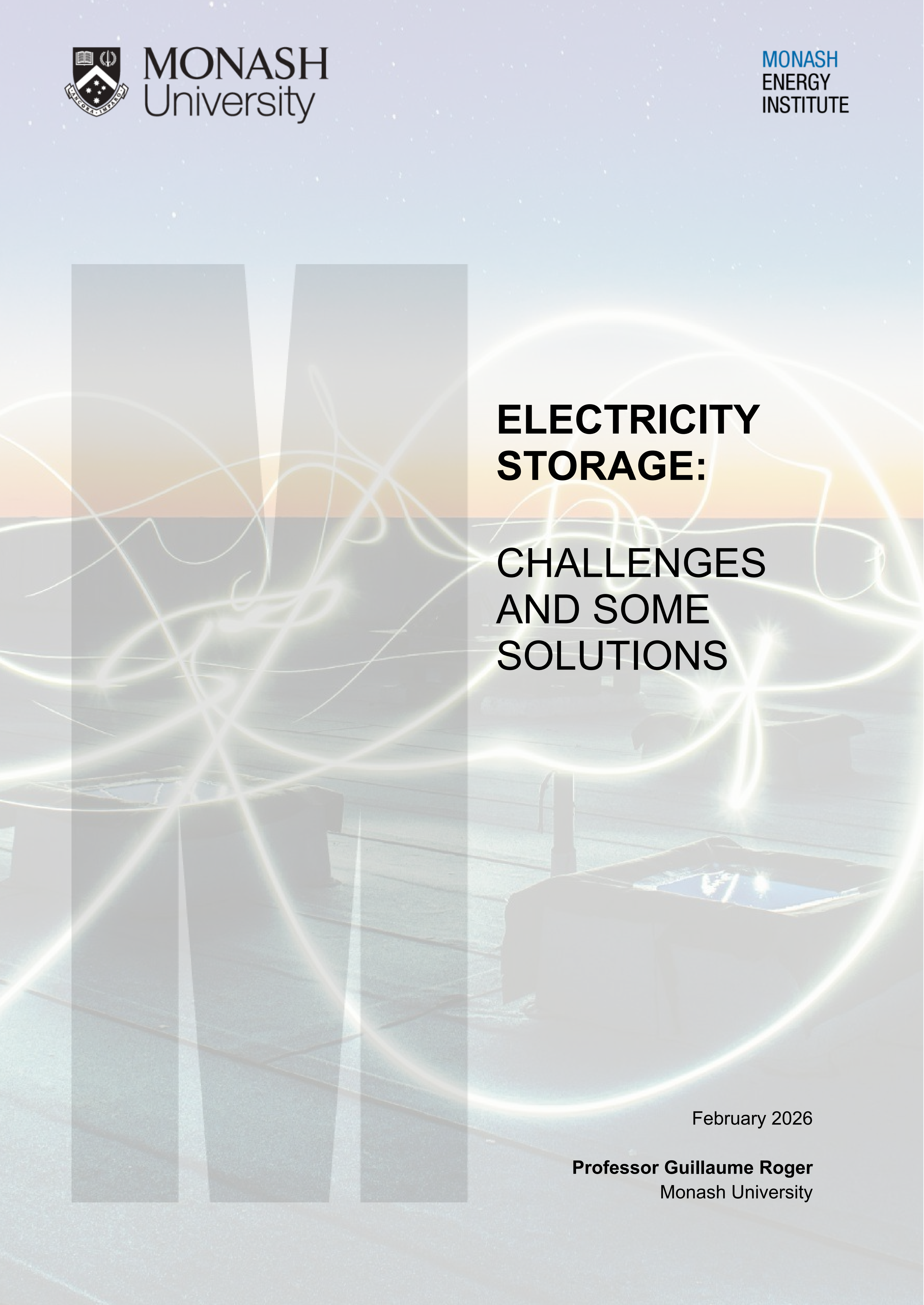

MONASH University

MONASH
ENERGY
INSTITUTE

ELECTRICITY STORAGE:

CHALLENGES AND SOME SOLUTIONS

February 2026

Professor Guillaume Roger
Monash University

Project partners

ARENA

Australian Government

Australian Renewable
Energy Agency

AEMC

PSC

Specialist Consultants
to the Electricity Industry

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Thanks to the team

This brief paper is based on the work of an entire team at Monash University, including Dr Sergei Balakin, Dr Nawaaz Khalfan and Dr Ningyi Sun.

