Submission to the ACT's Integrated Energy Plan

ANU Institute for Climate, Energy and Disaster Solutions

September 2023

Contributors:

Dr Bin Lu, Dr Lee White, Timothy Weber, Anna Nadolny, Dr Yuan Peng, Dr Wenting Cheng, Dr Igor Skryabin, Brad Riley, Professor Ken Baldwin, Genevieve Newey, **ANU Zero-Carbon Energy for the Asia-Pacific Grand Challenge**

Clare de Castella, Keith Hickson, **ANU Below Zero Program**

Dr Elizabeth Ratnam, Dr Bjorn Sturmberg, **ANU Battery Storage and Grid Integration Program**

Summary of Recommendations

1. Developing smart energy infrastructure to tap into the enormous resources of distributed energy storage, e.g., electric vehicle batteries and hot/condenser water storage, is crucial to the ACT's energy transition. As electrification of transport and heating intensifies, distributed energy storage is emerging as an efficient approach to energy balancing and stabilisation.
2. The increasing utilisation of electric heat pumps for space and water heating could result in a significant increase in hydrofluorocarbon emissions. Discussions on strategies to mitigate hydrofluorocarbon emissions from refrigeration and air-conditioning need to be incorporated into the Integrated Energy Plan.
3. Rooftop solar uptake:
   - 3.1. As the Small-scale Renewable Energy Scheme approaches its end, the ACT Government should offer a subsidy to support ongoing rooftop solar uptake.
   - 3.2. Transparency of rooftop solar value in tangible financial terms could support choices by tenants to pay a fair value of increased rent for the installation of solar panels.
   - 3.3. A policy that encourages community solar garden development could allow renters and apartment dwellers to benefit from solar energy without requiring approval from landlords or strata.
4. Electrify complex buildings:
   - 4.1. The plan could outline pathways for electrifying diverse types of existing complex buildings, including cultural institutions, government departments, defence facilities, educational facilities (including various universities), sporting facilities such as the Australian Institute of Sport, and apartment buildings.
   - 4.2. The plan could be enhanced by considering complex buildings with unique challenges, e.g., research buildings and medical facilities, which use fossil fuel gas for steam generation for sterilisation and humidification.
   - 4.3. In order to provide a model for degasification of complex commercial buildings or precincts and share learnings with industry and other organisations, the ACT Government could help overcome first mover barriers by providing support to pilot implementation of centralised thermal hubs in the Territory, creating a demonstration site.
5. To overcome industry resistance to change, the ACT Government could work with early movers to support innovative demonstration sites, develop case studies and promote knowledge sharing.
6. Ongoing work should assess the impact on groups at greater risk of having their energy needs unmet during the energy transition. This involves identifying vulnerable groups and implementing new policy instruments to address their specific challenges.

7. Commitments to monitoring the progress of the ACT's energy transition and updating the Integrated Energy Plan are needed. It would be useful to sub-divide information by location such as Statistical Area Level 1 or postcodes.
8. Energy efficiency and productivity are integral components of a zero-emissions energy transition strategy, which require a comprehensive approach in the Integrated Energy Plan.
9. Supporting residents to electrify their homes through a "one-stop" approach allows to simplify the electrification and degasification processes. This approach could enable residents to contract with a single entity capable of managing all aspects of electrification, including electrical work, plumbing and heat pump installation.

Mapping of Recommendations to the ACT Integrated Energy Plan consultation questions

Recommendations	Consultation questions
1. Smart energy infrastructure	Q2
2. Hydrofluorocarbon emissions	Q1
3. Rooftop solar uptake	Q2
4. Electrifying complex buildings	Q7, Q8
5. Knowledge sharing	Q3, Q14
6. Groups at risk of being negatively impacted during the transition	Q6
7. Monitoring the transition process	Q1, Q15
8. Energy efficiency and productivity	Q1
9. A "one-stop" approach to electrification	Q4, Q6

1. Smart energy infrastructure

Recommendation: Developing smart energy infrastructure to tap into the enormous resources of distributed energy storage, e.g., electric vehicle batteries and hot water storage, is crucial to the ACT's energy transition. As electrification of transport and heating intensifies, distributed energy storage is emerging as an efficient approach to energy balancing and stabilisation.

