Enhanced System Planning Project

C4NET | ESP Enhanced System Planning

C4NET Project Overview

Comprehensive techno-economic modelling of alternative/complementary storage options

Work Package 2.10

May 2025

Table of Contents

1. Purpose of the report

The Enhanced System Planning (ESP) project is a significant and collaborative research project aimed at informing planning below transmission level in Australia beyond 2030. Its focus is on building methodologies and approaches for bottom-up modelling and to highlight the opportunities presented through the distribution system and by integrating Consumer Energy Resources (CER) and Distributed Energy Resources (DER), with the goal of informing whole of system planning. The ESP seeks to inform gaps that would emerge if the Australian Energy Market Operator's (AEMO) current Integrated System Plan (ISP)[1] is expanded beyond its current scope to take a more whole-of-system approach in alignment with the Energy and Climate Change Ministerial Council's (ECMC) recommendations for enhancing energy demand forecasting in the ISP.[2] The ESP project is targeted at addressing the distribution system considerations aspect of this expanded scope, with particular focus on bottom-up modelling approaches from the low voltage distribution system upwards, as outlined in *Figure 1*. For the bigger picture of integration with the ISP see *Appendix Two.*

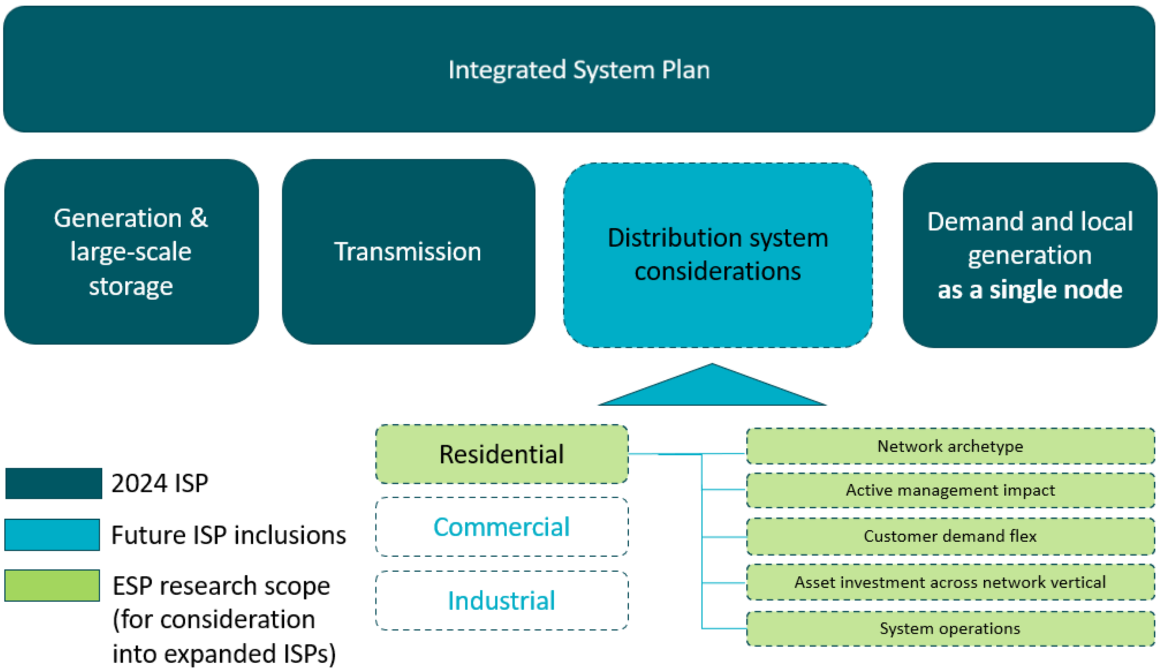


Figure 1 – Relationship between ISP and ESP

This has been addressed through fifteen projects across three distinct work packages:

- **Work package one:** Key inputs, methodologies, and demand network implications of electrification to inform foundational elements of bottom-up modelling.

[1] 2024 Integrated System Plan (ISP), Australian Energy Market Operator, June 2024

[2] Review of the Integrated System Plan: ECMC Response, ECMC, April 2024

- **Work package two**: Impact of flexibility options within distribution networks Techno-economic implications of future architectures.
- **Work package three:** Active distribution network considerations for whole-of-system planning implications: technical, economic and policy

A key project of work package two, Melbourne University undertook an independent research project: Comprehensive techno-economic modelling of alternative/complementary storage options (WP 2.10) to evaluate the techno-economic impacts of increasing levels of Consumer Energy Resource (CER) coordination. The CERs considered were Battery Energy Storage Systems (BESS), Electric Vehicles (EVs), and controllable thermal loads such as domestic hot water (DHW) and heating and cooling demands (referred to as building fabric related storage, BFRS).

The project developed a comprehensive bottom-up methodology and advanced modelling for creating high-granularity energy demand profiles in Victoria that could represent uncoordinated and coordinated profiles for the three types of CERs, in both unconstrained and constrained network environments. The profile development process captured the diversity of demand by accounting for network type, geographic location, and seasonal variability. These detailed demand profiles formed the basis of three case studies designed to evaluate the techno-economic impacts of increasing levels of CER coordination. The project case study results illustrated the potential of CER coordination to offer cost-effective alternatives to traditional infrastructure upgrades.

This summary report is designed to guide stakeholders in their understanding of this comprehensive techno-economic modelling approach.

In addition, C4NET has sought through this report to summarise and evaluate the research, identify any opportunities or limitations with the approach taken, and highlight any observations or insights for distribution network service providers (DNSPs), regulators and policy makers and market operators and for future research. This has also been done taking into consideration broader consultation and a range of stakeholder views and seeks to maintain a focus on consumers as the beneficiaries of an integrated energy system.

2. Project Summary

As Australia transitions towards a more sustainable energy future, storage systems play an increasingly important role in the energy system. Storage systems provide economic benefits such as energy arbitrage by storing electricity from periods of low-cost production (often coinciding with high renewable generation) and releasing it during higher cost hours (often coinciding with peak demand periods). This energy arbitrage not only improves the economics of energy supply but also reduces energy curtailment while improving system reliability. The rapid expansion of renewable energy sources is increasing the price differential between low-cost and high-cost periods, which makes storage solutions increasingly attractive to stakeholders, driving an accelerated deployment of storage across all grid levels from transmission to distribution networks. The Australian Energy Market Operator (AEMO) forecasts that distribution-connected storage installed by consumers ("Coordinated CER storage" and "Passive CER storage") will experience the highest long-term penetration, contributing several gigawatts of capacity to the grid, as shown in Figure 1.

