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Renewable Energy Integration and Electricity Prices： Australia’s Energy Transition Experience

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1.Introduction

Australia stands at the forefront of a global energy transformation. Its National Electricity Market (NEM) is currently navigating a monumental transition from a reliance on centralized coal-fired power generation to an embrace of variable renewable energy (VRE). Notably, Australia's commitment to renewable electricity capacity installation surpasses that of other nations, being 2.5 times greater than its closest competitor, Germany, as in 2019 (Stocks et al., 2019). Furthermore, Australia distinguishes itself as a pioneer in solar PV generation, much of which is derived from household rooftop installations (AER, 2021).

Historically, the trajectory of Australia's electricity industry reforms spanned several decades, primarily focusing on deregularization. However, the narrative has evolved in recent times. The imperatives of climate change, advancements in technology, and the ageing of coal-fired generators have steered the latest wave of reforms. Originating with a robust fleet of coal-powered plants, the NEM has been predominantly fuelled by fossil fuels, positioning the electricity sector as a significant contributor to the nation's greenhouse gas emissions (AER, 2021).

With the pressing challenge of climate change, Australia's electricity sector bears a crucial responsibility. It is instrumental in actualizing the country's emissions reduction goals, especially the ambitious net-zero carbon dioxide emissions target set by state governments. Renewables, in this context, emerge as pivotal players in the decarbonization process. Yet, the transition is not without its dilemmas. Balancing emissions reduction with the dual imperatives of affordability and system reliability—often referred to as the "energy trilemma"—poses a significant challenge.

This policy brief seeks to illuminate the evolving landscape of Australia's energy sector, exploring pertinent policies, elucidating challenges, and proffering recommendations for a sustainable renewable energy future.

2.Strategic Initiatives for Emissions Reduction and Renewable Transition

2.1 Australia's Renewable Energy Target (RET)

Australia's commitment to a sustainable future is evident in its pledge to achieve net-zero emissions by 2050. In alignment with the Paris Agreement (2016), the nation has undertaken to curtail its carbon emissions to 26-28% below 2005 levels by 2030 (AER, 2021). Successive federal government interventions have led to the development of policies designed to support the adoption of renewable energy. A notable example is the Renewable Energy Target (RET). This ambitious goal was set to harness 33,000

GWh of electricity from large-scale renewable energy by 2020, equating to 23.5% of Australia's electricity generation capacity. Remarkably, this target was realized in September 2019, a year ahead of projections, underscoring Australia's aggressive strides in VRE adoption (CEC, 2023).

2.2 Carbon Pricing Mechanism (CPM)

The Australian government (2007-13) instituted the Carbon Pricing Mechanism (CPM; operational from 2012 to 2014), which sought to incentivize major carbon emitters to augment their energy efficiency and pivot towards sustainable energy sources (CER, 2021, AER 2021). The overarching objective was to mitigate carbon and other greenhouse gas emissions to a level 5% below the 2000 benchmark by 2020. By the time of the CPM's cessation, there was a marked reduction of approximately 25% in coal-fired generator output. Coal generation's market share saw a historic low, leading to a 10.3% reduction in the electricity sector's carbon emissions during the CPM's operational tenure (AER 2015).

2.3 Regulatory Transformation in NEM

On October 1, 2021, the NEM experienced its most significant regulatory shift since its inception in 1998. The settlement period for wholesale electricity was shortened from 30 minutes to 5 minutes. This change was designed to deliver better price signals to flexible generators, enabling them to rapidly respond to the variable nature of renewable energy, and hence support the smoother integration of renewables into the grid (AEMC 2021, AEMO 2021)

3. The Challenges of VRE Integration in the NEM

The pace at which VRE is being integrated into the NEM is both unparalleled and beyond initial market anticipations. The NEM's foundational structure was conceptualized around fossil fuel energy sources, a time when the prospect of VRE generation was neither envisaged nor present. This has made accommodating the rapid influx of VRE a formidable challenge, given its unique characteristics which diverge from traditional fossil fuel-centric designs.