Distributed energy storage resources include electric vehicle batteries, residential and commercial batteries, and hot water storage. Distributed energy storage can provide significant storage capacity as well as large demand flexibility to the ACT's future energy system. Enabled by smart energy infrastructure, these kWh-scale storage resources can be aggregated and used for GWh-scale energy time-shifting (Lu et al., 2021). As stated in the ACT Government's Powering Canberra report, "Strategic use of distributed energy resources will play a vital role in maintaining grid stability, reducing peak energy demand, network upgrades and consumer bills." By strategic management of distributed energy storage resources, ACT's energy transition can be reliable, secure and achieve optimal economic outcomes.

As outlined in the Position Paper, electrification of transport and heating has been chosen by the ACT Government as the long-term transition pathway to displace oil and natural gas. Therefore, the ACT energy system will be reshaped in transitioning to a zero-carbon energy future. Distributed energy storage resources will be an important part of the future energy system to support electrification and renewable energy integration. For example, the ACT's motor vehicles can contribute to more than 10 GWh of storage capacity – 20 times the storage capacity of the Canberra Big Battery (0.5 GWh). According to the ABS Motor Vehicle Census 2021, the total number of motor vehicle registrations in the ACT was 318,148. Passenger vehicles (264,753) and light commercial vehicles (34,829) together accounted for about 94% of the ACT motor vehicles. In the Electric Vehicle Database, the usable battery capacity of electric vehicles ranges from 21.3 kWh to 123 kWh, with an average capacity of 68.7 kWh. Considering the upward trend in electric vehicle battery capacity, we can assume an average battery capacity of 75 kWh to calculate the total storage potential of electric vehicle batteries. Based on this assumption, the total battery capacity in the ACT's passenger vehicles and light commercial vehicles is estimated to be 22.5 GWh. Assuming half of them can be smart charging in response to electricity tariffs, the motor vehicles can contribute to more than 10 GWh of storage capacity. This also assumes that charging infrastructure is provided in locations where cars will be parked during times of both expected off-peak demand (to charge the car) and for on-peak demand (to discharge to the grid). In addition, hot and condenser water storage can also contribute to GWh-scale storage capacity. According to the ABS 2021 Census, the total number of private dwellings in the ACT was 186,963. The ACT Climate Choices suggests that hot water energy use for a typical household ranges from 4.7 kWh (electric heat pump water heater) to 14 kWh (electric resistance water heater). Therefore, hot water storage can provide more than 1 GWh of storage capacity in a zero-carbon energy future. Use of this storage mode is dependent on the type of water heating – instantaneous electric water heaters, which are sometimes used in apartments, do not provide storage capacity due to the lack of a dedicated hot water tank. This could have implications for future building code requirements.

Apart from peak shaving and grid stabilisation (Nadolny et al., 2022), distributed energy storage can also help accommodate the rapid uptake of rooftop solar. As of 30 June 2023, 28.4% of the dwellings (51,302 out of 151,363) in the ACT were equipped with rooftop solar, with a total installed capacity of 404 MW. According to Australian PV Institute's estimates, the total potential for rooftop solar on the ACT buildings is 2368 MW, which could generate 3313 GWh of electricity on an annual basis. Electric vehicle batteries and hot water storage can help absorb solar energy from rooftops and thus alleviate the congestion on the distribution grids. Furthermore, distributed energy storage resources can help enhance the resilience of the ACT energy system during disruptive events. Extreme weather events, e.g., storms and rising temperatures, are becoming more frequent due to the impact of climate change, which have had a significant impact on global energy security including the major blackouts in California (2020) and Texas (2021). Consequently, it is critical that a zero-carbon energy future has the ability to remain secure, reliable and resilient during extreme weather events and cybersecurity threats (Roberts et al., 2022; Ratnam et al., 2020). With the support of smart energy infrastructure, demand-side storage participation can be an effective approach to ensuring a high level of energy resilience and supporting the future energy system to withstand, mitigate and rapidly recover from disruptive events.