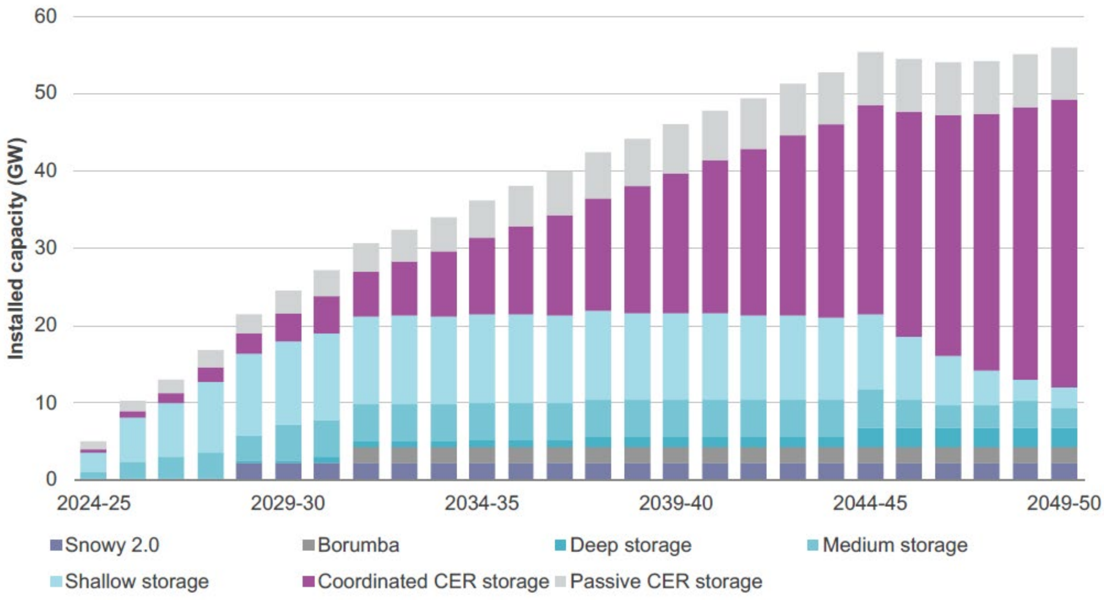


Figure 1 - Forecasts of storage Installed capacity in the ISP, NEM (2024-25 to 2049-50)[3]

In addition, AEMO estimates that $4.1 billion in large-scale investments could be avoided if energy resources in distribution networks in the form of CER storage, rooftop and distributed solar, and demand-side participation are effectively coordinated[4].

However, current projections often overlook the potential contributions of emerging storage technologies such as electric vehicles (EVs) and thermal storage devices, including

[3] AEMO, "2024 Forecasting Assumptions Update," 2024
[4] 2024 Integrated System Plan (ISP), Australian Energy Market Operator, June 2024

building fabric-related storage (BFRS) in buildings, and domestic hot water (DHW) storage in tanks. The mix of energy storage technologies, their capacity and energy supply duration are shown in Figure 2. This figure illustrates the individual contributions of various storage technologies, which typically operates for minutes to hours, with power capacities ranging from kilowatts to megawatts. The orange area in the figure represents an example of the expected envelope resulting from the aggregation of these technologies within a single distribution network. Coordinating storage across multiple distribution networks for transmission-level applications could unlock a substantial storage capacity in the order of gigawatts/gigawatthours.

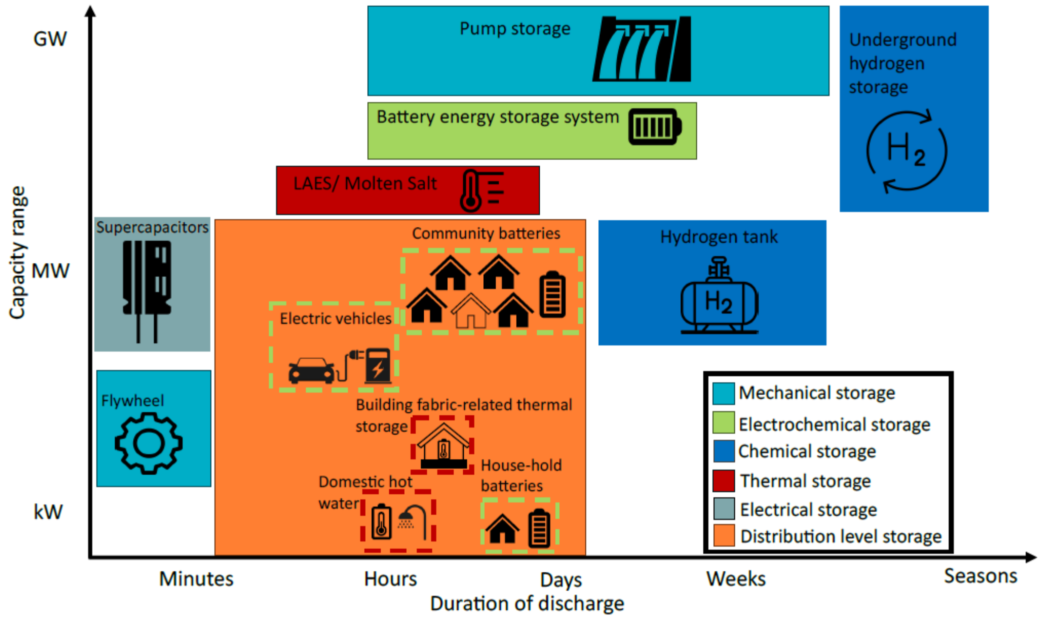


Figure 2 - Type of storage systems classified according to their supply duration and capacity

Using three case studies, this project provides a techno-economic assessment of the benefits brought by coordinating multiple storage options, individually and in combination, in the distribution networks (household and community batteries, EV storage and thermal storage), and assess the impact of various storage model and scenario parameters on the networks, further informing scenario developments of different stakeholders (storage support to mitigate the impact of 100% solar penetration, storage support for different sizes and mix of constrained/unconstrained export/import scenarios, cumulative impact of EV penetration). The project's relationship with other research projects in Work Packages 1 & 2 is illustrated in Figure 3.

