

**Australian Research in Power System
Transformation**

Topic 8 – Distributed Energy Resources

2025/26 Evolving Dynamic Operating Envelopes for Vehicle-to-Grid Integration

Commonwealth Scientific and Industrial Research
Organisation

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1. Introduction

The Australian energy system is undergoing a transformation driven by the increasing penetration of distributed energy resources (DERs), particularly rooftop solar PV. This has led to the development of Dynamic Operating Envelopes (DOEs)—mechanisms that dynamically manage energy export and import limits based on real-time network capacity. The Common Smart Inverter Profile – Australia (CSIP-AUS) standard underpins these mechanisms, enabling interoperability and active management of DERs.

Recent literature highlights the importance of integrating social values and stakeholder perspectives into technical systems [1], [2], [3]. The Vehicle-to-Grid (V2G) technology, which allows electric vehicles (EVs) to discharge energy back into the grid, presents a complex use case for DOE evolution due to its dual role as transport and energy storage. Prior research [4], [5] has shown that user values significantly influence V2G operation and acceptance.

This research addresses a critical gap in understanding how DOEs must evolve to accommodate V2G technologies. While technical trials have explored DOE applications, few have integrated stakeholder values and perspectives into foundational design [6], [7]. This project combines social research and technical modelling to ensure future DOE frameworks are both technically robust and socially acceptable.

2. Research completed

The research to date brings together three major bodies of literature—Vehicle-to-Grid (V2G), Dynamic Operating Envelopes (DOEs), and the Capability Approach—to establish the foundations for a socio-technical understanding of V2G–DOE integration.

Extensive V2G research highlights its technical value (grid support, renewable integration, resilience), user-centred factors (financial expectations, minimum charge guarantees, range anxiety, trust), and systemic barriers including battery degradation concerns, interoperability limitations, and regulatory gaps.

Parallel research into DOEs demonstrates the evolution of methods for allocating dynamic import/export limits, ranging from linearised to full AC optimal power flow models, and identifies the technical, computational and governance challenges inherent in deploying DOEs at scale. Together, these areas reveal both the promise and complexity of coordinating mobile storage assets within constraint-managed distribution networks.

A third body of work—applications of Nussbaum’s Capability Approach [8] to energy systems [9], [10]—has established a strong theoretical basis for evaluating energy technologies in terms of real freedoms, equity, and consumer agency. Studies across energy poverty, justice, digitalisation, and renewable transitions demonstrate the framework’s utility in assessing how infrastructure and policy shape people’s ability to participate meaningfully in energy systems. Integrating this with V2G and DOE literature highlights a key gap: while technical and economic analyses dominate both domains, little work has explored how DOE-V2G architectures affect household capabilities, autonomy, and fairness. The research to date therefore provides a comprehensive foundation for addressing this gap, showing both the technical interdependencies and the socio-institutional dimensions that must be reconciled to design DOEs that work for V2G users, networks, and society.

3. Outstanding activities

The research is conducted through three coordinated work packages that together integrate empirical evidence, modelling, and stakeholder requirements.

Work Package 1, led by ANU, collects and synthesises evidence on current DOE practices, emerging DOE evolution pathways, and the ways V2G is expected to operate within Australian grids. This includes reviewing DOEs and CSIP-AUS implementation, analysing global and Australian V2G products and value propositions, and conducting expert consultations with Distribution Network Service Providers (DNSPs), CSIRO, aggregators, retailers and training institutions. Insights are translated into modelling parameters (DOE evolution prototypes, optimisation targets, and operational constraints) and summarised into classifications, pathways, and interaction descriptions for use in the next phase.

Work Package 2, led by Elentar, builds on this evidence through a techno-socio-economic modelling framework that represents electrical, behavioural, and economic dimensions at the NMI connection-point level. Using smart-meter data and explicit vehicle modelling, this phase tests how different DOE settings interact with V2G across user mobility needs, value streams (retail, VPP, wholesale passthrough), and network objectives. Scenario cases, developed from the interviews, quantify impacts across feeders and assess how diversity of customer archetypes shapes DOE requirements. Outputs include a detailed, validated model and scenario results that describe the most influential DOE-V2G interactions.

Work Package 3, jointly undertaken by ANU and Elentar, interprets the modelling results alongside qualitative insights to derive pragmatic recommendations for DOE framework changes that support V2G integration. This iterative synthesis produces evidence-based proposals grounded in stakeholder perspectives and quantitative system impacts. The findings are communicated through industry reports, academic outputs, and engagement with DNSPs, market bodies and researchers via the CSIRO AR-PST program.