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PSC Consulting has played a pivotal role as the project's knowledge-sharing partner, alongside the Monash GIH. Since inception, PSC has hosted a client-focused knowledge-sharing event, produced a widely circulated interview featuring PSC subject matter expert Victor Francisco and Prof Guillaume Roger, and deepened its engagement across the partnership. PSC has also contributed to board-level discussions shaping the project's direction, ensuring alignment with industry needs and policy developments. This involvement has extended to internal Lunch and Learn webinars that empower teams to advocate for the research and its real-world applications. These efforts underscore PSC's commitment to advancing understanding of energy storage and fostering collaboration across the energy ecosystem.

The **Energy Lab** at Monash Business School delivers impactful research on energy market design in collaboration with industry and policymakers, coordinated through the Monash Energy Institute. The Lab comprises global academic experts and former regulators in energy economics and market design, and works at the frontier of energy market reform and competition policy through deep theoretical and empirical research capacity to inform the energy transition.

Context and Background

In Australia, the transition of the electricity industry is outpacing the speed at which the institutions governing the market have been adjusting. As is the case in other industries, innovation takes these market directions that are poorly understood by the overseeing institutions – and the market participants themselves. However, the electricity grid is a nest bed of externalities: what a participant does affects everyone else, and in some cases can lead to very damaging failures.

This project set out to explore the economics of storage in detail to inform policymakers, such as the AEMC, the AER, the ACCC, and the market operator (AEMO). The goal was to deliver a suite of research papers to understand the behaviour of profit-maximising storage operators, to explore the development of an adequate market design in which storage is a significant player, and to understand some issues of competition policy with storage.

From the early works of Karaduman (2020) and Andres-Cerazo and Fabra (2023), we know that operating a storage unit is very different from operating a power generation unit, and that the industrial organisation of the market is an important consideration for competition policy. This project convincingly shows that social efficiency, even in the second-best, requires market design and the formulation of corrective policies. To complete this task, policymakers need more and better information as to the economics of storage.

The knowledge vacuum the NEM is exposed to is all the more concerning, as the necessary investment in storage to complete the energy transition is staggering. As of mid-2025, the dispatchable capacity of the NEM is approximately 43 GW, which can be on essentially non-stop for any duration. A *complete* transition requires a vast amount of investment that deserves some study (see Roger, 2024).

1. Storage as a bottleneck

Storage is a revolution in electricity markets because it allows the intertemporal shifting of production, and so complements renewable energy generation. Today, storage is the bottleneck of any meaningful energy transition. This is made obvious in the Figures. In Figure 1, the LHS is the variable VRE supply, and the RHS is the gross demand in the NEM. Energy is produced when not needed.

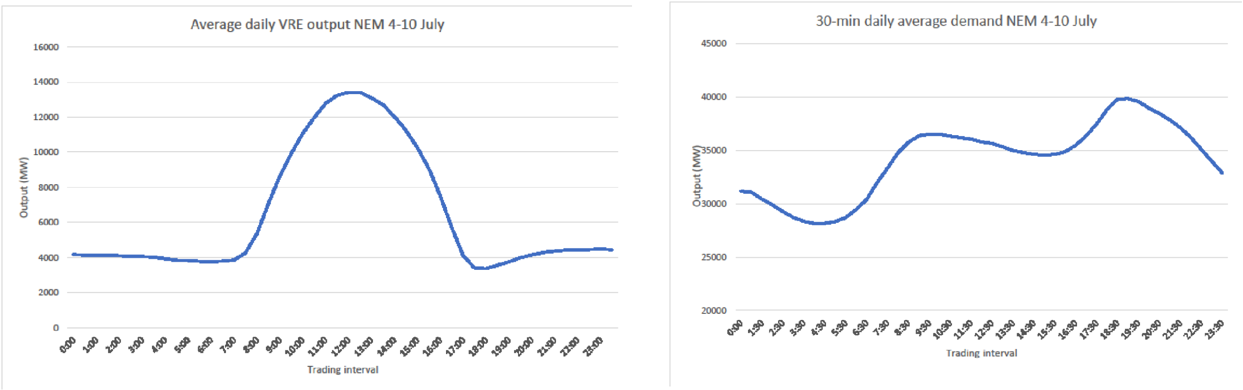

Figure 1: VRE supply (left) and total demand (right).
Storage can shift production from the middle of the day to high-demand periods.

