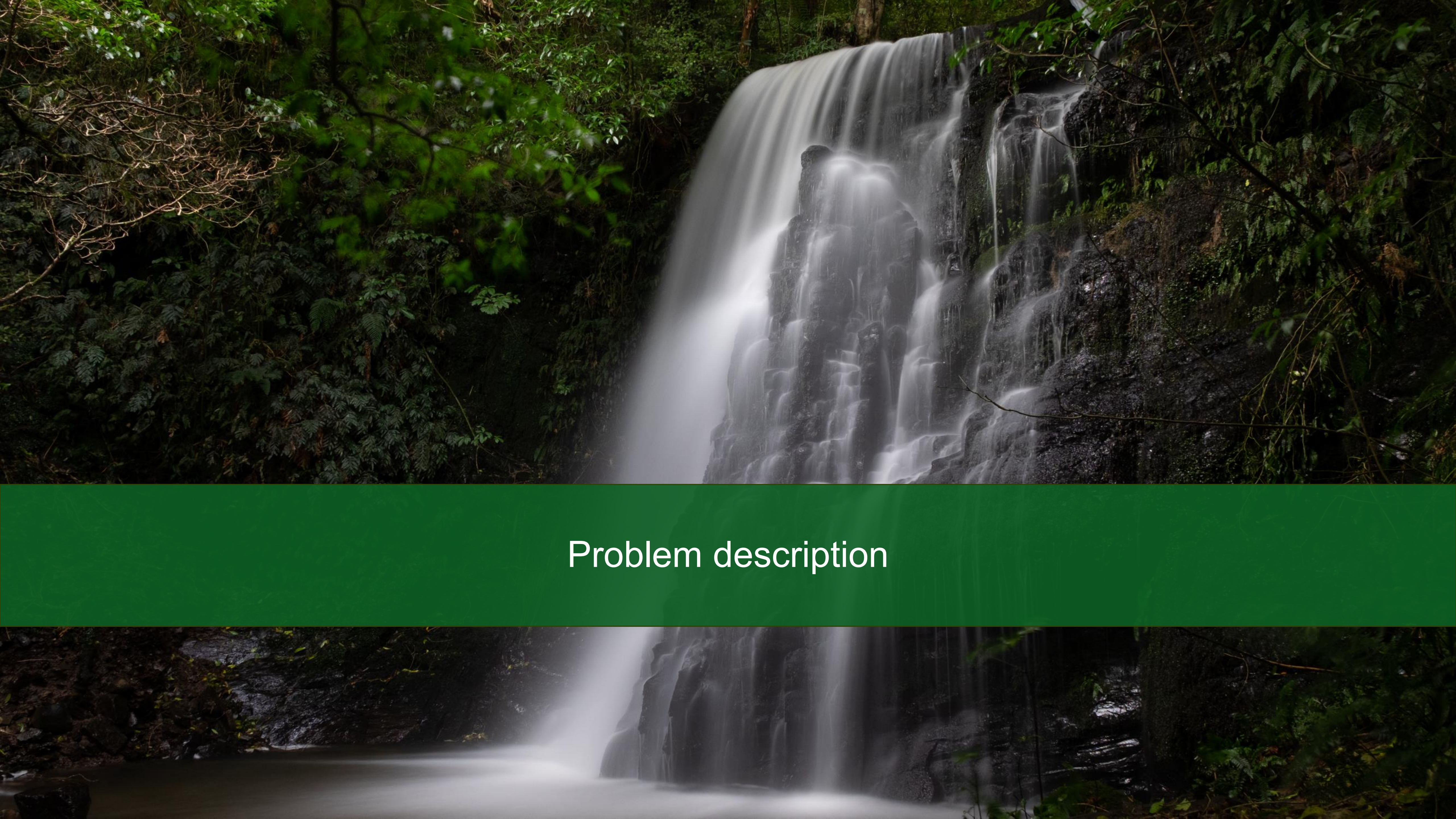
The battery charges by consuming power from the grid

→

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 <u>assuming perfect future price visibility</u>. 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 <u>assuming no future visibility of price</u>. 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.

Training (3 years)
January 2018 to December 2020

Test (6 weeks)

JAN APR JUL OCT JAN APR JUL OCT JAN APR JUL OCT JAN FEB MAR APR MAY JUN JUL AUG SEP OCT

2018 2019 2020 2021

The Test period will be used for results presentation. However, the model revenue performance will be based on a sampled period during the entire time horizon (selected at the discretion of the examiners).

Cross-validation (6 months)
January 2021 to June 2021

Due date
October 2021

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 *(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 *(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 *(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

Evaluation process

Mandatory task (7%)

<table>
<tr><th>Grade</th><th>Technical performance
Battery operates within technical parameters (slide 17)</th><th>Revenue performance
With comparison to the best performing group</th><th>Code quality
Approach, efficiency and readability</th></tr>
<tr><td>7%</td><td rowspan="6">Correct implementation
(Trivial errors that don’t impact revenues are allowed)</td><td rowspan="2">Within X% of best performing group’s revenue</td><td>Fair to Good</td></tr>
<tr><td>6%</td><td>Poor</td></tr>
<tr><td>5%</td><td rowspan="2">Within Y% of best performing group’s revenue</td><td>Fair to Good</td></tr>
<tr><td>4%</td><td>Poor</td></tr>
<tr><td>3%</td><td rowspan="2">Better than baseline models provided</td><td>Fair to Good</td></tr>
<tr><td rowspan="2">2%</td><td>Poor</td></tr>
<tr><td rowspan="2">Minor errors that impact revenues</td><td rowspan="3">Less or equal to than baseline models provided</td><td>Fair to Good</td></tr>
<tr><td>1%</td><td>Poor</td></tr>
<tr><td>0%</td><td>Incorrect implementation</td><td>Not assessed</td></tr>
</table>

X and Y will be based on the number of groups and the distribution of results

Bonus task (3%)

Grade	Proposed approach Description of adjustments to switch to model with no price foresight	Commentary on challenges Explanation on the functional and practical implications of no price foresight
3%	Credible approach	Excellent commentary
2%	Credible approach	Fair or poor commentary
2%	Poor approach	Excellent commentary
1%	Poor approach	Fair or poor commentary
0%	Not attempted	Not attempted