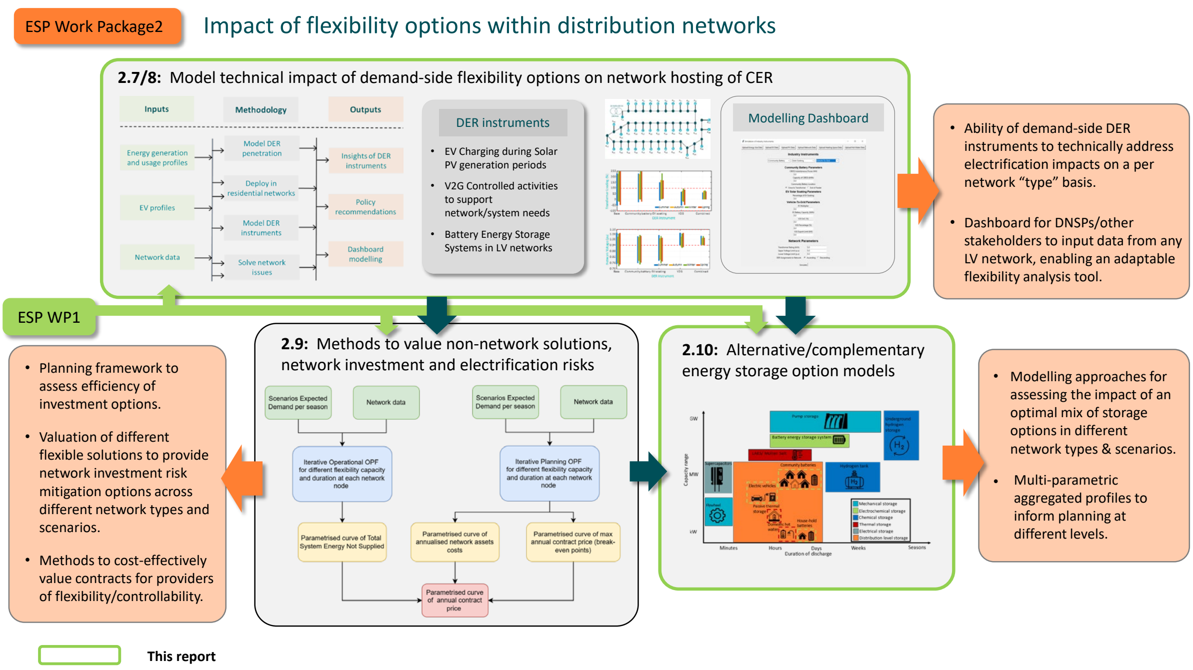


Figure 3 – Relationship between this research project and other projects in Work Packages 1 & 2

3. Research methodology and approach

The methodology has three steps which are summarised in Figure 4.

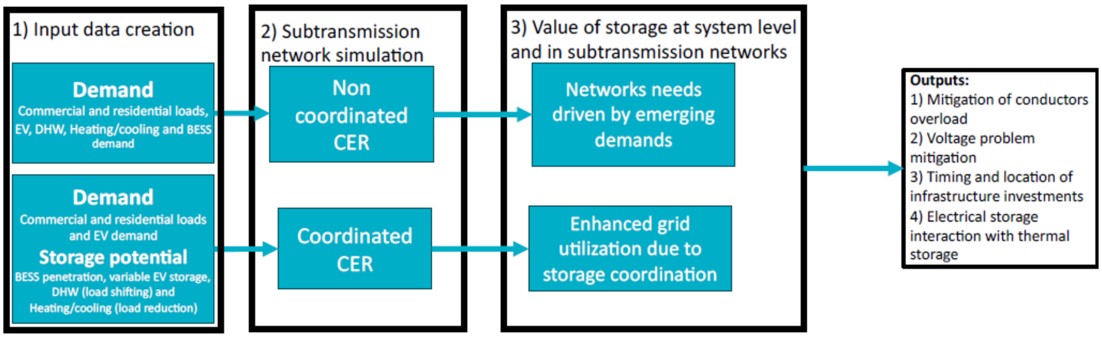


Figure 4. Project methodology

3.1 Input data creation

The first step was input data creation, which employed a bottom-up profile generation approach. This step involved creating individual demand profiles for different technologies within distribution network and, where applicable, obtaining their storage potential.

Commercial and residential load profiles were derived from historical data; household battery demand projections were obtained from AEMO's forecasts; and demand profiles for EVs, DHW, and heating/cooling were generated using highly granular models reflecting their unique characteristics, services, and operational behaviours. Apart from residential and commercial loads which did not offer storage capabilities, the remaining technologies provided storage in different ways: household batteries act as conventional storage, EVs offer time-varying storage, DHW enabled load shifting, and heating/cooling demands provided load reduction to decrease peak demand. Further details of technology modelling can be found in the relevant sections of the research report[5].

Consistent with other ESP research projects, in particular work package one, aggregated load profiles were created for typical days across three seasons (shoulder, summer, and winter), four network types (urban, suburban, short rural, and long rural), and four locations (Ballarat, Melbourne, Shepparton, and Traralgon). The commercial load profile connected to the LV and MV networks was assumed to be consistent across all seasons, networks, and locations. Residential load and household battery profiles varied by season. Electric vehicle (EV) profiles varied by network type. Heating/cooling and DHW demands varied by location, network type, and season. The aggregated profiles for specific areas used in the case studies (e.g. supply area of a terminal station) were created based on ssumed rural and urban customer distribution. Examples of forecast aggregated profiles for the whole state of Victoria in 2040 and 2050 are shown in Figures 5 and 6. Further details

[5] Comprehensive techno-economic modelling of alternative/complementary storage options, WP2.10, May 2024, Section 4, pages 32-24

of the bottom-up profiles creation methodology and aggregation can be found in the relevant sessions of the research report[6].

