How are customer benefits and market arbitrage benefits of behind-the-meter solar-batteries affected by tariff optimisation?

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Outline

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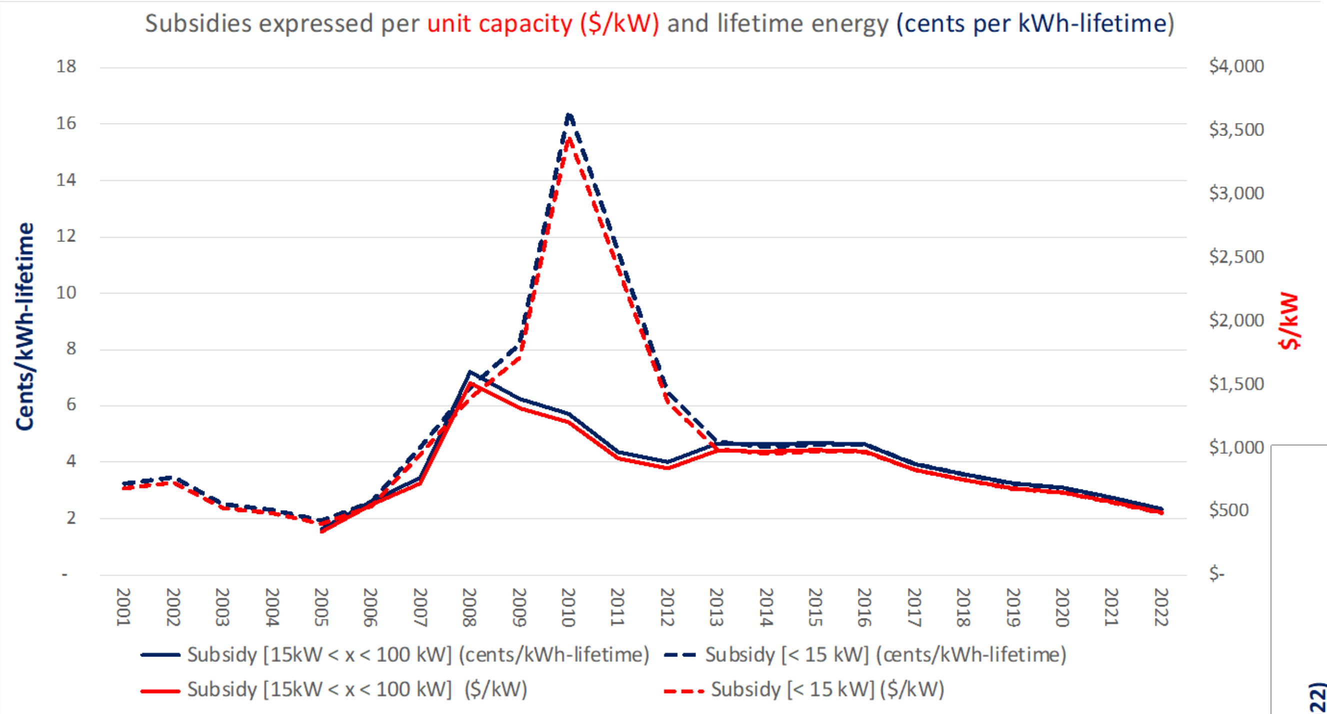
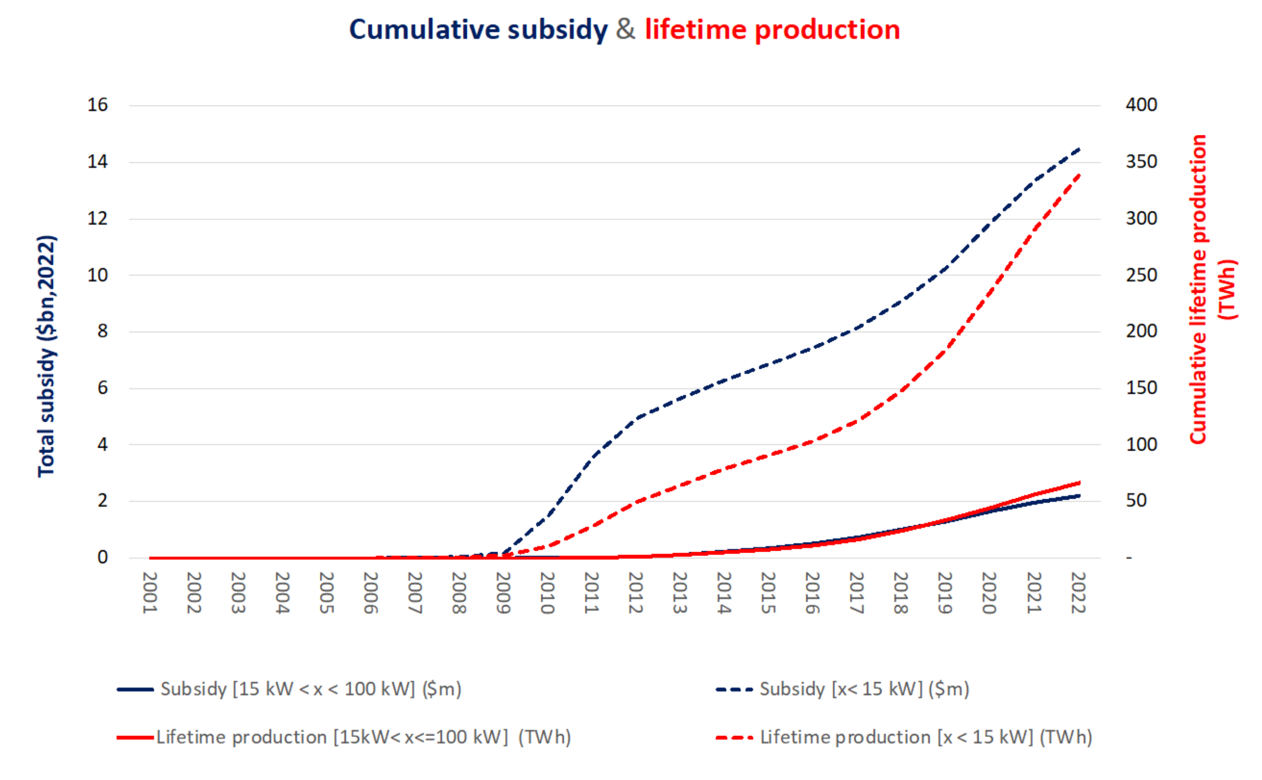
Capital subsidies have promoted rooftop solar





Data source: Clean Energy Regulator; authors' assumptions on yield (1.4 MWhpa / kW) and average asset life (15 years)

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Premium feed-in tariffs (production subsidies) played a smaller role than capital subsidies in promoting rooftop solar