Figure 2 illustrates the economic implications: in periods of high production, low system demand induces low clearing prices. The consequence is a stall in the energy transition.

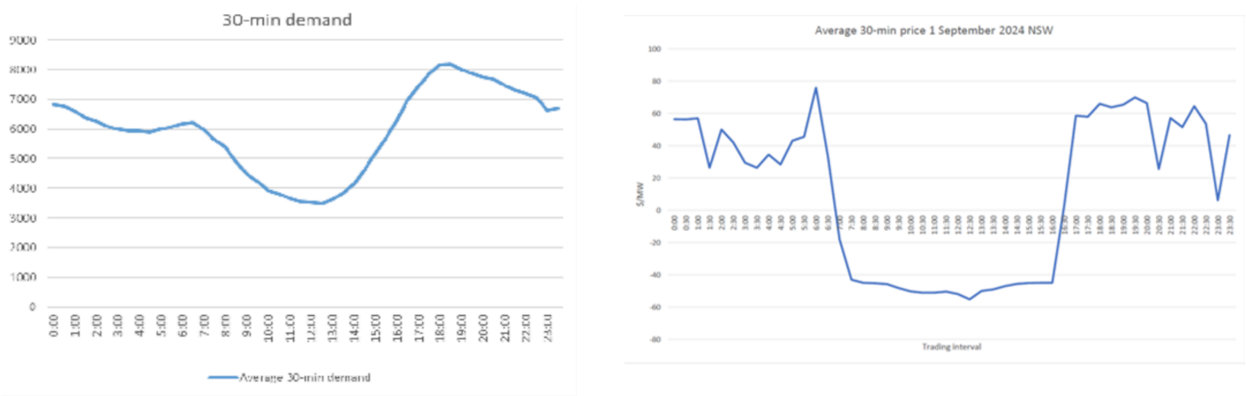

Figure 2: low demand (left) and corresponding clearing prices. September 1, 2024.

The premise of storage is to transport the energy produced when not needed to higher-demand periods (Figure 1). It does so by exploiting price differences over the course of the day (Figure 2).

However, despite being a simple idea, energy arbitrage is difficult to implement.

2. Storage operation

In a series of papers with Sergei Balakin, I study optimal trading strategies for storage in different environments (Balakin and Roger, 2025 and 2025c). Successfully operating storage is difficult for two reasons: (*i*) trading is dynamic, and (*ii*) it must be performed in a very uncertain environment. Throughout, we find that a storage operator faces strong incentives to withhold quantities for two important reasons. The first one is that storage must buy to sell; the important consideration is not the selling price but the price difference between buying and selling. This *arbitrage spread* is eroded as soon as the storage unit sells and also when it buys. Furthermore, buying is typically decided when the demand is uncertain; prudent operation induces the unit to buy less rather than more. The second reason is less traditional and rooted in the fact that trading is dynamic and uncertain. This gives rise to the *continuation risk*, that is, the risk of being stuck full and unable to sell. This is twice costly because buying and waiting is costly, and foregoing trading opportunities is costly. As a result, a unit with finite capacity rarely trades its capacity in full. For the same reasons, we also find that competing storage units face strong incentives to engage in collusion; this collusion can take many forms because storage can also collude on buying (Balakin and Roger, 2025b).

These results suggest that storage units have strong incentives to engage in anticompetitive behaviour. Competition authorities should be on the lookout and:

- in light of the absence of returns to scale in battery storage systems, privilege the emergence of many small-scale players over a few large ones
- restrict large-scale conventional generators from also owning storage assets (see Andres-Cerezo and Fabra, 2023)
- promote entry by new entrants rather than letting incumbents develop storage assets.

3. Market design considerations

Beyond these aspects of competition policy, market design can also be called upon to improve the performance of storage assets.

- **Markets with storage**

  Given that storage units have strong incentives to engage in anti-competitive behaviour and dislike risk, well-designed market rules should address these problems head-on. First, it is worth recalling that storage units take advantage of price variations. Locational Marginal Pricing can multiply these price variations, in space and over time. Second, a day-ahead market delivers the twin benefit of certainty in revenue before demand realisation and is known to be pro-competitive.