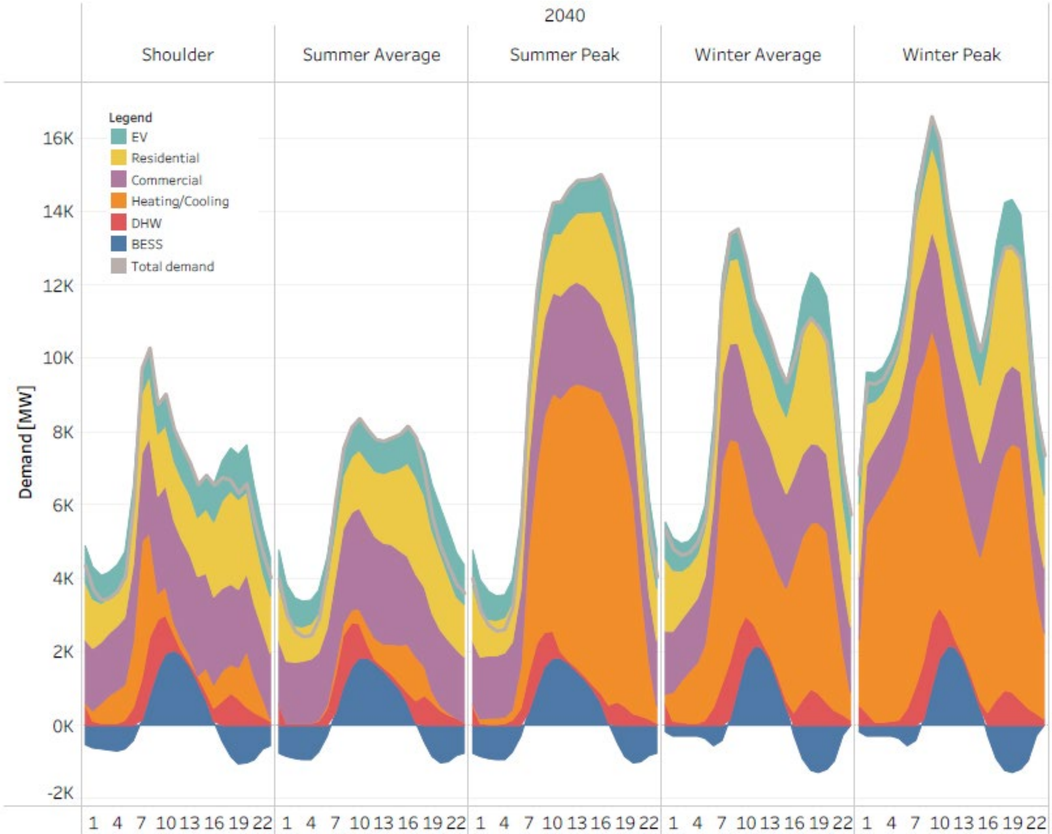


Figure 5 – Aggregated demand profles for the state of Victoria, 2040

[6] Comprehensive techno-economic modelling of alternative/complementary storage options, WP2.10, May 2024, Section 3, pages 14-31

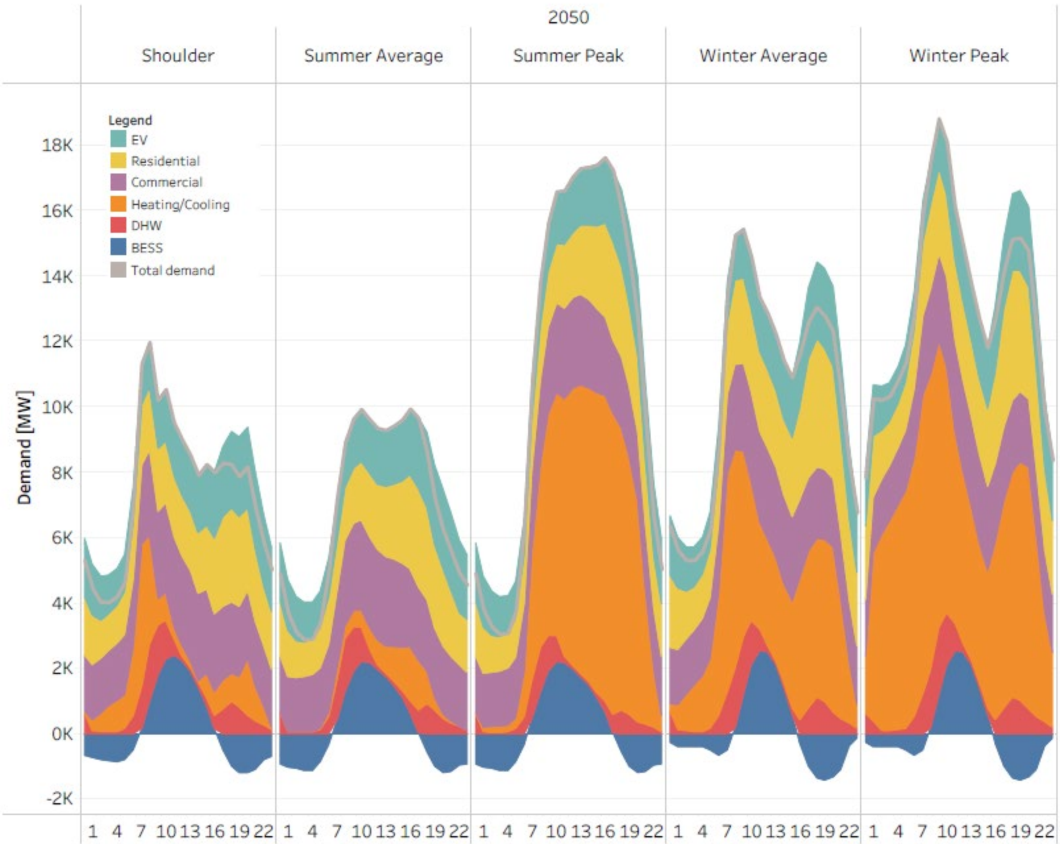


Figure 6 – Aggregated demand profiles for the state of Victoria, 2050

3.2 Network Simulations

The second step involved simulating distribution network models under two scenarios. The first scenario examined a non-coordinated CER case, where storage was modelled as a fixed demand profile. This baseline analysis helped to understand system needs without any storage coordination. The second scenario investigated a coordinated CER case, which analysed the CER coordination impact on the peak demand, line overloading and other metrics. It is important to mention that in both scenarios the simulation aims to minimise peak demand, network imports, line overloading, and voltage deviation.

The simulations were performed for three case studies. The first, a single-bus model encompassing Victoria's entire aggregate demand and excluding network constraints, explored the full potential of coordinated CER without considering network constraints. To understand the impact of incorporating the constraints of real distribution networks, two additional studies were conducted. The first of these used an HV/MV network model, which analysed three Victorian sub-transmission networks with distinct characteristics. Finally, one of these sub-transmission networks was modelled where CER coordination was driven by market price consideration, not network benefits. All these models incorporated the input data developed in step 1.

3.3 Storage value assessment

The simulation results from the second step informed the third step, which focused on evaluating the value of storage in subtransmission networks. In this step, the non-coordinated CER case helped to identify emerging network constraints, while the coordinated CER case highlighted the benefits of storage in reducing PV generation curtailment, optimising grid utilisation, enhancing voltage levels, and mitigating line overloading. Furthermore, this step offered valuable insights into the interactions between various storage technologies.

3.4 Summary of assessment

3.4.1 Case study 1

In the first case study, a single-bus model was used to represent aggregate demand in Victoria and demonstrated the potential of coordinating each CER technology individually and as a full coordination of all the technologies. The results show that CER coordination can help to reduce peak demand, increase solar self-consumption, and flatten the overall demand profile. BESS in particular stands out by not only lowering peak demand but also significantly flattening the load profile. The effect of the various CER storage technologies on the typical day demand profile in 2040 and 2050 is shown in Figure 7.