4. Progress against the Roadmap

| Task | Topic | Contributions from this project |
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| RQ0.1 | What data flows (DER specifications, measurements, forecasts, etc.) are needed to ensure AEMO has enough visibility of DER/net demand to adequately operate a DER-rich system in different time scales (mins to hours)? | <p>The project investigates and model the operation of Vehicle to Grid within the DOE Framework. The work assesses the V2G visibility to DNSPs and AEMO, including quantifying the differences and similarities between V2G and stationary storage DER.</p> <p>DNSPs have identified gaps in the DER registration process, allowing V2G to connect without their knowledge. All V2G needs to be approved by DNSPs and enrolled in the DER register. AC V2G is not allowed without an approved EVSE and vehicle pair and requires explicit connection approval. One DNSP is allowing V2G connections without Clean Energy Council (CEC) listing by exception.</p> <p>There is inconsistency in how V2G chargers report metering and state of charge data back to operational systems, particularly when coupled with a stationary battery.</p> |
| RQ1.1 | For each of the potential technical frameworks for orchestrating DERs in Australia (e.g., based on the OpEN Project), what is the most cost-effective DER control approach to deal with the expected technological diversity and ubiquity of DERs? | <p>The DOE Framework (including flexible export connection agreements) is expected by intermediaries to be the solution on the export side by incorporating all exporting DER including V2G. DNSPs are adapting rules to explicitly allow this, and in time expect V2G to seamlessly integrate into DOE Frameworks. At present however, there are issues and challenges with Behind the Meter (BTM) interoperability that are causing some DNSPs to take conservative approaches to their connection agreement rules, which in some cases are limiting V2G adoption.</p> <p>There are divergent approaches proposed by networks on import side DOEs, in particular in how household optionality is achieved.</p> <p>Our research has shown that some assumptions that DNSPs may hold (such as the likelihood a V2G charger will discharge into the grid during negative prices) may be incorrect in certain circumstances, based on observations of current V2G users.</p> |
| RQ1.2 | For each DER control approach, what is the most adequate decision-making algorithm (solution method)? | <p>V2G control algorithms are still evolving and are currently very nascent. The algorithms available today are either extensions of home hybrid inverter controllers (including solar and stationary BESS) or expected to integrate with third-party site level optimisation controllers. Both offerings currently have limitations, limiting the V2G output or ability to connect in the first place. These issues are likely to fall away in time. In practice there will be many permutations of control systems, optimisation objectives and resulting impact/benefit on the energy system.</p> <p>A key exploration of this project is understanding the human decision making within the system, either as purchasing decisions or configuration decisions. These decisions are critical in understanding future system behaviours. V2G users are very early adopters at this stage. This is evident both in our discussions with current V2G users, and through how V2G product developers are positioning their products today. V2G today is not seamless, and users are still regularly needing to intervene in the operation of their V2G systems.</p> |
| RQ1.3 | What is the role of DER standards in concert with the future orchestration of DERs? | <p>Central to this project is the application of V2G within the CSIP-AUS standard. This project furthers the adoption of CSIP-AUS for DOEs by explicitly providing recommendations to ensure V2G alignment and benefits. This work also considers</p> |

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| | | additional standards, OCPP 2.1, IEC15118-20, AS4777.2, AS5438 (Draft) and DNSP connection standards. |
| | | CSIP-AUS version 1.2 is now active, with version 1.3 (with pricing and storage extensions) in development. |
| RQ2.1 | For each of the potential technical frameworks for orchestrating DERs and the corresponding decision-making algorithms, what is the most cost-effective communication and control infrastructure? | <p>This project highlights the current EV User V2G solutions offered by energy retailers and V2G hardware and software solutions. This highlights the current level, expected improvements and key challenges to adoption of a theoretical optimal solution.</p> <p>Products today are very early in their development journeys. The orchestration frameworks are not clear yet. In particular, participants are unsure of how driving needs and the ebb and flow of attached storage capacity will be managed in future algorithms.</p> |
| RQ3.1 | What are the most cost-effective ancillary services that can be delivered by DERs considering the expected technological diversity and ubiquity of DERs? | Not considered in this project |
| RQ4.1 | What are the minimum requirements for a DER-rich distribution network equivalent model to be adequate for its use in system planning studies? | DOEs through hosting capacity can be incorporated into network planning studies. The investigation will consider the impacts of EVs within DOEs and hosting capacity for network planning. While V2G deployment is in its infancy, the operation of V2G will have particular characteristics that differ from stationary BESS. This project seeks to identify and quantify these differences. |
| RQ5.1 | What are the necessary organisational and regulatory changes to enable the provisioning of ancillary services from DER? | Research so far has shown ancillary services are not core considerations for current V2G products. The low prices for ancillary services coupled with their technical complexity makes them unattractive to product developers. This may become more important to developers in coming years. We will describe any further themes and revealed barriers to ancillary services in the final report. |
| RQ5.2 | What are the necessary considerations of establishing a distribution-level market (for energy and services)? | <p>Research has shown that there are divergent expectations among stakeholders around the need for and value of distribution level markets for energy and services. Some support full markets for local network capacity others see them as an unnecessary complexity.</p> <p>This project is DOE-focused however DOEs intersect local markets – for example through mechanisms to enable participants to access additional capacity at times they need it.</p> |