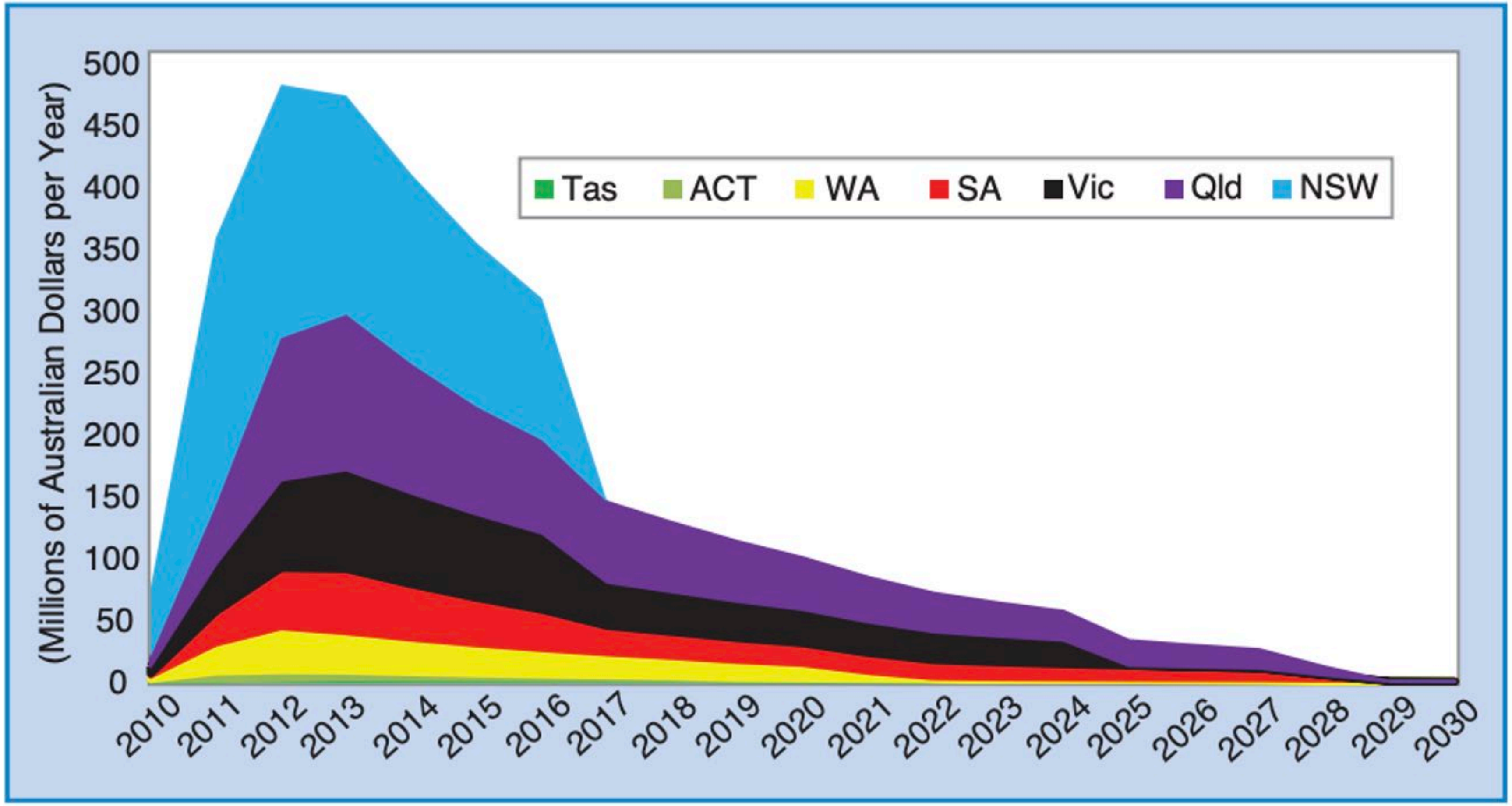

figure 7. Jurisdictional mandated FiTs, 2010 to 2030, in millions of Australian dollars (2014).

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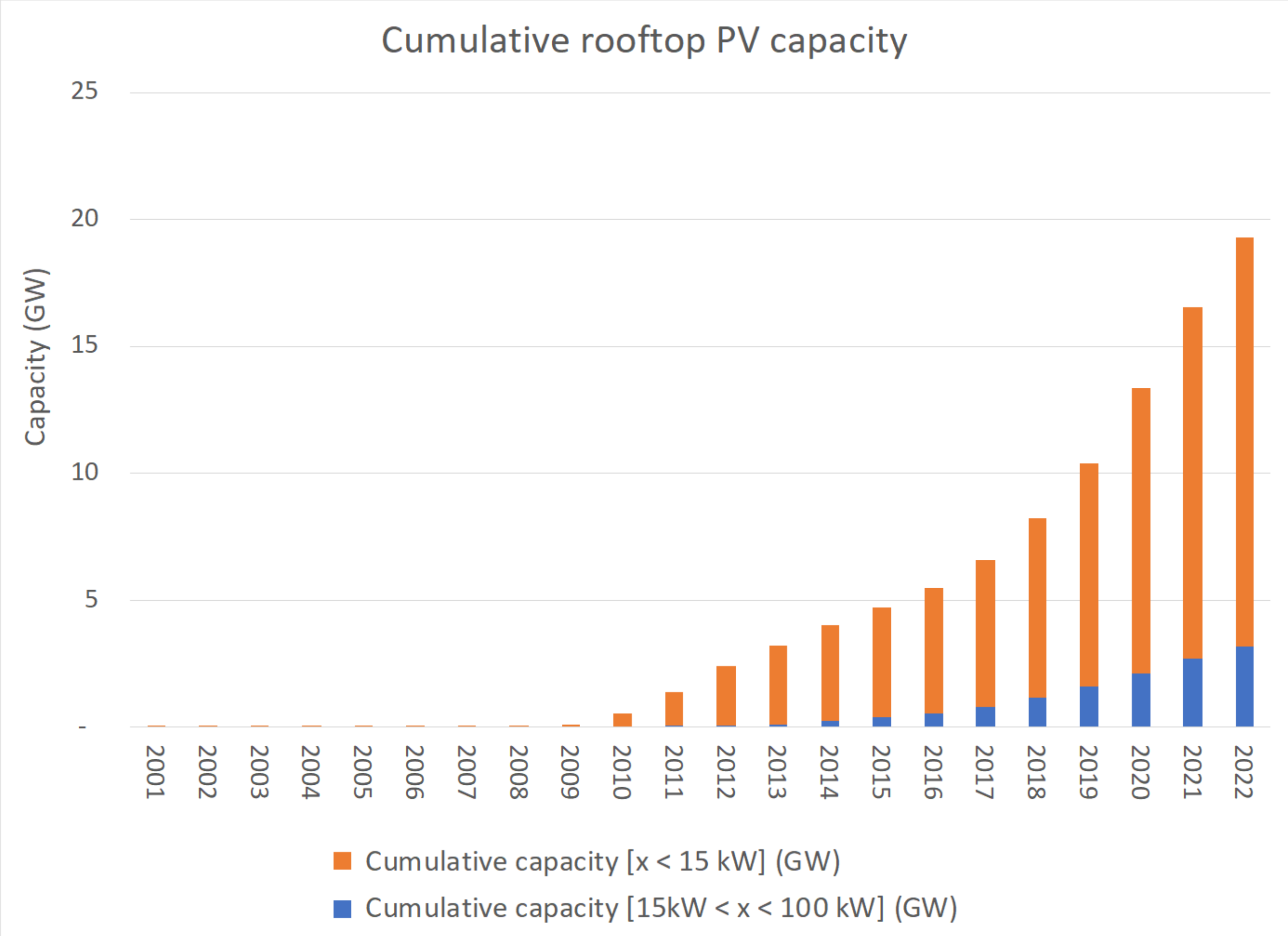
Source: Mountain and Szuster (2015)