- **Combinatorial markets**

  Modern electricity markets feature heterogeneous generation technologies, each with differing features such as marginal costs and start-up costs (see Jha and Leslie, 2025, for some evidence). In the NEM, which does not allow for minimum revenue requirements or such a device, this co-existence results in interruptions in operations, shutdown and restart, and negative prices. With Ningyi Sun (Roger and Sun, 2023 and 2024), we propose a new procedure that we call a combinatorial market, in reference to combinatorial auctions.

In a combinatorial market, the market designer collects adjacent trading intervals into strips of any duration – for example, 12 intervals in an hour. A dispatchable generator can bid not only for the five-minute intervals, but also for the strips on offer. The idea is to guarantee that dispatchable units can sell for a specified duration; adjacent trading intervals become complements. We show that the coexistence of the block markets and the five-minute market induces lower average prices.

These findings are validated by a small series of early experiments in the lab, whereby subjects play a market game. Indeed, subjects seek to take advantage of the certainty provided by the long-duration blocks and bid aggressively for them. The strategic effect then leads them to also bid more aggressively in the standard, 5-minute market. Thus, in spite of the complexity of such a market design, undergraduate students can rapidly learn to respond adequately.

4. Challenges

Now, let's turn to some more speculative aspects and contemplate the challenges ahead.

- **A world without thermal generation?**

The stated goal of the federal government is to reach 82% renewable energy in the NEM. So it seems worthwhile considering how such a market, with little to no thermal generation, may operate. This seemingly innocuous step is actually challenging. To fix ideas, suppose gross demand is price inelastic $D(t)=d$, and there is some (notoriously) price-inelastic VRE supply ε_t that is a random variable (e.g. wind supply). Such a market has no chance of clearing, except if storage steps in. Storage has a dual task: (*i*) store energy (when $d<\varepsilon_t$) and release it (when $d>\varepsilon_t$), and (*ii*) act as the marginal seller (when $d>\varepsilon_t$) or buyer (when $d<\varepsilon_t$). To be clear, storage restores demand elasticity so the market can clear and a price can be determined.

But it is not known how storage operators formulate their offers to sell or buy *absent* thermal generation. The difficulty is that the marginal cost of a storage unit is the opportunity cost of energy, which is determined as part of the equilibrium. It is necessary to understand this point to engage in market design.

- **Reliability**

A NEM with little to no thermal generation capacity raises the question of reliability. Currently, reliability can be guaranteed by knowing the total *power* capacity of the NEM because there is always enough fuel available to deliver energy to consumers. With a finite *energy* storage capacity, reliability requires knowing how much energy must be delivered – how much power and for how long. The picture on the LHS of Figure 3 illustrates a Dunkelflaute – a persistent period of no sun because there is also no wind to sweep the clouds away. The RHS shows the effects of a Dunkelflaute in the NEM: for two days on June 11th and 12th, most of the energy in the NEM was supplied by fossil fuels. Asking how long a Dunkelflaute lasts is tantamount to asking how long a piece of string is.

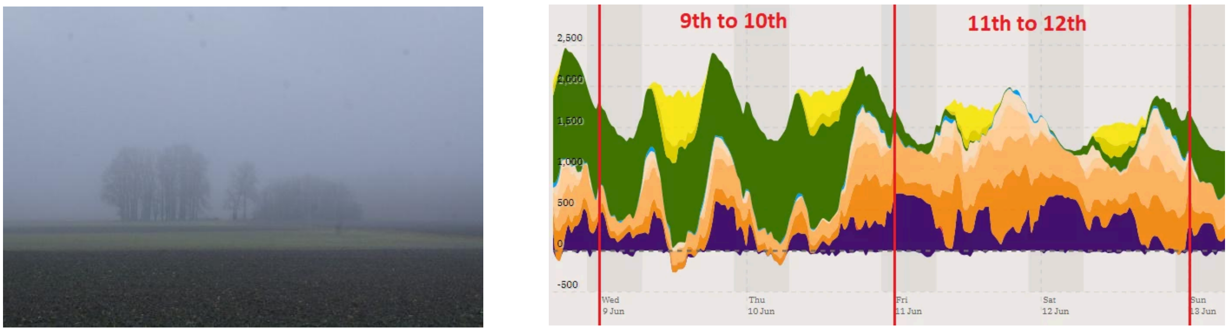

Figure 3: Dunkelflaute (left) and effects on the NEM, June 2025.