In addition, the Texas event showed that pricing strategies for electricity potentially needed further consideration in the context of resilience events. Some customers in Texas reported electricity bills of US$5000 for 5 days of electricity as they were provided with wholesale market prices (Chen et al., 2022).

2. Hydrofluorocarbon emissions

Recommendation: The increasing utilisation of electric heat pumps for space and water heating could result in a significant increase in hydrofluorocarbon emissions. Discussions on strategies to mitigate hydrofluorocarbon emissions from refrigeration and air-conditioning need to be incorporated into the Integrated Energy Plan.

Based on the latest ACT Greenhouse Gas Inventory (Point Advisory, 2022), hydrofluorocarbon (HFC) emissions from refrigeration and air-conditioning contributed to 164 kt CO2-e in 2021-22, accounting for 10% of the total emissions in the ACT. HFCs have high global warming potentials. For instance, HFC-410A, commonly used as a heat pump refrigerant, has a 100-year global warming potential value of 2088. HFC emissions are typically not included in the Energy category according to the IPCC category system. However, as electric heat pumps are increasingly used for electrified heating, there could be a surge in HFC emissions within the ACT Greenhouse Gas Inventory. In fact, HFC emissions in the ACT increased from 135 kt CO2-e in 2012-13 to 164 kt CO2-e in 2021-22, showing a 21% increase over the recent decade. The share of HFC emissions in the total emissions escalated from 3% in 2012-13 to 10% in 2021-22. Therefore, we recommend that discussions regarding measures to reduce HFC emissions from refrigeration and air-conditioning be included in the Integrated Energy

Plan. This could include requirements or incentives for heat pumps with HFOs or natural refrigerants. Some heat pump manufacturers offer these products to international markets but not Australia. Emissions abatement measures could include improved containment and effective recovery of refrigerants, as well as the replacement of HFCs with natural refrigerants, e.g., ammonia, carbon dioxide and hydrocarbons (Brodribb et al., 2023).

3. Rooftop solar uptake

Recommendations:

- **As the Small-scale Renewable Energy Scheme approaches its end, the ACT Government should offer a subsidy to support ongoing rooftop solar uptake.**
- **Transparency of rooftop solar value, in tangible financial (dollar) terms, could support choices by tenants to pay a fair value of increased rent for the installation of solar panels. An example of this is the Queensland Government's solar for rentals trial (Hammerle, et al., 2023).**
- **Policy that encourages community solar garden development to allow renters and apartment dwellers to benefit from solar energy without requiring approval from landlords or strata (Rutovitz et al., 2018).**

The Small-scale Renewable Energy Scheme (SRES) ends in 2030. The SRES has had a significant impact on Australian small-scale solar uptake and abated emissions at a cost of approximately US$36 per tonne CO_2 avoided (Best, et al., 2019). Small-scale technology certificates (STCs) are only deemed for rooftop systems based upon projected generation until 2030. The benefit offered by this Federal scheme is decreasing each year, creating an increasing price barrier for the installation of rooftop solar photovoltaics.

Property rights constrain renters from installing rooftop solar panels, improving energy efficiency, and adopting other clean energy technology (Amelia & Brandt, 2015). Policies that focus on addressing high upfront cost are expected to have a limited effect on this stakeholder group since property investors are concerned that tenants will not be interested in paying higher rent for rooftop solar (Hammerle et al., 2023).

Apartment dwellers face space constraints and transaction costs for installing rooftop solar panels. Apartment renters also have no voting rights within strata complexes, and there is little incentive for non-resident owners to vote for installation of rooftop solar and incur the cost themselves. Lack of engagement at strata Annual General Meetings or the use of proxy votes from multiple non-resident owners have the potential to block communal uptake of rooftop solar in apartment buildings (Roberts et al., 2019).