Traditional coal-fired power plants were not engineered with the flexibility required to support and complement the dynamic nature of VRE generation. The architectural blueprint of the NEM historically prioritized the supply side, envisioning electricity transmission as a unidirectional flow from large-scale, centralized generators to end consumers. This paradigm makes the integration of behind-the-meter resources, notably rooftop solar installations, a complex endeavour.

The inherent inflexibility of coal-fired plants restricts their ability to adapt to fluctuating demand patterns, particularly during periods of high VRE generation. This not only challenges their operational efficiency but also jeopardizes their financial sustainability, escalating the risk of premature decommissioning. While traditional coal and gas generation provide the foundational stability essential for the market, they contrast with VRE, which currently lacks certain stabilizing technical attributes (IEEFA, 2021). Cumulatively, this shift towards more sustainable, cost-effective energy solutions has perturbed the conventional modus operandi of the NEM, raising concerns about the future security and reliability of the system.

4. Wholesale Electricity Prices Amidst NEM's Renewable Transition

As the NEM evolves towards a more renewable-centric model, there's been a noticeable rise in the unpredictability of electricity prices (Mwampashi et al. 2021, 2022b). A testament to this is the increasing occurrence of negative prices, which have grown both in frequency and intensity.

Electricity markets are inherently volatile. The real-time balance of supply and demand, combined with limited cost-effective storage options, naturally results in price variability. The NEM's pivot towards renewables has amplified these fluctuations. Large wind and solar projects are reshaping the supply dynamics, while the growing popularity of rooftop solar installations is influencing demand. Consequently, while wind energy often moderates prices, it can also introduce sharp price spikes. These effects, however, are not uniform across the NEM, given the diverse energy mix in different regions (see Figure 1; Mwampashi et al. 2021, 2022b; Mwampashi and Nikitopoulos, 2023).

Solar energy introduces unique challenges to price stability. The intermittent nature of solar output, especially with the rapid increase of household rooftop solar panels, can lead to rapid shifts in demand. On bright, sunny days, abundant solar output can significantly reduce the grid's demand, driving prices down. This dynamic, however, can strain traditional power plants that aren't as flexible. The challenges peak during dawn and dusk when solar output is down, leading to price surges. Furthermore, the design and orientation of solar installations play a pivotal role. For instance, large-scale solar projects often employ sun-tracking mechanisms, offering more consistent output and prices, while most home installations have fixed, north-facing panels, leading to more pronounced variability in output and prices (Mwampashi et al. 2022b).

Moreover, when VRE generation rises, electricity prices tend to drop significantly during times when electricity is already cheaper. However, during the periods when electricity is relatively costly, the increase in VRE generally has a limited or no impact on reducing prices.