Combined with high retail electricity prices and declining PV costs, large amounts of rooftop PV capacity have been developed



Data source: Clean Energy Regulator

- More than 1 in 3 eligible homes have rooftop solar. Highest rooftop solar penetration globally, measured at country level.
- Commercial and industrial markets now growing quickly.
- Rooftop solar PV now largest source of renewable electricity (~ 10% of Australian electricity production)

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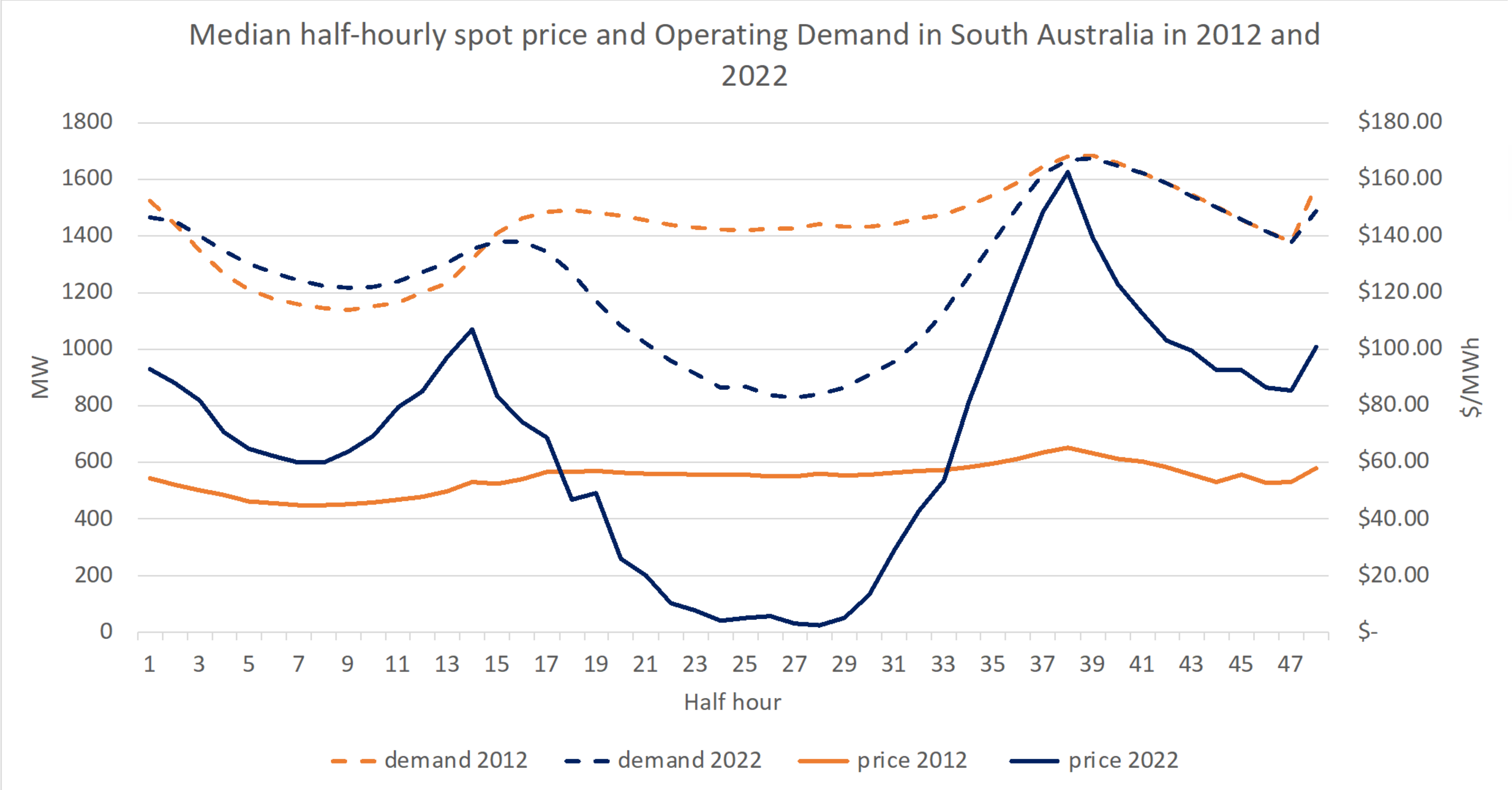
But rooftop (behind-the-meter) PV is starting to have a big impact on the demand for grid-supplied electricity and consequently on wholesale market prices