Supposing the existence of a (new) *energy*-based reliability standard, one must then tackle the question of the implementation of this standard in market operations: what rules (such as market-clearing rules) should a market operator (like AEMO) apply to guarantee energy delivery? Today, this is a relatively simple problem: increasing prices call for more supply; if this is not sufficient, AEMO can augment the dispatch by calling on reserves or even by directing generators. Because fuel is available, power can be produced for any duration. With storage, for energy to be deliverable, it first has to be in store. AEMO must manage the aggregate state of charge for *power* and *duration* over time. Duration can be relevant over a 24-hour cycle, with periods of charge and of discharge, and across multiple cycles – for example, in case of a wind drought. Balakin and Roger (2025c) show storage commits itself to withholding quantities over a cycle and across cycles by restraining *purchases*. To ensure reliability, the market operator needs to induce storage to purchase more than what it finds privately optimal. But Balakin and Roger (2025, 2025c) also show that increasing traded quantities reduces storage revenue, which in turn curtails investment in storage capacity. A successful suite of policies must address both issues of effective operations in the short run and adequate investment in the long run.

One avenue may be to introduce a dynamic *reliability constraint* on the cost minimisation problem of the market operator; this constraint becomes progressively binding as the aggregate state of charge decreases. To provide incentives for energy conservation, this constraint can induce *price separation*: in a discharge period, buyers pay a higher price than sellers receive, and this difference increases with scarcity. This creates revenue that can be appropriated by the market operator. To induce storage to purchase more energy than is privately optimal, this revenue can be rebated to storage operators when they charge their units. This is a subsidy: the price paid by buyers (storage) increases more slowly than that received by sellers. The details of such a scheme have to be developed.

- **Sufficient storage capacity**

This seemingly adjacent question is in fact quite different. So far, the presumption underlying storage deployment is that the arbitrage revenue it generates is sufficient to sustain the desired level of investment. Recent commentary suggests this need not be true. That is, the arbitrage revenue may be insufficient to support the capacity investment required to complete the energy transition. This is not a hypothetical exercise: even if arbitrage is sufficient to support the capacity required in *normal* operations, we already know it is not a viable proposition for the more *extreme* events that occur only a few hours of the year. This is an instance of market failure: social and private incentives do not align, and so may warrant intervention. Then what is an alternative mechanism to procure storage capacity and reach the target level of renewable penetration?

Because the *social* value of storage capacity exceeds the (private) value to investors, a “tax and subsidise” scheme may be appropriate to foster procurement. However, there are substantive departures from a standard procurement problem (see Laffont and Tirole, 1993, for example). First, to be useful, any subsidy must be contingent on energy delivery and not on capacity; it must foster operation and not just (idle) entry. Second, *novel* externalities emerge. The Laffont and Tirole framework elicits cost information to determine the operating subsidy, where that cost is *exogenous*. But for a storage operator, the marginal cost is *not* exogenous; it is the opportunity cost of energy. That cost is determined in equilibrium (endogenously) as part of the sequence of decisions to charge and discharge in the market. Hence, the *incentive constraints* that are necessary to elicit cost information and determine the subsidy also become *endogenous* objects, since costs are endogenous. This is a new class of problems, for which no solution exists yet.

Conclusion

In closing, I want to leave you, the reader, with three key ideas:

1) Storage is essential to any significant energy transition, and it is expensive.
2) Operating storage efficiently is difficult, and storage operators have a natural tendency to withhold quantities to manage their arbitrage spread.
3) Taking advantage of storage may require significant adjustments to market design.
4) Because the determining factor in storage is the energy capacity, new challenges arise: how much capacity is required, how to best operate it, and how to best procure the necessary storage capacity are new questions. In particular, procurement may need active intervention, later complemented by careful operation.