5. Research relevance to Australia

V2G has a large potential to positively and materially impact the level of storage in Australia, assisting the energy transition, but only if that storage is actively participating in the system. The ARENA Bidi roadmap forecasts 2300 GWh of storage potentially available from V2G by 2050 [11]. V2G products are beginning to emerge in the second half of 2025 in Australia, following the certification under AS4777.2, and we can now start observing how these solutions integrate into the grid. DOEs are the favoured approach for managing the impacts of V2G on the grid. Their intersection with demand response services is less defined. This project identifies and recommends changes to ensure V2G can reach its full potential.

V2G adoption is being led by consumer solution offerings, and this will continue as EV uptake increases, more models are available and promoted and the cost of V2G charging equipment reduces. Adoption rates and the shape of solutions are heavily influenced by human and behavioural values as well as monetary values.

Within the context of the AR-PST, the Roadmap considers the technical power system planning and operations, and seeks to integrate V2G into the energy system in a way that not only causes no harm to the operations, but maximises its efficiency through benefit DER (inc V2G) operations aligned to overall system needs and rewarding those that provide the benefits.

Within this context, we foresee and ongoing effort to ensure V2G can meaningfully contribute to system operations. We recommend the following key priorities:

1. Dedicated qualitative customer research on demand side DOEs, particularly focussing on fairness, impact, and agency
2. Continued assessment of non-monetary values on V2G solutions and offerings, including the decision-making process and considerations for V2G solutions.
3. Focus on fit-for-purpose network value streams that align operations to network benefits and reward participants accordingly.
4. Guardrails monitoring and refinement- Broaden investigation to all guardrails for gaps, technical performance and areas where the guardrails are limiting operations.
5. Continue to maintain and build the V2G offering taxonomy to include all DER solutions

6. Recommended Research Priorities

Embedding human factors into DER technical frameworks and models

Future DER research should prioritise the explicit integration of human decision-making into technical frameworks, forecasting tools, and system models. This project demonstrates that DER outcomes are strongly shaped by consumer purchasing choices and by subsequent configuration decisions that determine how assets are actually operated. These personal drivers often prioritise autonomy, reliability, and self-use over system-level optimisation, materially influencing DER availability and behaviour.

Current planning, forecasting, and benefit assessments typically assume economically rational or fully optimised DER operation, and therefore risk overstating uptake, flexibility, and system benefits. Research is needed to develop models and tools that represent realistic consumer preferences, configuration defaults, and behavioural constraints, and to examine how standards, default settings, and connection frameworks can implicitly align consumer outcomes with system needs while preserving user agency.

Robust DER operation under imperfect behind-the-meter coordination

Future DER research should prioritise the development of network and orchestration frameworks that remain robust under conditions of limited or poor behind-the-meter (BTM) coordination. While interoperability research continues, this project reinforces that real-world DER deployments often involve fragmented control across devices, vendors, and optimisation layers, with coordination largely dependent on manufacturer-led solutions that are progressing slowly. As DER penetration increases, assuming effective BTM coordination risks creating fragile system designs.

Research is therefore needed to identify technical approaches, guardrails, and DOE designs that tolerate incomplete visibility, conflicting control signals, and sub-optimal local optimisation, while still maintaining predictable network outcomes. This includes exploring conservative-by-design controls, adaptive envelopes, probabilistic modelling of DER behaviour, and fail-safe mechanisms that protect system integrity without requiring perfect interoperability. Developing DER frameworks that perform acceptably under these imperfect conditions is essential to enabling scalable DER integration in the near to medium term.

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