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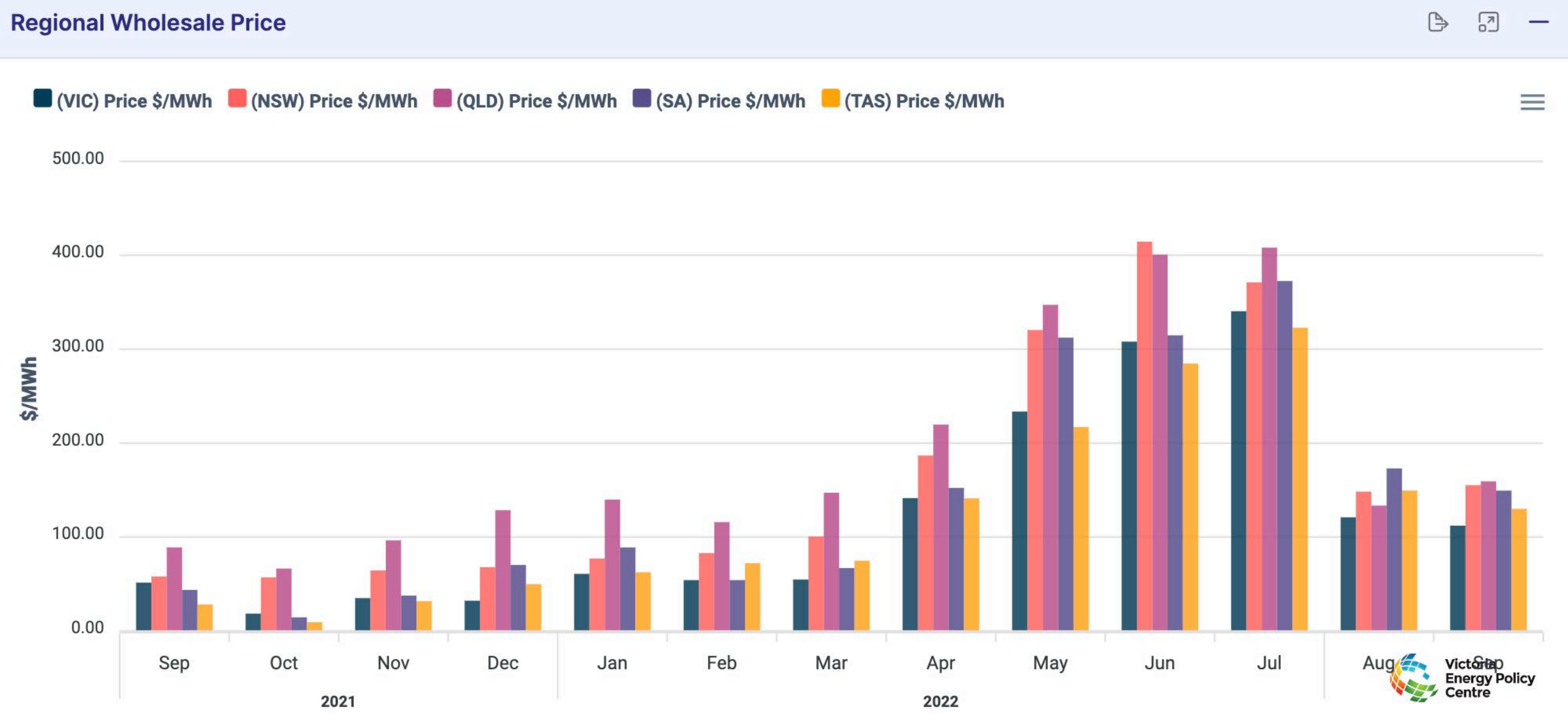
Also relevant for our study is the huge surge in wholesale prices (to 5X long run averages) in May, June, July of 2022



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Our data

- Grid injections and withdrawals, PV production, battery charge/discharge, tariff rates at 5 minute resolution for 12 months for 1000 homes with rooftop PV and BTM battery:
  - 463 (max) homes with single rate (“flat”) grid purchase (“buy”) and feed-in (“sell”) rates [“flat_flat:]
  - 135 (max) homes with time-of-use (“TOU”) buy and flat sell rates [“TOU_flat”]
  - 371 (max) homes with TOU buy and 5 minute spot market (“spot”) sell rates [“TOU_spot”]
  - 32 (max) homes with spot buy and spot sell rates [“spot_spot”]
  - These homes are located in all five regions in the NEM
- Data provided (in confidence) by Australian BTM software solution provider
- Regional Operating Demand and Spot price data published by Australian Energy Market Operator.

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Research questions

1. How are the financial gains for households from behind-the-meter (BTM) solar-batteries (“customer benefit”) affected by tariffs?

2. How is spot market arbitrage (“arbitrage benefit”) of BTM solar-batteries affected by tariffs?

3. Do customer benefits come at the expense of wholesale market arbitrage benefits (i.e. do private and public gains align)?

Relevant details

- “Flat-flat” batteries charge from BTM solar only (not from grid).
- All others are optimised with algorithms that seeks to maximise battery value to the customer considering volume of surplus BTM solar, grid buy price & grid sell price. Where relevant, the spot price used in the optimisation is the predicted (not actual) 5 minute spot prices.
- Grid purchase (at spot) incurs network charge of ~ 8 to 10 cents/kWh (varying by distribution area). For all other tariffs, these are included in the full retail charge that applies to grid purchases in the usual way.

The economics of customer benefit is tricky

- Wholesale market arbitrage: Battery charge and discharge valued at relevant spot price

- Customer benefit calculus is based on assumption that solar is first consumed by house, then put in battery then (if surplus remains) exported to grid. And then:
  - Battery discharge is priced at opportunity cost of grid purchases (if battery discharges to house) or feed-in price if discharged to the grid.
  - Battery charge is priced at opportunity cost of grid exports if charged from solar with any shortfall from solar priced at grid purchase price.

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Summary statistics – power and state of charge (all kW-5 minutes)

Variable	Minimum	p1	p50	Mean	p99	Maximum	Count (5 min intervals)
October 2021 - March 2022							
Battery power	-15.06	-2.92	0.03	-0.02	2.63	8.70	33,679,542
Meter power	-19.75	-4.67	0.00	-0.12	3.51	22.92	33,679,542
Solar power	-2.76	-0.01	0.05	0.90	5.85	19.99	33,679,542
Load power	-9.77	0.04	0.45	0.76	4.45	10.00	33,679,542
State of charge	0.00	4.40	51.68	53.67	100.00	101.00	33,679,542
April 2022 - September 2022							
Battery power	-10.00	-2.89	0.03	-0.02	3.04	9.58	34,607,345
Meter power	-17.50	-3.58	0.03	0.30	4.55	14.74	34,607,345
Solar power	-4.10	-0.01	0.00	0.53	4.57	18.01	34,607,345
Load power	-5.42	0.04	0.45	0.81	4.66	9.99	34,607,345
State of charge	0.00	4.04	35.32	45.81	100.00	102.00	34,607,345

Some households drop out over the study period (mainly because we exclude entries if grid demand is > 10 kW)