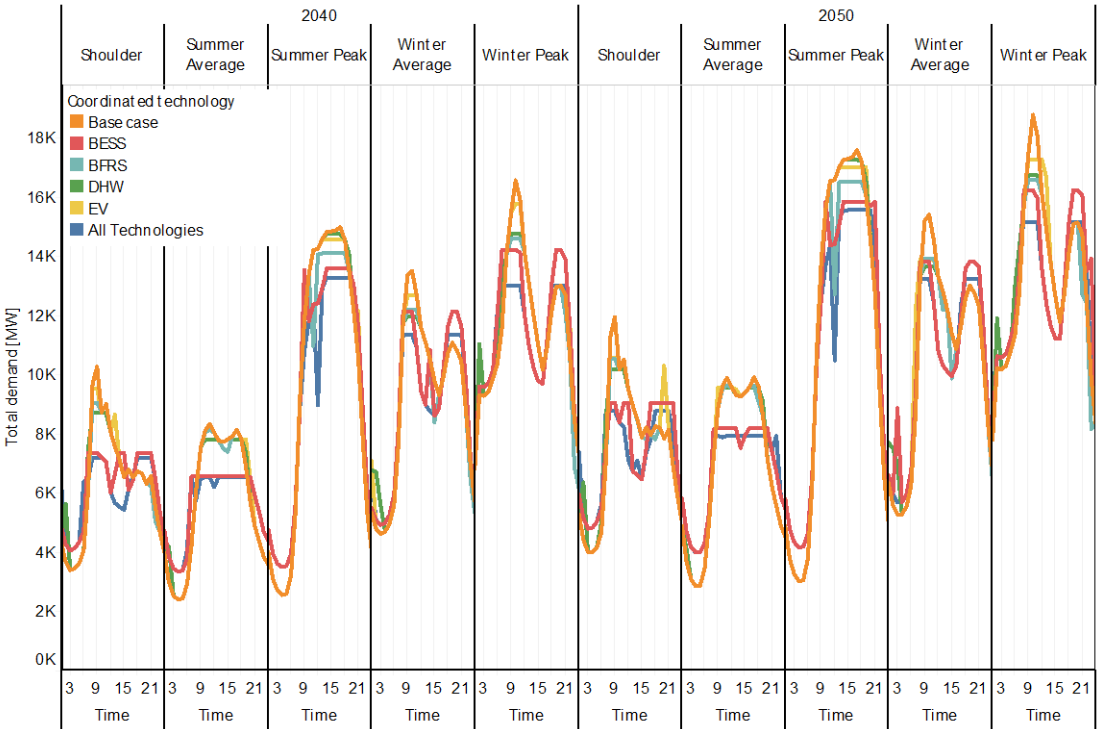


Figure 7 – Hourly demand profiles for representative days in 2040 and 2050 considering the coordination of different CER technologies[7]

[7] Comprehensive techno-economic modelling of alternative/complementary storage options, WP2.10, May 2024, Section 5.1, page 37

3.4.2 Case study 2

The second case study investigated the impact of network constraints within three sub-transmission networks. Without CER coordination, various lines in the sub-transmission networks were found to be overloaded for the increased peak demands in 2040 and 2050. CER coordination generally leads to reductions in peak demand, energy imports, PV curtailment, and line overloading. The effectiveness of CER coordination in mitigating congestion varied across the networks, illustrating the importance of considering local grid characteristics in the operational strategies. An example of line overloading situation in one sub-transmission network for 2040 and 2050, with different CER coordination percentages, is shown in Figure 8. The percentage refers to the share of each CER technology that is being coordinated in each case. For example, if 100 kW of a given technology (such as EVs, DHW, BESS, or heating/cooling demand) is available: 0% coordination means the entire 100 kW behaves as a load, following a demand profile. 50% coordination means 50 kW continues to follow the original demand profile, while the remaining 50 kW is available for coordination (such as load reduction, demand shifting, or charging/discharging). 100% coordination means the full 100 kW is available for coordination.

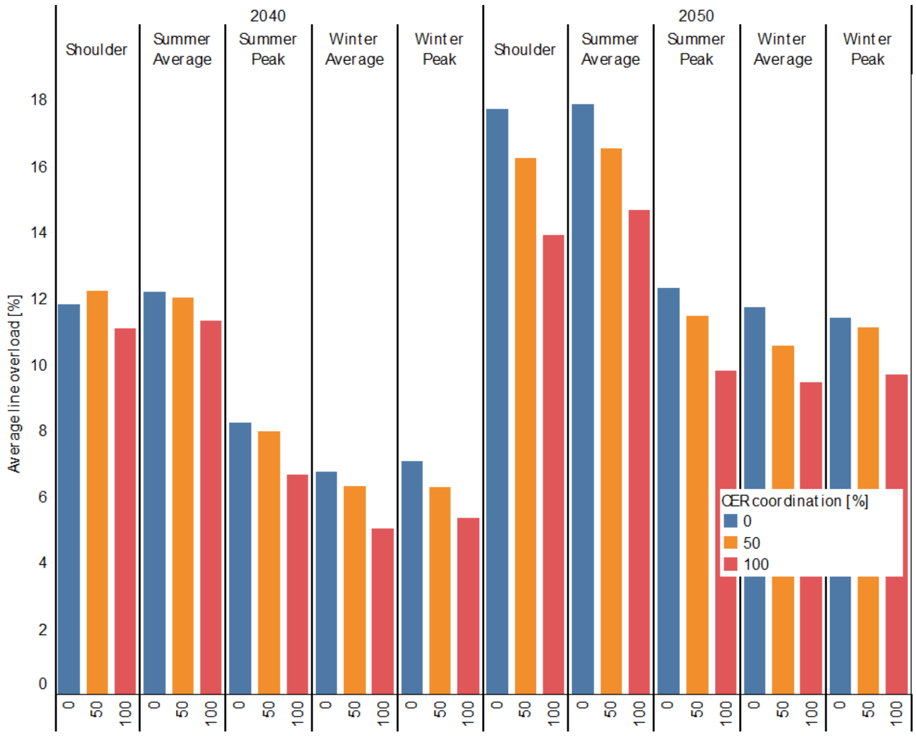


Figure 8 - Average line overload for representative days in 2040 and 2050 for different CER coordination levels[8]

3.4.3 Case study 3

The third case study examined the integration of market price signals into CER coordination within a rural sub-transmission network. The findings highlight that while CERs responding to market prices maximised energy arbitrage opportunities, this behaviour at times worsened line congestion. This

[8] Comprehensive techno-economic modelling of alternative/complementary storage options, WP2.10, May 2024, Section 5.2.1, page 41

trade-off points to the need for more refined strategies that simultaneously consider economic drivers and technical constraints.