Ongoing support for solar installation from the ACT Sustainable Household Scheme is recommended. Household solar installation can be an enabler for electric vehicle uptake (Wen et al., 2023; Kaufmann et al., 2021), thereby policy should amply this joint-adoption effect. The current rooftop solar adoption rate in the ACT is about a quarter of existing dwellings. This is below the typical tipping point (or critical mass) of new technology adoption, which is 30–40% of the population (Peng & Bai, 2023; Rogers, 2010). After reaching the tipping point, the adoption would proceed in a self-sustaining manner. Policy support is critical to enabling early adopters to reach the tipping point. Income contingent loans, where repayments on the capital cost of the solar installation are tied to future income levels (like HECS), could represent a way to support solar installation with little cost to government over the long term (Baldwin et al., 2015) - although these are likely to be more effective for homeowners than for renters.

Renters are currently largely excluded from access to rooftop solar; only 3-4% of rental properties have solar panels installed. Rooftop solar can help reduce exposure to high costs of grid electricity, particularly for households that are able to self-consume a lot of the rooftop generation – that is, using electricity while the sun is shining. However, renters are dependent on landlords to provide rentals that have solar installed. Recent work looking at landlords' motivations found that the two biggest reasons they hesitate to install solar on their properties are 1) upfront costs, and 2) perception that renters wouldn't pay more for a home with solar (Hammerle et al., 2023). A follow-up analysis within the study found that when offered a hypothetical interest-free loan, less than two thirds of the landlords valued this in making their hypothetical installation decisions. Loans may also be of limited interest to landlords because they are typically personal loans and are not transferrable with the property, although most landlords also saw only limited appeal in a hypothetical policy option that would tie loans to property instead of to the person (Hammerle et al., 2023). That is, to encourage landlords to install solar on rental properties, more than loans will be needed. It is also notable that renters are in fact willing to pay more for properties with solar (Fuerst et al., 2020; Fuerst et al., 2018; Best et al., 2021), which many landlords currently seem unaware of when making investment decisions.

Recommendations (Sturmberg et al., 2023) beyond loans include:

- Investing resources into educating property managers about the benefits of rooftop solar. Property managers could then include such features in home advertisements and talk about these benefits in discussions with landlords and prospective tenants;
- Making the benefits of solar more visible to both property investors and tenants – such as through a resource that describes expected savings. This could help landlords see solar as a better investment;
- Considering requirements for minimum rental standards. This could include overall requirements for minimum energy costs, which could be met in practice through a combination of solar installation and energy efficiency upgrades;
- Streamlining processes for solar installation in multi-family housing, such as mandated processes for Strata to follow to approve solar requests. Many landlords see Strata as a potential barrier to installing solar for apartments that they own.

4. Electrifying complex buildings

Recommendations:

- **The plan could outline pathways for electrifying diverse types of existing complex buildings, including cultural institutions, government departments, defence facilities, educational facilities (including various universities), sporting facilities such as the Australian Institute of Sport, and apartment buildings.**
- **The plan could be enhanced by considering complex buildings with unique challenges, e.g., research buildings and medical facilities, which use fossil fuel gas for steam generation for sterilisation and humidification.**
- **In order to provide a model for degasification of complex commercial buildings or precincts and share learnings with industry and other organisations, the ACT Government could help overcome first mover barriers by providing support to pilot implementation of centralised thermal hubs in the Territory creating a demonstration site.**

While the Position Paper mentions complex residential buildings, it does not cover existing complex commercial buildings or precincts. The degasification of these facilities in the ACT presents particular challenges, including:

- The requirement to deal with extremes of temperature at both ends of the spectrum due to Canberra's climate;
- Structural and spatial limitations to installing heat pumps on a roof or adjacent a building;
- Heritage limitations to installing heat pumps;
- Electrical supply limitations to installing heat pumps;
- Acoustic constraints to installing heat pumps;
- Industry scepticism and inexperience with heat pump technology;
- Cost of electrical infrastructure upgrades and heat pump equipment.