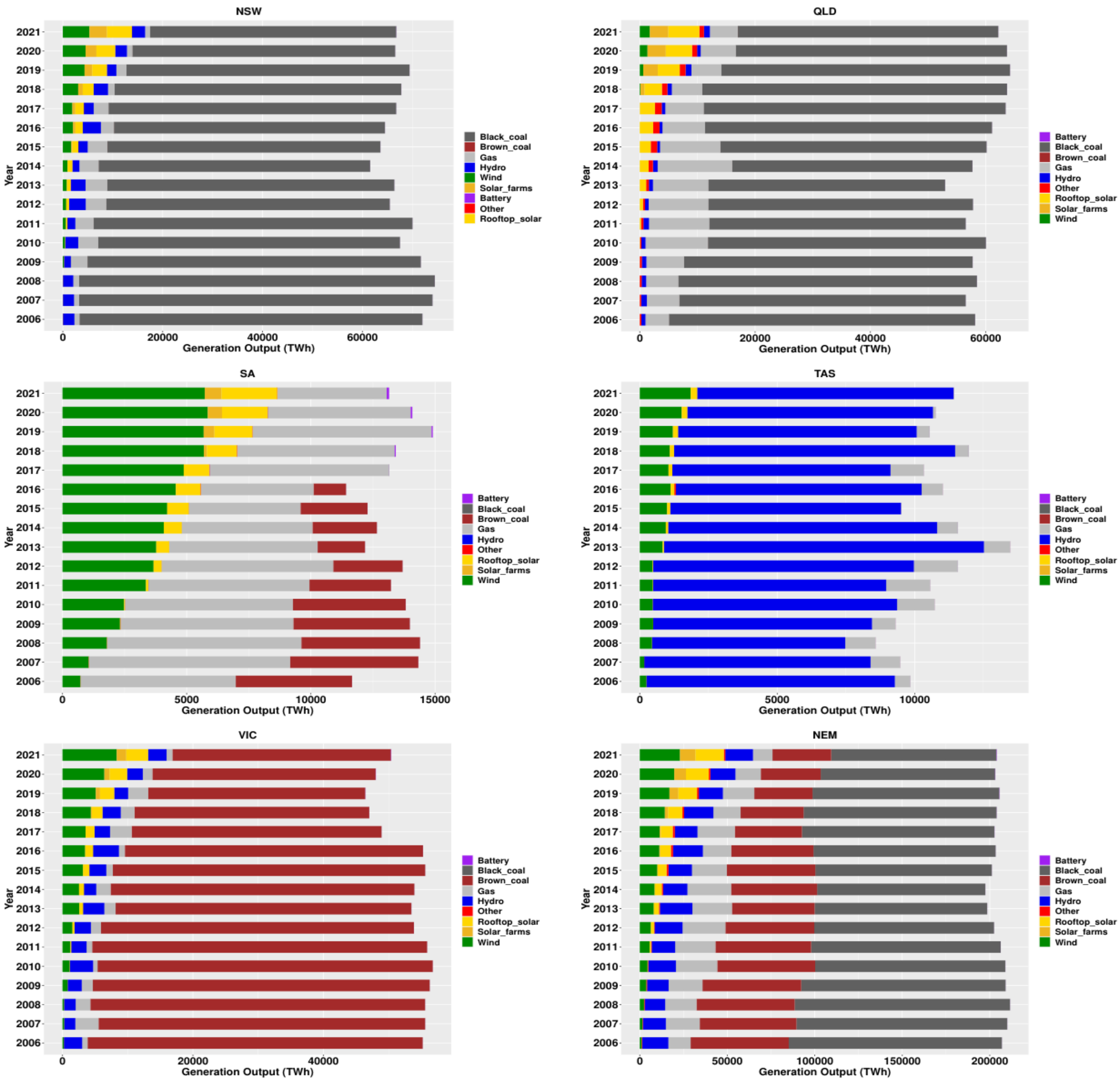

Figure 1: Electricity generation by fuel source in the NEM from 2006 to 2021.
Source: Mwampashi and Nikitopoulos, 2023

An exception to this pattern is South Australia, a state known for its high VRE penetration (Mwampashi and Nikitopoulos, 2023).

Beyond renewables, factors like hydropower, electricity demand, and gas price shifts account for high price and their variability. The interconnectedness of the NEM's regions, facilitated by cross-border links, also plays a crucial role in determining price trends (Mwampashi et al. 2021, 2022b; Mwampashi and Nikitopoulos, 2023).

5. Insights from NEM's Renewable Transition

Navigating the NEM's rapid embrace of wind and solar generation presents a clear challenge: managing price volatility and uncertainty. This transition, while forward-thinking, raises concerns about system security and reliability. Our analyses indicate a pressing need for policies that better align VRE with operational demand, aiming to stabilize price fluctuations (Mwampashi et al. 2021, 2022a, 2022b; Mwampashi and Nikitopoulos, 2023). Below are strategic recommendations for a sustainable future:

5.1 Strategic Transition to a Diversified Energy Portfolio

Transitioning from coal to renewables in the NEM is a complex and gradual process. Given Australia's historical dependence on coal, which currently (2022/23 financial year) account for about 63.4% of NEM's generation output (AER, 2023), the task is to phase out coal without compromising energy stability. With an anticipated 62% of coal fleet retirement by 2033 (AEMO, 2023), the focus should be on a diversified approach. Key considerations include:

- Diversified Energy Mix: The NEM's future lies in a balanced and diversified energy portfolio. This involves not just embracing renewables but also integrating utility-scale energy storage solutions—batteries and pumped storage hydro, run-off river hydro and flexible thermal generation technologies. Further, adapt to the changing demand patterns in the NEM due to the rise in rooftop solar PV. An emphasise should be directly towards new plant designs and demand-side adaptations that enhance system flexibility, complemented by market connectedness and storage technologies. These technologies can complement VRE sources and are apt for the 5-minute settlement (5MS) market design.

- Optimizing Coal Power Plants: As coal phases out, continuous optimization of these plants for energy-saving, carbon reduction, and improved efficiency is vital. This involves adopting technologies for cleaner coal combustion, efficient carbon capture, and reducing environmental footprints (World-Nuclear, 2021). Furthermore, with renewables' inherent variability, modifying coal power plants to serve as "peaking plants" could be a solution. They can augment energy production during renewable output lows.

5.2 Flexible Management of Grid Energy Exports

The dynamic/flexible solar export mechanism would probably provide a more robust solution to the increasing penetration of rooftop solar generation compared to current static or arbitrary limits. This would allow absorption of all households' excess solar power, by varying the export amount from time to time based on the supply and demand conditions and other network constraints. Effective management of rooftop exports via flexible export limits in conjunction with other planned mechanisms to support the penetration of solar generation, such as increased interconnections, would eliminate the need to switch off rooftop solar systems completely to maintain grid stability.

5.3 A Two-Sided Market Approach

In the NEM's traditional model, electricity predominantly flowed from centralized generators to consumers. However, with advancements in automation, digitalization, and the Internet of Things (IoT), a shift is underway, enabling dynamic demand-side participation. Now, consumers can directly respond to price signals, like suppliers, without engaging into complex energy trading or continuously adjusting their consumption (Rai et. al, 2021). This evolution in market dynamics is prompting a transition from static tariff structures to flexible pricing models, such as time-of-use (ToU) rates and innovative "solar-sponge" tariffs. Embracing a two-sided market approach can optimize the utilization of VRE, reduce the need for peaking generation, and provide a more cost-effective, sustainable solution for addressing peak demands.

For the effective implementation of a two-sided market reform, it's imperative to address current limitations. Demand-side response in the energy market necessitates the transformation or upgrading of most existing electrical equipment, which, in their current states, are not readily adaptable to demand-side response and exhibits excessive sensitivity to energy fluctuations.

5.4 Separate Pricing for Ancillary Services

In the evolving landscape of the NEM, ancillary services, especially Frequency Control Ancillary Services (FCAS), are increasingly crucial for grid stability. Historically, the NEM's FCAS was oversupplied, leading to negligible prices. However, as the mix of generation shifts away from coal and towards renewables, the demand for FCAS and its pricing have surged. This transition underscores the importance of pricing ancillary services distinctly, capturing their true value (Gilmore, 2024). Recent mandates in Australia for primary frequency response (AEMC, 2020), without adequate pricing, highlight the risks of grid security challenges. Moreover, the intertwined nature of FCAS pricing with spot electricity prices signifies the need for a comprehensive pricing approach. As the NEM progresses, properly pricing ancillary services becomes pivotal for its stability and efficiency.

5.5 Rooftop PV-plus-Battery Systems

The variability associated with rooftop PV underscores the importance of supporting solar PV-plus-battery systems. Given South Australia's notable rooftop solar footprint, enhancing battery storage capabilities can ensure a more consistent energy supply. By adjusting federal and state policies to favour solar-plus-battery systems, we can ensure stored electricity is available when needed most, balancing peak demands.