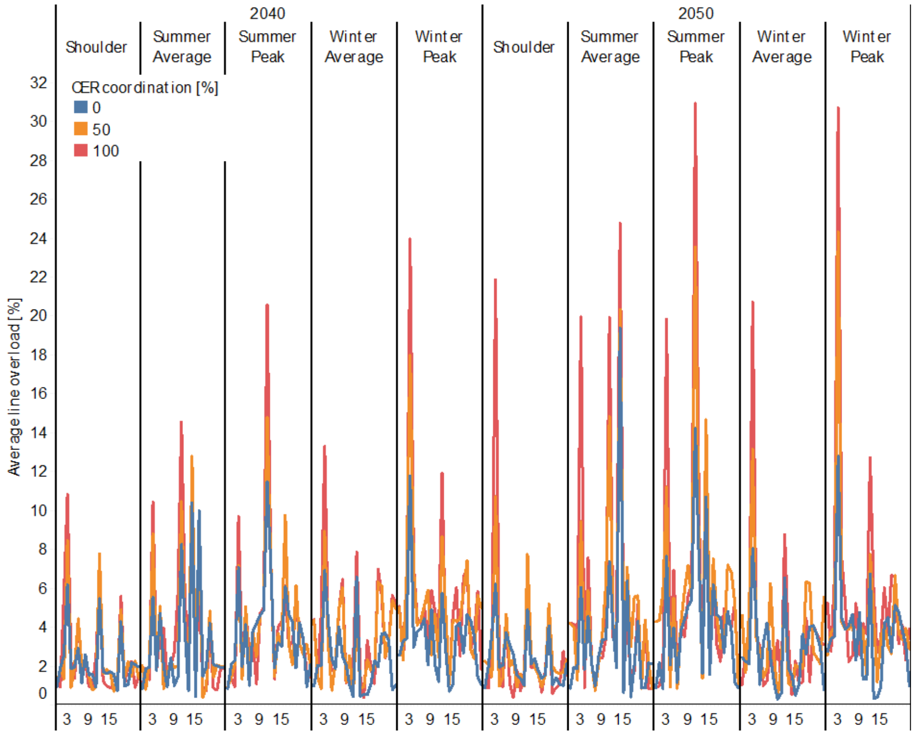


Figure 9 - Hourly average line overload per year and typical day for different CER coordination levels for GNTS-MBTS sub-transmission network[9]

Overall, the case studies highlight the potential of coordinated CER to enhance sub-transmission system flexibility by reducing peak demand, increasing alignment between demand, solar generation, and alleviating network overloading. By leveraging the synergies between diverse storage technologies, coordinated CER operation offers a powerful tool for shaping energy demand in Victoria, providing a pathway to reduce reliance on grid imports, shift consumption to periods of high PV generation, ultimately mitigating network overloading and reducing PV curtailment.

[9] Comprehensive techno-economic modelling of alternative/complementary storage options, WP2.10, May 2024, Section 5.3, page 53

4. Observations, insights and key reflections for stakeholders

Through the evaluation of the work undertaken, C4NET has identified some observations, insights and key reflections for stakeholders. Outlined below we have summarised these for DNSPs, AEMO, policy makers and researchers, with a section highlighting observations in relation to consumer outcomes. While these are summarised for stakeholder type, this section should be read as a whole to ensure cross-sectoral awareness.

4.1 DNSPs

The project expands the scope of CER storage in distribution network to include DHW and BFRS, in addition to the conventional consideration of BESS and EVs. With this expanded scope, a significant portion of the grid load demand in future could provide storage opportunity provided that consumers consent for their load to be coordinated.

The beneficial effects of coordinating CER storage to relieve grid asset overloading, increase network utilisation (via flattening of the demand curve), and reduce PV curtailment have been demonstrated through the first two case studies. The advanced CER profile and coordination modelling techniques that have been developed, which also consider network constraints, lend themselves to potential future application in DNSP planning activities. The third case study illustrates that the objective function for CER coordination needs to be defined and agreed upfront as network requirements do not always align with market prices. One possible mechanism for safeguarding network integrity is the use of dynamic operating envelopes, a subject that has been explored in related research projects (WP 1.5 & 1.6).

In view of the enormous potential for CER storage to reduce distribution network impact from the forecast increase in load demand and defer network augmentation, DNSPs should consider developing deeper understanding of the different forms of CER storage option and their efficacy in managing electricity demand, including the requirements for associated appliance standards and functionalities of Active Distribution Network (ADN) to unlock the CER storage flexibility.

4.2 AEMO

AEMO should take note of the expanded options of CER storage which may affect their forecast of CER storage capability in the ISP and how it is impacted by distribution network constraints. The developed highly granulated CER technology and coordination models may be useful in future whole-of-system planning activities. Unlocking CER storage flexibility will require a coordinated effort between AEMO, DNSPs and ultimately the consumers who would need to provide permission for their CERs to be coordinated. The coordination ensures that the distribution network, and possible augmentations, can support CER and more broadly, DER, integration without exceeding its capacity.

4.3 Policy makers

Learnings from the modelling of each CER storage option and its coordination value, together with their combined application, can inform CER related policy development and incentives.

The illustrative case studies demonstrate the potential huge benefits that come from the expanded scope of CER storage options, as well as their relative coordination merits, not just for solving distribution network constraints in face of increasing load demand, but also for lowering electricity prices by CER participation in the electricity supply system.

As customer participation is key to achieving a high percentage of coordination, policy makers can play a significant role in facilitating customer participation through market and policy developments.

4.4 Consumer

Consumers will ultimately benefit from any reduction of infrastructure costs through lower network charges. Coordination of various forms of CER storage will require active customer participation. The degree of consumer engagement and participation will depend on their willingness to participate, and this will likely depend on having the appropriate incentives to do so. It will also be necessary to have safeguards in place to prevent adverse treatment of the consumer assets or perverse consumer outcomes occurring.

4.5 Research

The illustrative case studies focus on load demands of the whole state of Victoria and three example sub-transmission networks. While different levels of CER storage coordination percentages have been tested in sensitivity analysis, the basic assumption is there are no distribution network constraints in the MV and LV networks to restrict CER storage participation. Further case studies incorporating MV and LV network constraints could shed more light on the possible level of CER storage capability that can be unlocked.