Central thermal electric hubs can provide rapid transformation of complex commercial buildings and provide energy and peak electrical demand savings, addressing many of these challenges. Compared with an entirely decentralised approach, centralised thermal hubs can provide multiple benefits, including:

- Maximise efficiency leading to overall energy savings;
- Have lower installed thermal load due to heat recovery and greater diversity;
- Minimise ongoing maintenance costs;
- Provide most flexibility in the event of changes to buildings/building use;
- Incorporate energy storage to assist in managing peak demand and reduce the extent of electrical infrastructure upgrades;
- Facilitate waste heat reclaim from sources such as data centres;
- Allow for energy exchange between buildings. This is especially useful for different building types. For example, heat generated from cooling a commercial building during the day could be stored and transferred to heat a residential building at night.

Thermal hubs have been used to supply heating and cooling to precincts in cities in Europe and America. This approach could be applied at campus/precinct environments throughout the ACT, such as hospitals, government departments and other commercial, recreational and residential facilities. However, to our knowledge, this approach has not yet been applied in the ACT or in Australia. Piloting this technology in a cold climate would be cutting edge.

There are several barriers for any first mover. These barriers need to be overcome before widespread implementation can proceed, including:

- Proof of concept within the ACT (and Australia);
- Higher development costs. It is widely understood that decarbonisation, including electrification, often requires high upfront capital expenditure but at the same time provides reductions in ongoing operational costs, leading to lower lifecycle costs. This is eminently financeable but can require innovative approaches to funding pathways;
- Requirement for higher contingency rates for first movers;
- Requirement to educate industry about the new approach, including engineers, suppliers and tradespeople.

The Australian National University is currently exploring a range of models available to implement and finance this complex electrification process using thermal electric hubs (ANU Below Zero, 2023). Successful implementation of this approach would provide valuable learnings for industry, workers and other organisations, including on financing pathways, helping to fast-track electrification of complex commercial buildings and precincts across the Territory.

Body corporates play an important role as regulatory intermediaries in the electrification of complex buildings. Body corporates can be engaged in the regulatory process to achieve the electrification targets. The ACT Government can collaborate with body corporates to carry out concrete activities in areas where it lacks the necessary capacity, or where direct involvement would be cost-prohibitive, e.g., delivering services, providing advice, facilitating target implementation, monitoring target behaviour, and sometimes enforcing regulations. A valuable capacity that body corporates possess is “access”. Body corporates are often better positioned to contact with residents and understand how to achieve targets in their unique contexts.

5. Knowledge sharing

Recommendations: To overcome industry resistance to change, the ACT Government could work with early movers to support innovative demonstration sites, develop case studies and promote knowledge sharing.

Knowledge sharing will be critical given existing industry scepticism around heat pump technology. Demonstration sites can provide proof of concept for industry, tradespeople and engineers, overcoming resistance to new ways of doing things. This will be particularly important in the early stages of the transition to provide innovative models for electrification. As an educational institution, the Australian National University has received positive responses to knowledge sharing, with ANU Engineering staff conducting tours of recently electrified buildings for industry and government, presenting to industry groups and chairing the Australian Institute of Refrigeration, Air Conditioning and Heating - Electrification Technical working group.

Enhanced access to education opportunities for the ACT's communities can help residents acquire required knowledge and up-to-date information on the electrification technologies. This can help effectively clear up some misconceptions about new technologies, thereby building user confidence. Collaborations between the ACT Government and local NGOs would allow effective facilitation of these education activities.

It would also be useful to support innovations on Power Purchase Agreements (PPAs), e.g., innovations in industry and residential customers coming together through PPAs to support larger wind/solar/battery (and supportive transmission assets) with benefits to the community and to industry.

6. Groups at risk of being negatively impacted during the transition

Recommendation: Ongoing work should assess the impact on groups at greater risk of having their energy needs unmet during the energy transition. This involves identifying vulnerable groups and implementing new policy instruments to address their specific challenges.

The ACT's identification of low-income households and renters is a good starting point. Assistance to these residents should be implemented. In general, those more reliant on energy (such as for health needs) or those who may face procedural disadvantages or lack of recognition of their unique needs (such as racial or ethnic minorities) are also at greater risk of having their energy needs unmet during transition (White & Sintov, 2020). Ongoing work should attempt to assess impacts on these groups as the transition progresses, and new policy instruments should be considered as needed if these groups are facing disparate impacts.