FURTHER READING RELATED TO THIS PROJECT

- Roger, G. (2024) "The storage imperative: powering Australia's clean energy transition", *white paper, Monash Energy Institute*
- Balakin, S. and G. Roger (2025) "Dynamic trading strategies for storage" *Journal of Economic Dynamics and Control*, No 176
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- Balakin, Sergei and Guillaume Roger (2026b) "Modeling trading over time" (PREPRINT OR EQUIVALENT)
- Roger, G. and N. Sun (2023) "Supply function equilibrium with non-convexities." (PREPRINT OR EQUIVALENT)
- Roger, G. and N. Sun (2024) "Combinatorial markets." (PREPRINT OR EQUIVALENT)

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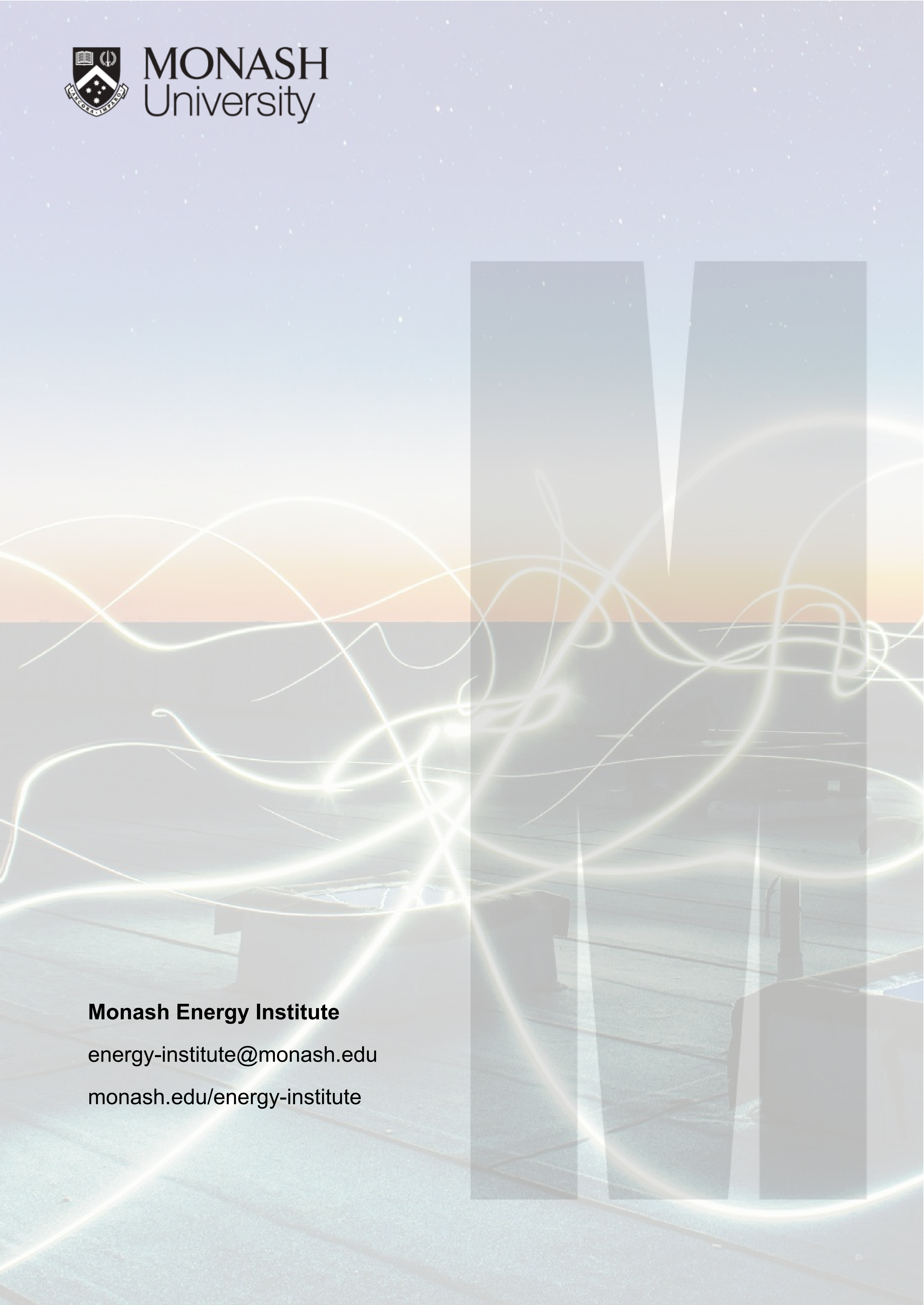

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