5.6 Feed-in Tariffs (FiTs)

State governments and retailers should move from offering flat-rate FiTs to FiTs that vary throughout the day (dynamic FiTs). These rates should be set in such a way that they are lower during the day when demand, especially at the residential level, is typically low and higher during morning and evening demand peaks. This shift would motivate solar owners to supply excess energy during peak demand times, such as mornings and evenings, promoting efficient energy consumption patterns.

5.7 Addressing Market Concentration and Entry Barriers

Within each NEM region, dominant players hold significant control over the generation capacity. The current landscape, characterized by a high concentration of generation ownership and a predominant reliance on slower-response generation technologies, poses challenges in adapting swiftly to demand spikes or outages. This concentrated landscape empowers these major generators, enabling them to potentially dictate price outcomes. If these large-scale participants also dominate the ownership of emerging fast-response technologies, the projected benefits in terms of wholesale and subsequent retail price reductions might be compromised (Wood et al., 2018). Therefore, to truly harness the potential advantages of the 5MS, it's imperative for the NEM to implement policies that mitigate entry barriers and promote investments that can dilute the existing market concentration.

5.8 Carbon Pricing and Emissions Trading Systems

The World Bank's emphasis on the widespread adoption of carbon pricing mechanisms serves as a compelling reminder for Australia to re-evaluate and adapt its energy policies. As 73 global jurisdictions now rally behind either carbon taxes or Emissions Trading Systems (ETSs), and with Australia's own evolving trajectory towards a rate-based ETS, there's a noticeable shift in global energy dynamics (WBG, 2023). Historically, Australia introduced the CPM to address its own environmental challenges. This mechanism, during its brief tenure, made significant contributions in reducing the country's dependence on fossil fuels, favouring the adoption of renewable energy sources (AER, 2014). The CPM's legacy in the NEM is hard to overlook, as it paved the way for sustainable energy practices. However, its discontinuation created a gap, with the RET continuing to operate amidst its own set of challenges (Wood and Blowers, 2016; Simshauser and Gilmore, 2020, Mwampashi et al. 2021).

In light of Australia's recent legislative reforms to the Safeguard Mechanism, commencing from July 1, 2023, there seems to be a renewed commitment to environmental sustainability. This reform, effectively transitioning the Safeguard Mechanism into a rate-based ETS, is a laudable step forward (PMC, 2023). As Australia navigates green energy transition, continuous monitoring and evaluation of these policies are vital. If circumstances demand, there should be a willingness to revisit mechanisms such as the CPM, which not only demonstrated promise during its implementation but also garnered supportive evidence from subsequent studies (Rajabi, 2023). Aligning with global carbon pricing practices isn't just about environmental stewardship; it's about ensuring Australia remains economically competitive on the global stage.

5.9 Energy Market Resilience

The 2022 energy crisis underlined the urgency for robust regulatory measures and energy security strategies to mitigate future NEM disruptions. The crisis highlighted the importance of diversified energy sources, especially as it revealed the pivotal roles of gas generation and opportunity cost hydro in setting prices when coal prices spiked and many coal plants became inoperative. Diversified energy portfolios not only enhance resilience but also buffer against unexpected disruptions. This scenario serves as a reminder for the need to ensure a consistent energy supply, especially as coal plants near the end of their operational life and VRE expansion persists. Policymakers must ensure that as coal-fired generators phase out, there's a strategic increase in renewable generation and firming capacity. Investments in state-of-the-art firming technologies, coupled with a ready-to-deploy replacement capacity, are essential steps in ensuring NEM's energy security.

6. Conclusion

As Australia progresses towards a sustainable energy future, the strategies highlighted in this brief—including promoting a diversified energy mix, enhancing renewables' integration, and considering resilience pricing—alongside sound investments in energy infrastructures and informed policy reforms, stand out as vital. Such measures can further boost the benefits of renewable energy, guiding Australia towards its ambitious goal of net-zero emissions by 2050. Collaboration between federal and state governments has been key in progressing these recommendations. With the energy landscape rapidly evolving, upholding consistent energy and climate-change policies to attract new investments is paramount for the NEM's stability and advancement.

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