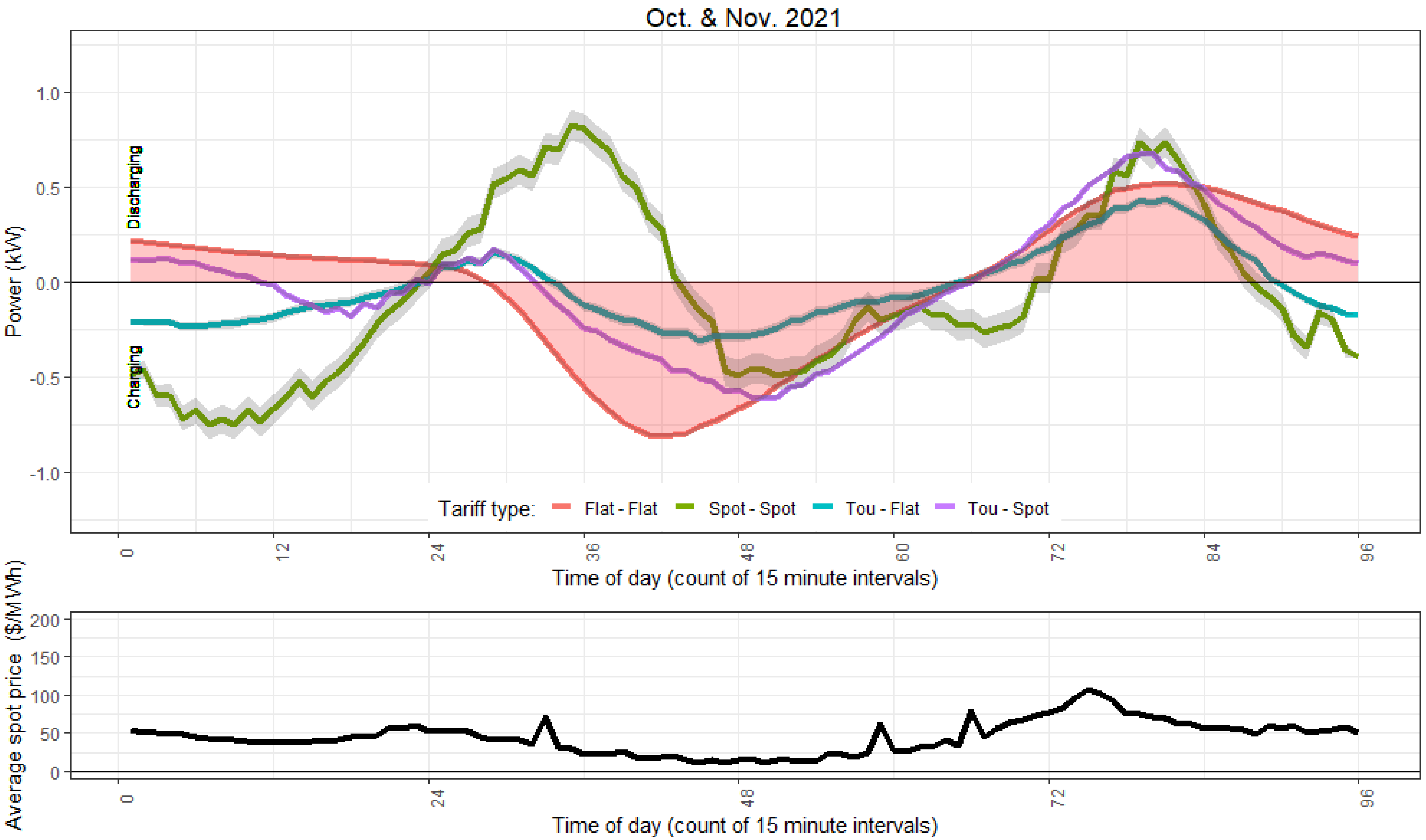
		Oct Nov 2021	Dec 21 Jan 22	Feb Mar 2022	Apr May 2022	Jun Jul 2022	Aug Sep 2022
Flat Flat	No. hh	463	436	458	463	412	442
	No. obs	7,260,804	7,344,608	7,380,331	7,538,265	6,671,813	7,252,388
Tou Flat	No. hh	135	124	132	71	53	61
	No. obs	2,246,814	2,075,148	2,096,675	1,098,191	819,943	962,400
Tou Spot	No. hh	371	368	371	372	346	361
	No. obs	6,205,318	6,213,454	6,052,191	6,190,816	5,732,881	6,061,676
Spot Spot	No. hh	32	31	31	11	10	11
	No. obs	552,594	495,348	484,818	174,724	166,190	182,017
Total	No. hh	1001	959	992	917	821	875
	No. obs	16,265,530	16,128,558	16,014,015	15,001,996	13,390,827	14,458,481

Analysis

- Regressions to understand differences in battery dispatch across the four tariff types, by time of day:
  - Random-effects linear models with an AR(1) disturbance (xtregar in Stata)
  - Battery power (kW) [Dependent var.] with dummy variables for 15-minute intervals [Explanatory var.]

- Comparisons of arbitrage benefits and customer benefits for four tariff classes.

Lets examine in detail the two months with *lowest* spot prices



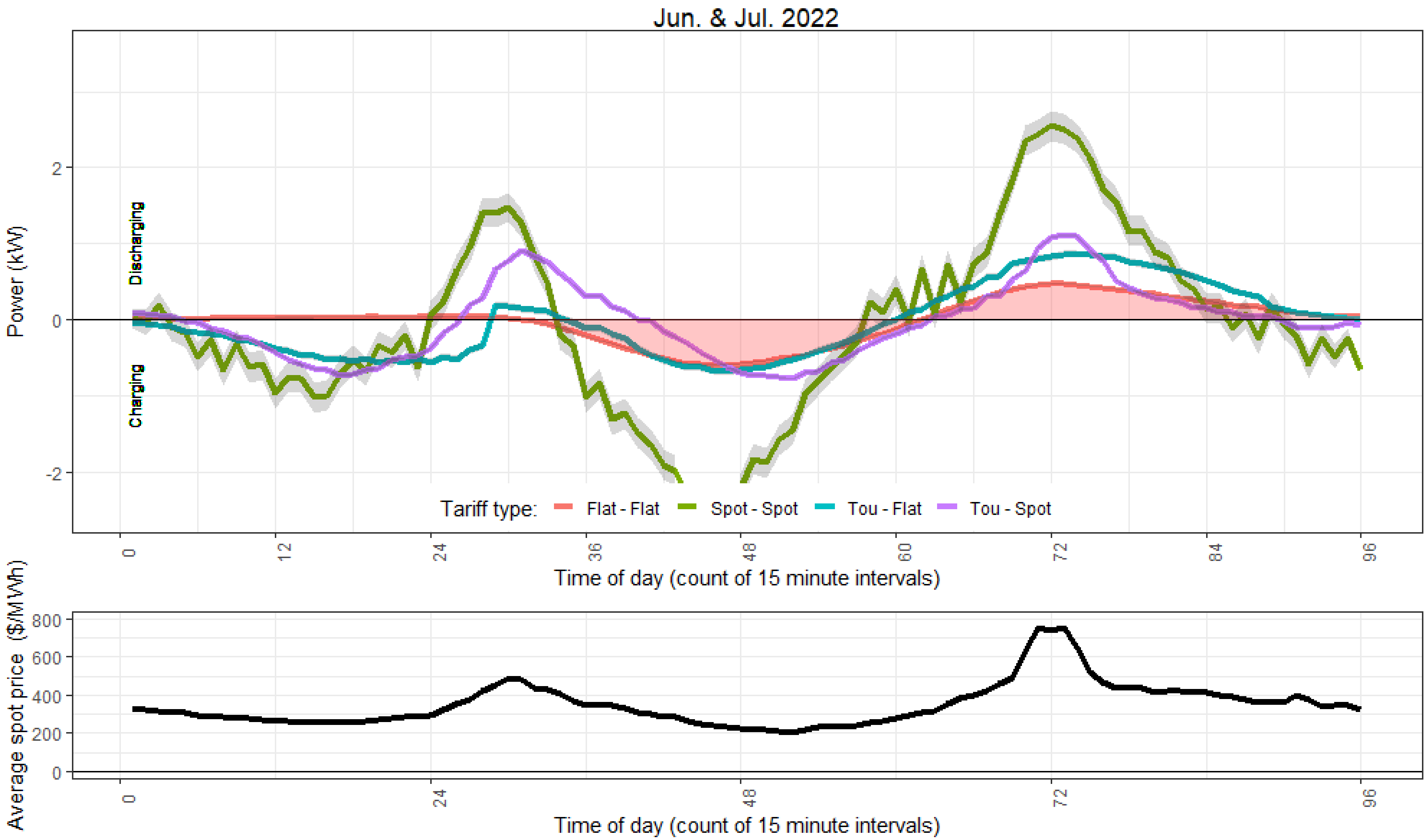
Flat/flat: battery charges from solar. Expected