Appendix One

Researcher profile

Conducted by: University of Melbourne, Melbourne

Lead Researcher: Bastian Moya Ureta

Research Team: Lucas Quiertant, Sleiman Mhanna, Prof. Pierluigi Mancarella

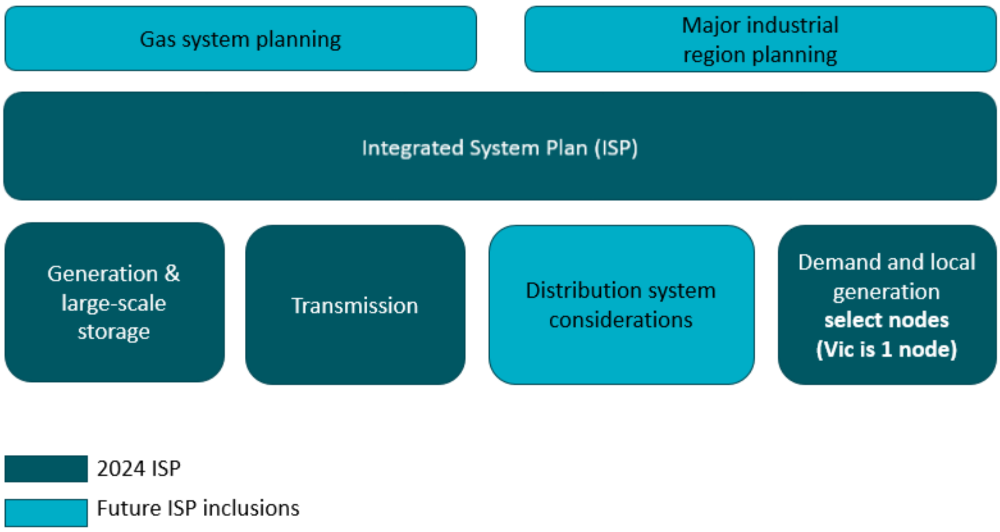
About C4NET

C4NET delivers multi-disciplinary solutions to the challenges the energy industry is facing. Working with complexity requires diverse skills, reliable data and new approaches, which C4NET facilitates by bringing together governments, industry and universities, creating new links across the sector.

Central to C4NET's program of work is the Enhanced System Planning (ESP) project, a significant and collaborative research project aimed at informing sub transmission level electricity planning beyond 2030, with a focus on building methodologies and approaches for bottom-up modelling and to highlight the opportunities presented through the distribution system and integrating Consumer Energy Resources (CER), to inform whole of system planning.

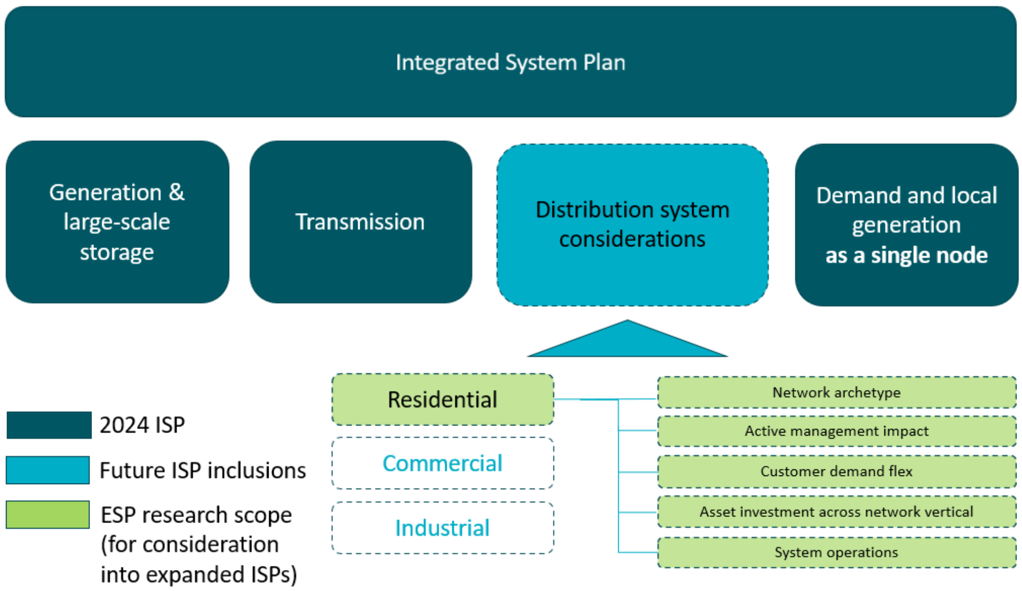
Appendix Two – Bigger picture integration with the ISP

Shift towards whole of system planning



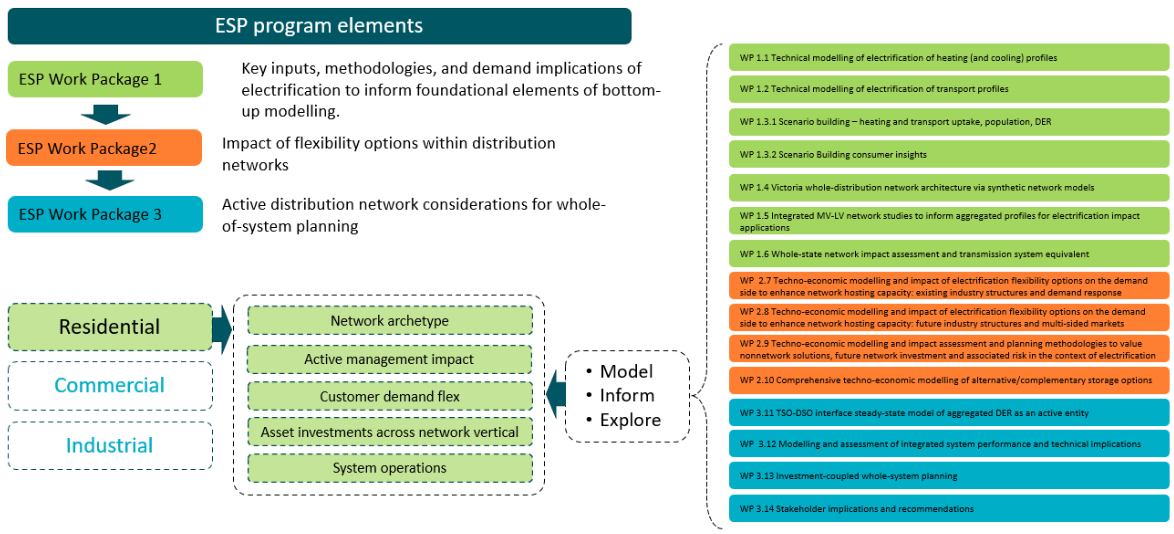
The Energy and Climate Change Ministerial Council (ECMC) accepted the recommendations of the review of the ISP which target transformation of the energy system as a whole, with particular reference to gas system planning, major industrial region planning and distribution systems.