Policy also needs to ensure that low-income households and renters have access to the benefits of monetary incentives, e.g., the Sustainable Household Scheme. Electrifying existing dwellings can be difficult and unforeseen costs can come up. Consideration for low-income households should be included in this policy, for example through subsidised pricing of household electrification, zero or low interest loans for household electrification. This is an important issue for an equitable transition, and the demographic and socioeconomic configuration of population in the ACT may have unique characteristics. Therefore, ongoing development of surveys is recommended to better assess this issue. This is an area where the ACT and ANU can continue to collaborate to understand the needs of the population, and to understand the benefits of ACT policies for vulnerable populations.

7. Monitoring the transition process

Recommendation: Commitments to monitoring the progress of the ACT's energy transition and updating the Integrated Energy Plan as needed. It would be useful to sub-divide information by location such as Statistical Area Level 1 or postcodes.

The Position Paper puts forth solid foundational principles for energy transition, including recognising the importance of clear policy signalling and the importance of supporting those who may otherwise be left behind in the transition. To this end, a further principle or commitment to monitoring progress would be beneficial. This could be accompanied by a commitment to updating the plan as needed to support segments of the population that are revealed to need additional resources for energy transition.

At minimum, it would be useful to sub-divide information by location such as Statistical Area Level 1 or postcodes. Reporting only on the total number of gas connections could obscure areas where transition is more difficult, and these are the areas that will need greater targeted policy support. It will be important to track both the total volume of gas used in the ACT (for climate change mitigation assessment purposes) and the residential connections (to understand who is left behind). Greater granularity will be needed to truly understand the second. This may require investigation of data availability beyond central AER reporting, which may not provide sufficient granularity.

In addition, the Position Paper sets a goal of 2040 for full electrification of the ACT's government assets. This is a long timeframe, and interim targets would support transparency of progress towards this goal, e.g., percentage goals for 2030 and 2035. Alternatively, interim targets could be set based on commitment to transition all of set types of assets by 2030 or 2035 (such as fleets and office buildings) with only hard-to-abate buildings such as hospitals taking until 2040.

8. Energy efficiency and productivity

Recommendation: Energy efficiency and productivity are integral components of a zero-emissions energy transition strategy, which require a comprehensive approach in the Integrated Energy Plan.

Energy efficiency and productivity encompass a wide range of strategies, including:

- Thermal considerations such as insulation, building design, and glazing;
- Modal shift for transport;
- Improving walkability, gentle density (i.e., six storeys), and apartment building standards to allow more residents to live close to shopping and employment hubs in comfortable and efficient homes;
- Control and optimisation of energy consuming and generating assets;
- Pathways for removing gas from diverse types of complex commercial buildings, such as office complexes and precincts, which represent a significant source of emissions within the Territory.

9. A “one-stop” approach to electrification

Recommendation: Supporting residents to electrify their homes through a “one-stop” approach simplifies the electrification and degasification processes. This approach could enable residents to contract with a single entity capable of managing all aspects of electrification, including electrical work, plumbing and heat pump installation.

A comprehensive service for electrification, with tradespeople who are experienced and reliable, at either a fixed cost, or zero interest loans, represents a highly effective strategy for home electrification. Being able to contract a team consisting of a plumber, an electrician, and a reverse-cycle air conditioner installer could help streamline the electrification process, allowing it more manageable and achievable. Renovations in the home electrification often require additional work and expenses beyond initial estimates. Therefore, a “one-stop” approach could ensure that home electrification is a more attractive choice than persisting with gas connections. A “one-stop” approach enables residents to contract with a single entity capable of managing all aspects of home electrification, including electrical work, plumbing and heat pump installation. The ACT could explore developing a list of trusted suppliers to support this approach. It may be possible to work with local trade bodies to increase coordination over time.

References

ANU Below Zero. 2023. ANU kicks off the transition away from gas heating.