TOU/flat: battery charges from the grid at night. Why?

TOU/spot: battery charges from grid to discharge for morning peak. Expected.

Spot/spot: batteries work the hardest (two discharge cycles). Expected

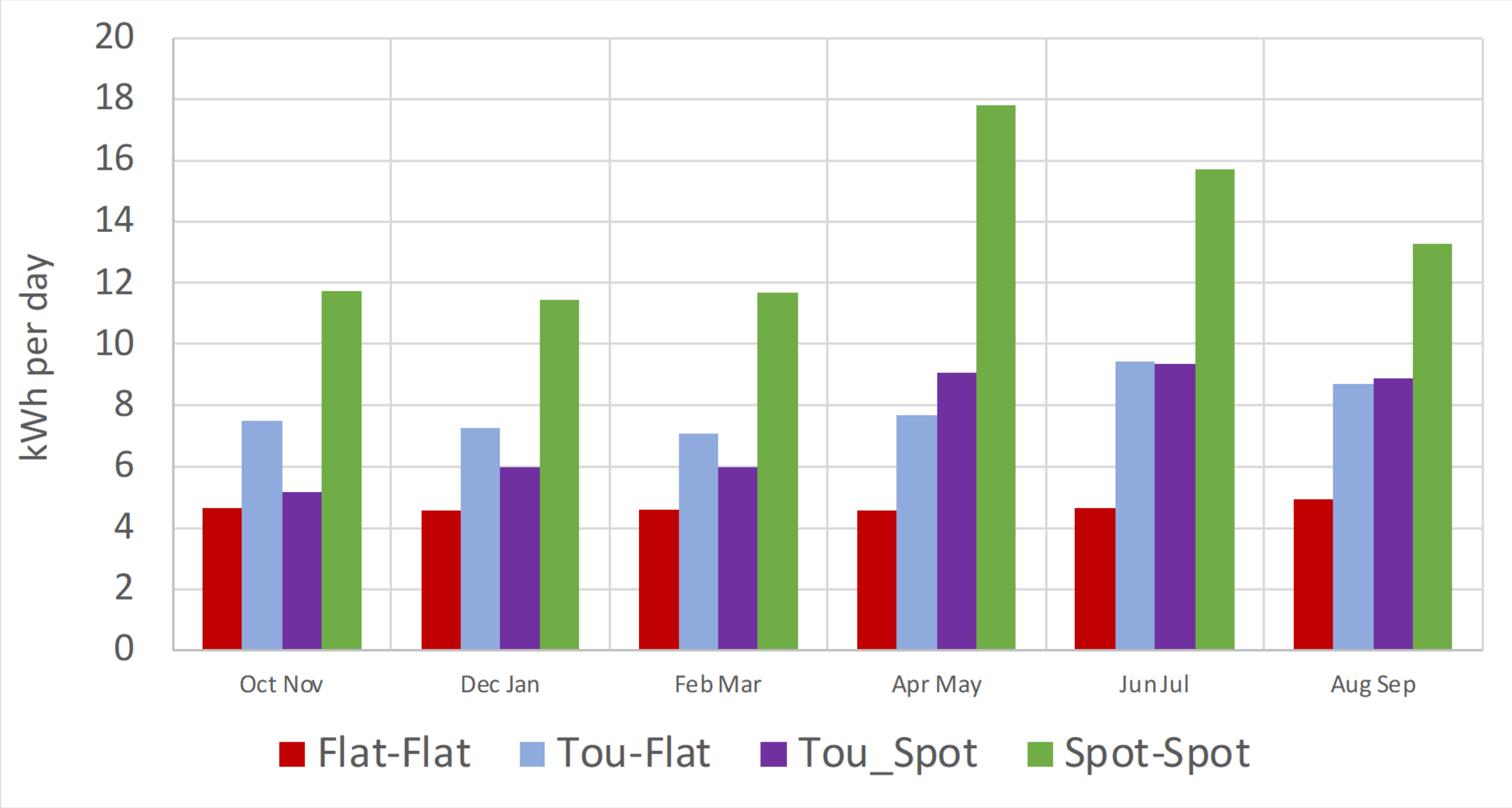
Lets examine in detail the two months with *highest* spot prices



Charging patterns as expected.

Note much heavier use of spot-spot batteries

Average daily battery discharge (kWh/day) shows that batteries exposed to time variant rates are working much harder



Flat-flat batteries do the least work ~ 5 kWh per day. Expected.

TOU_flat and TOU_spot are similar (5-9 kWh per day) and less than Spot_spot.

Spot-spot batteries work much harder(12-20 kWh per day) particularly when spot prices are high. Expected.