Distribution system components of whole of system planning

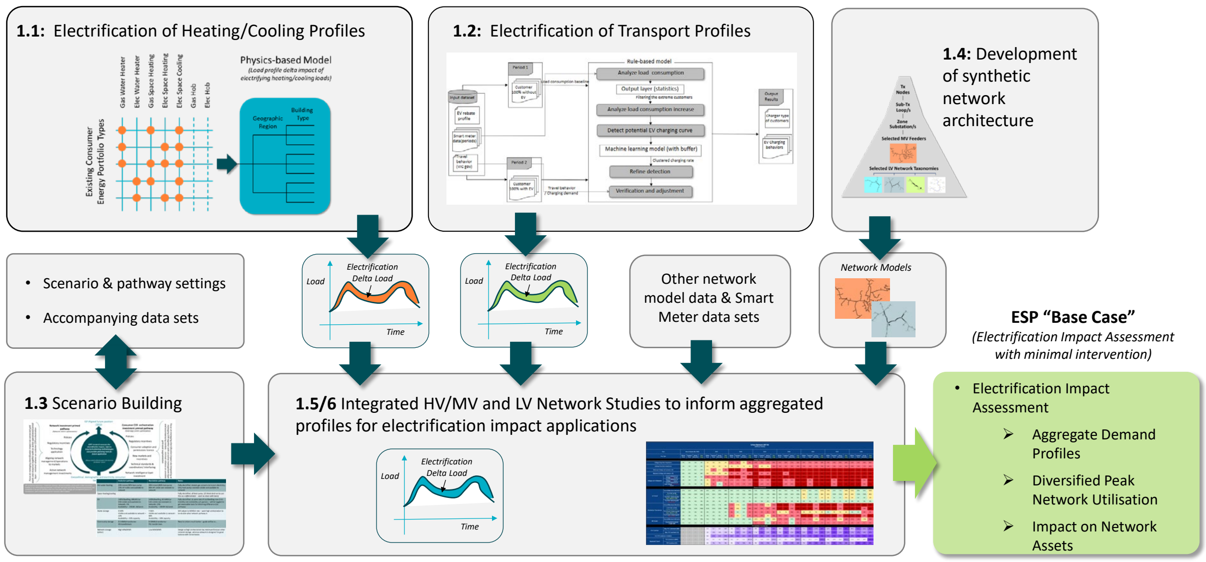


The ESP was scoped to be deliverable with the resources and time at hand to inform feasibility of broader application. It focussed on the more complex areas around residential and low voltage assets of the distribution system, with an application across Victorian networks with methodologies applicable to any region in the NEM.

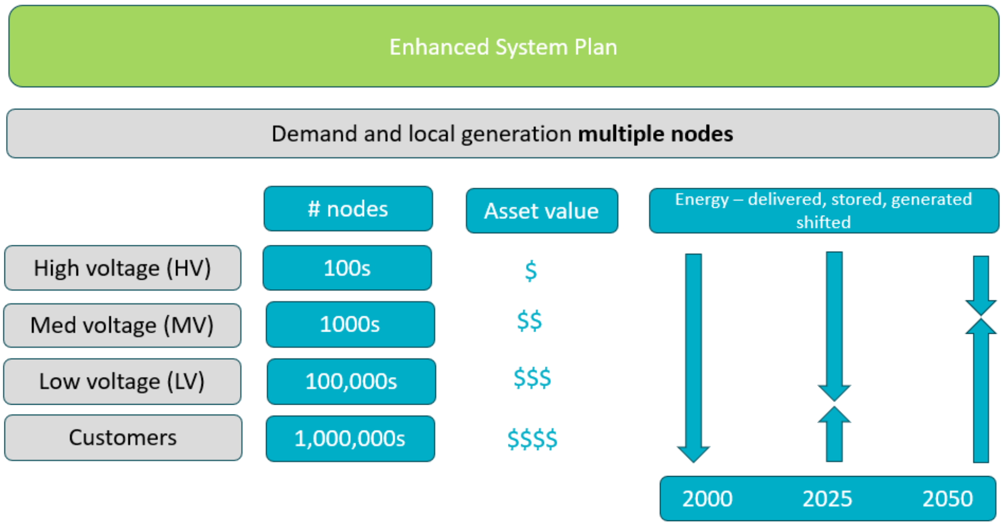
ESP alignment with distribution system components of whole of system planning



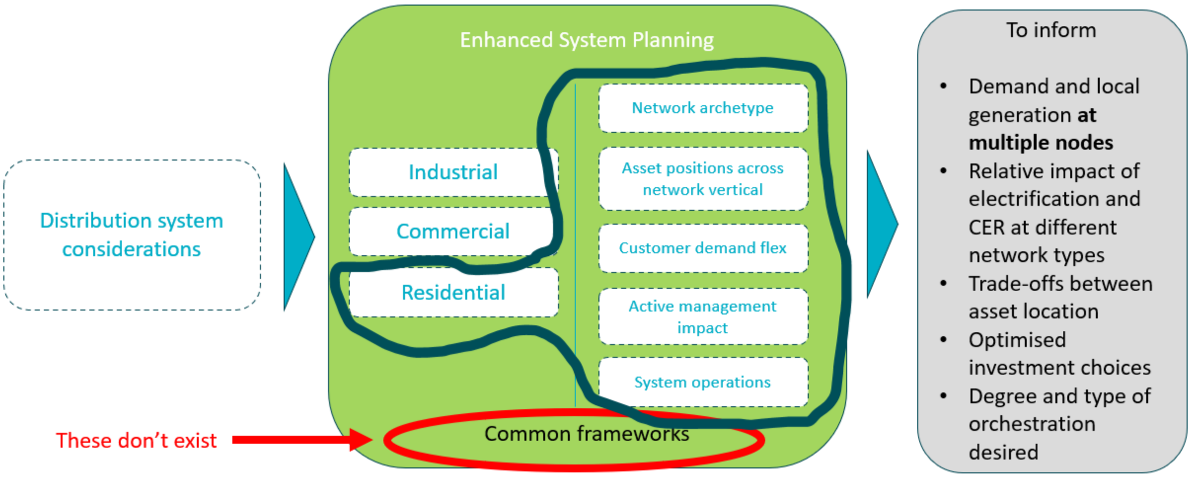
The 'base case' for residential electrification impact assessment, the flex options and relativity to other investment options



Elements needed to meaningfully inform distribution system aspects in whole of system planning



Methodological gaps in whole of system planning



Appendix Three – ESP project and research partners