Amelia, N. & Brandt, N. 2015. Determinants of households' investment in energy efficiency and renewables: evidence from the OECD survey on household environmental behaviour and attitudes. *Environmental Research Letters*, 10, 044015.

Baldwin, K., Chapman, B. & Raya, U. 2015. Using Income Contingent Loans for the Financing of the Next Million Australian Solar Rooftops. *SSRN*, 2738314.

Best, R., Burke, P.J. & Nishitateno, S. 2019. Evaluating the effectiveness of Australia's Small-scale Renewable Energy Scheme for rooftop solar. *Energy Economics*, 84, 104475.

Best, R., Esplin, R., Hammerle, M., Nepal, R. & Reynolds, Z. Do solar panels increase housing rents in Australia? *Housing Studies* 0, 1–18 (2021).

Brodribb, P., McCann, M. & Dewerson, G. 2023. Cold Hard Facts 2022.

Chen, Y., Islam, R., Ratnam, E. L. et al., 2022. Competitive equilibriums and social shaping for multi-agent systems. *Automatica*, 146, 110663.

Fuerst, F., Haddad, M. F. C. & Adan, H. Is there an economic case for energy-efficient dwellings in the UK private rental market? *Journal of Cleaner Production* 245, 118642 (2020).

Fuerst, F. & Warren-Myers, G. Does voluntary disclosure create a green lemon problem? Energy-efficiency ratings and house prices. *Energy Economics* 74, 1–12 (2018).

Hammerle, M., White, L.V. & Sturmberg, B. 2023. Solar for renters: Investigating investor perspectives of barriers and policies. *Energy Policy*, 174, 113417.

Kaufmann, R.K., Newberry, D., Xin, C. et al. 2021. Feedbacks among electric vehicle adoption, charging, and the cost and installation of rooftop solar photovoltaics. *Nature Energy*, 6, 143–149.

Lu, B., Blakers, A., Stocks, M., Cheng, C. & Nadolny, A. 2021. A zero-carbon, reliable and affordable energy future in Australia. *Energy*, 220, 119678.

Nadolny, A., Cheng, C., Lu, B., Blakers, A. & Stocks, M. 2022. Fully electrified land transport in 100% renewable electricity networks dominated by variable generation. *Renewable Energy*, 182, 562-577.

Peng Y., Bai, X. 2023. Peer Effect and Perceived Social Tipping Point of Ev Adoption. *SSRN*, 4459205.

Point Advisory. 2022. ACT Greenhouse Gas Inventory for 2021-22.

Ratnam, E. L., Baldwin, K., Mancarella, P. et al. 2020. Electricity system resilience in a world of increased climate change and cybersecurity risk. *The Electricity Journal*, 33, 9, 106833.

Roberts, L., Lu, B. & Catchpole, K. 2022. Effect of La Niña weather conditions on operation of a future 100% renewable grid in Australia. *Proceedings of 2022 IEEE PES Innovative Smart Grid Technologies - Asia (ISGT Asia)*, 116-119.

Roberts, M.B., Bruce, A. & MacGill, I. 2019. Opportunities and barriers for photovoltaics on multi-unit residential buildings: Reviewing the Australian experience. *Renewable and Sustainable Energy Reviews*, 104, 95-110.

Rogers, E.M. 2010. Diffusion of Innovations. Simon and Schuster.

Rutovitz, J., McIntosh, L., Ison, N., Noble, E., Hicks, J., & Mey, F. 2018. Social Access Solar Gardens for Australia. Institute for Sustainable Futures, University of Technology Sydney.

Sturmberg, B., White, L. & Hammerle, M. 2023. Electricity prices are rising again. Here's how to ensure renters can cash-in on rooftop solar. *The Conversation*, May 26, 2023.

Wen, L., Sheng M.S., Sharp B. et al. 2023. Exploration of the nexus between solar potential and electric vehicle uptake: A case study of Auckland, New Zealand. Energy Policy, 173, 113406.

White, L., Sintov, N. D. 2020. Varied health and financial impacts of time-of-use energy rates across sociodemographic groups raise equity concerns. Nature Energy, 5, 16–17 (2020).