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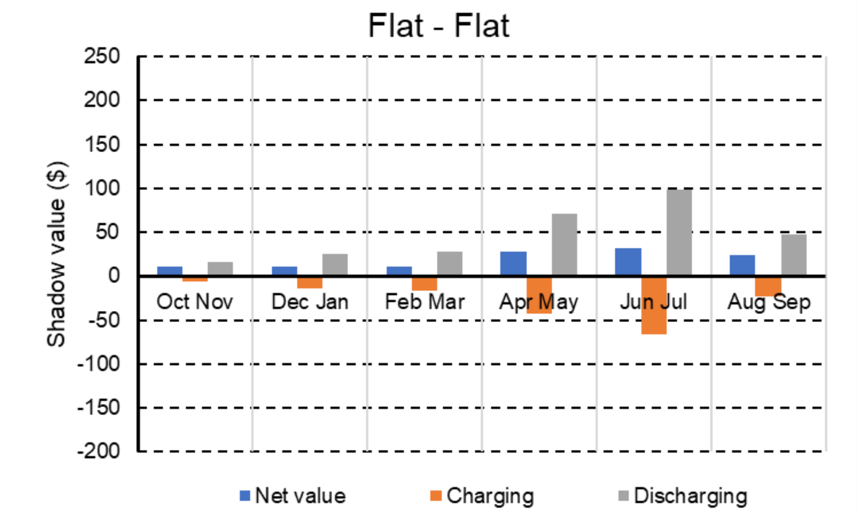
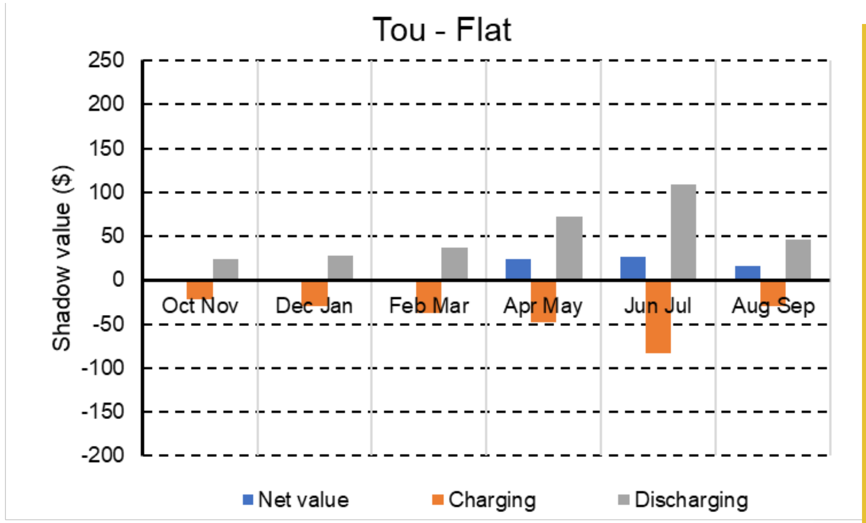
Arbitrage benefits: varied greatly over the period but in all cases falls short of the level needed for profitable investment in batteries



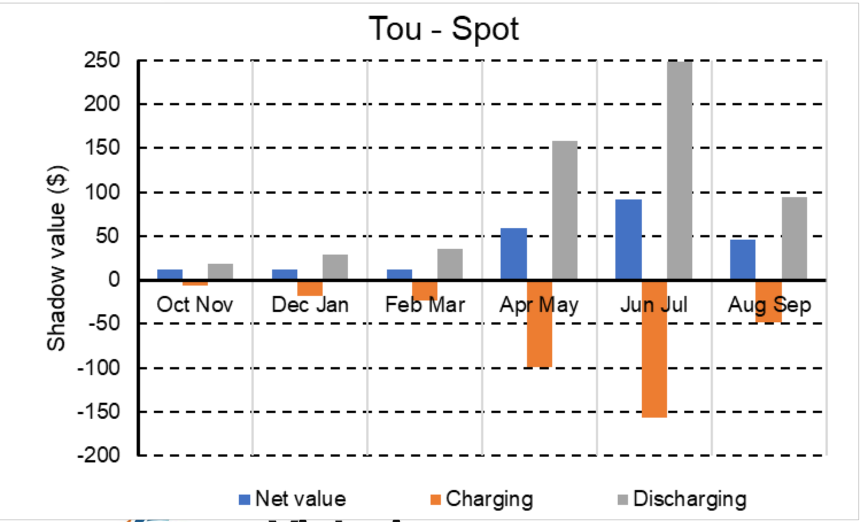


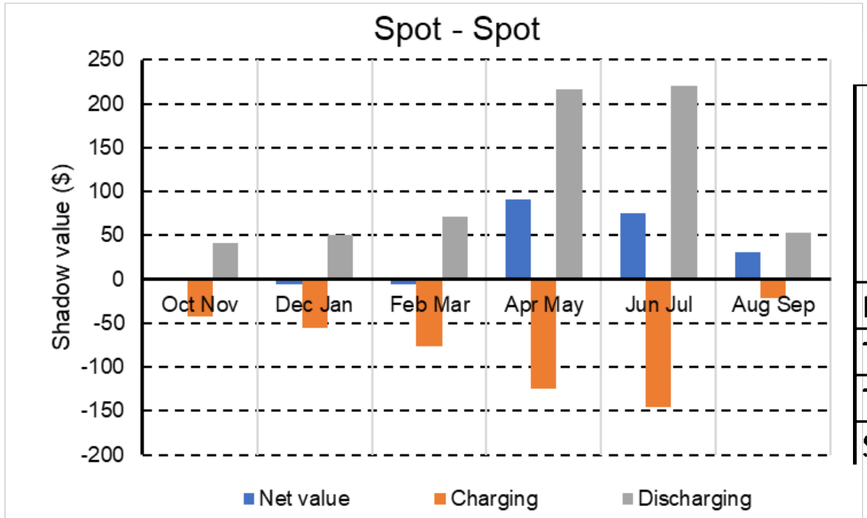
Flat-flat not great benefit, but second most efficient arbitrage

TOU-flat poor income and inefficient arbitrage

TOU-spot high income and most efficient arbitrage

Spot-spot results disappointing considering how hard they tried.





	Arbitrage benefit for the year ($)	Average daily discharge (kW)	Average arbitrage per MWh ($/MWh)
Flat-flat	$ 117	4.7	$ 69
TOU-flat	$ 66	8.0	$ 23
TOU-spot	$ 232	7.4	$ 86
Spot-spot	$ 185	13.6	$ 37

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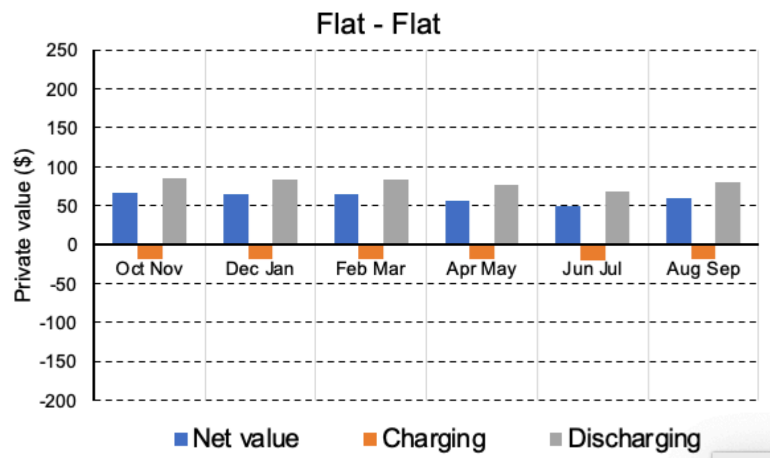
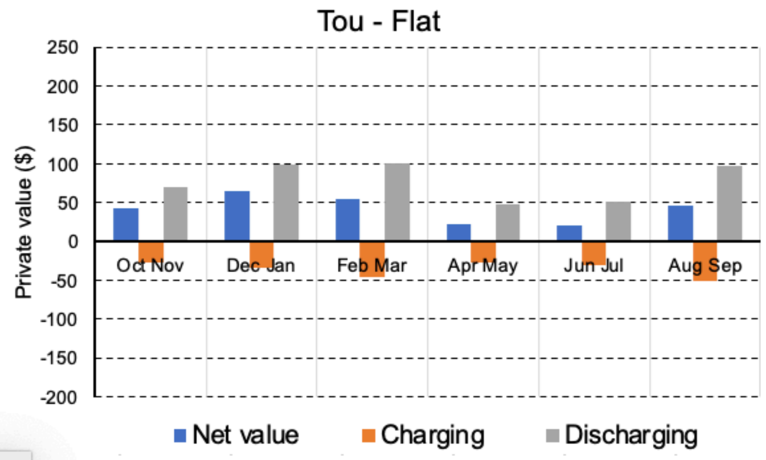
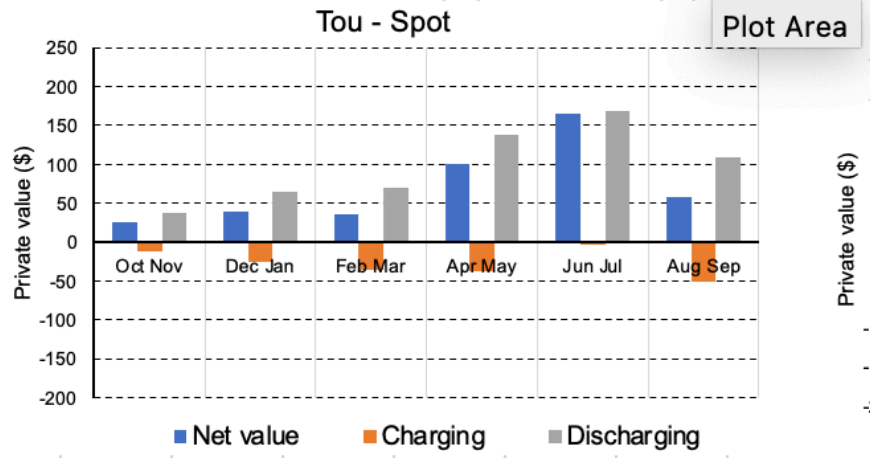
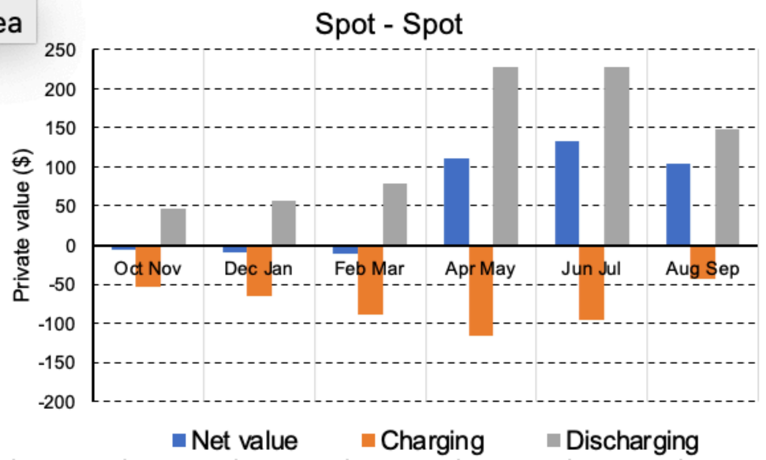
Customer benefits: Flat-flat households gained more from their batteries than spot-spot; and flat-flat was much more efficient









Flat-flat second-highest customer benefit and most efficient.

TOU-flat lowest benefit and second least efficient

TOU-spot highest benefit nut much less efficient than flat-flat

Spot-Spot third highest benefit but the least efficient

	Customer benefit for the year ($)	Average daily discharge (kW)	Average customer benefit per MWh ($/MWh)
Flat-flat	$ 340	4.7	$ 200
TOU-flat	$ 235	8.0	$ 81
TOU-spot	$ 392	7.4	$ 145
Spot-spot	$ 329	13.6	$ 66

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Main observations

1. Tariffs have a big impact on battery dispatch.
2. “Spot” optimisation (whether spot only when selling to grid, or spot when buying and selling) only provided non-trivial arbitrage profits when spot prices reached stratospheric levels. Even so, these batteries worked very much harder at all times and so can expect shorter working lives.
3. Spot arbitrage gains are in all cases are not enough to justify investment in a BTM battery. (Perhaps this will change with refined optimisation and the prospect of a widespread “duck curve”?)
4. Spot market arbitrage benefit was the biggest (and most efficient) for TOU-spot. Flat-flat was half as big, but more efficient than Spot-spot.
5. Customers on flat/flat tariffs gain more than customers on spot/spot. Flat/flat is the most efficient at delivering customer benefits.

Tentative conclusions

1. Spot-spot rates (many economists' pursuit) produced adequate outcomes for customers but are inefficient in delivery of spot market arbitrage and customer benefits (Does this reflect poor trading?)
2. Passive (not optimized) batteries take a lot of beating: Most of the value in a battery is gained from its ability to store cheap BTM solar and use it later to avoid expensive grid-supplied electricity.
3. Tying policy support for BTM batteries to spot market arbitrage benefits will also provide customer benefits, but at the expense of shorter asset life and lower efficiency (particularly spot-spot). Battery support policy should also have regard to efficiency. This favours flat-flat tariffs.
4. These conclusions may change in future if optimization is refined and/or market prices become more volatile and tariff rates reflect greater temporal variation.

Direction for future research

- To what extent can these results be explained by poor optimization or because the value is not there to be had?

- Taking account of the whole picture for households with BTM battery and solar – i.e. also including self-consumed solar, grid purchases consumed not stored, and solar exported to the grid - which tariff arrangement is the most attractive for customers?