Enhanced System Planning Project

C4NET | ESP Enhanced System Planning

C4NET Project Overview

Development of illustrative distribution network models for Victoria

Work Package 1.4

March 2025

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1. Purpose of the report

The Enhanced System Planning (ESP) project is a significant and collaborative research project aimed at informing electricity 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.*

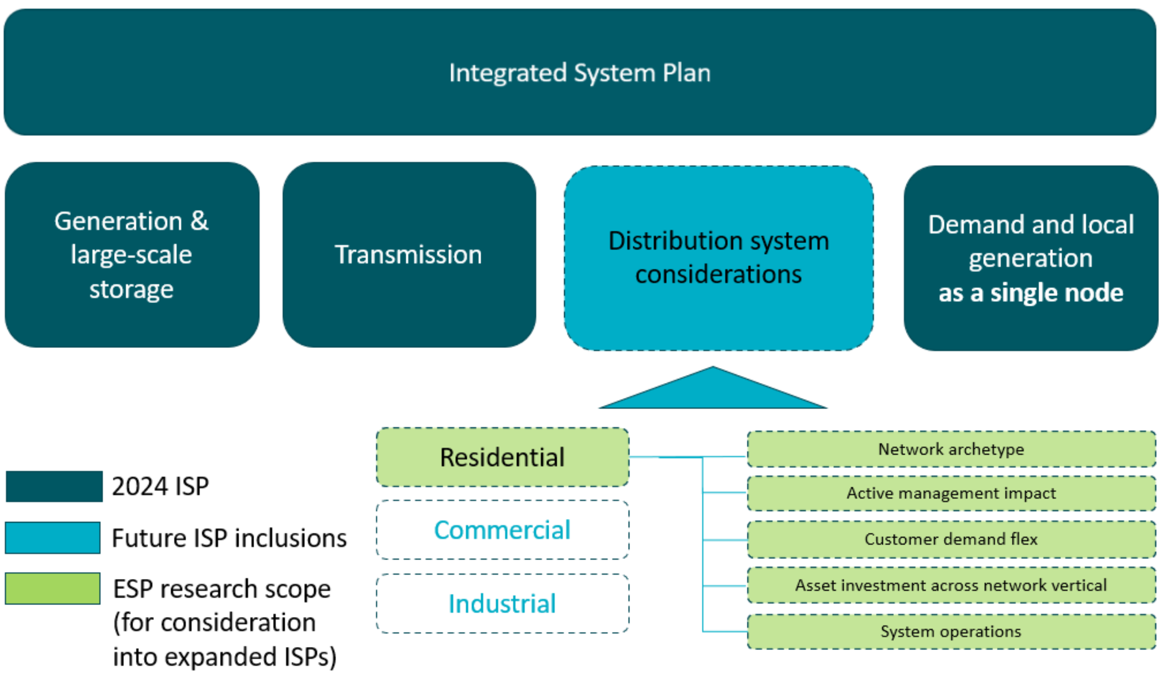

Figure 1. - Distribution system components of whole of system planning

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.
- **Work package two**: Impact of flexibility options within distribution networks Techno-economic implications of future architectures.

[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 three:** Active distribution network considerations for whole-of-system planning implications: technical, economic and policy.

A foundational project of work package one, RMIT University undertook an independent research project: Development of illustrative distribution network electrical models for Victoria, with the goal of developing electricity distribution network models that can be used to broadly represent the Victorian grid in a way that enables simplified "bottom-up" analysis by researchers and industry. The models were intended to be used for subsequent work packages to perform various power system studies, including load flow analysis, voltage constraint evaluations, hosting capacity assessments, and techno-economic evaluations.

This report is designed to guide stakeholders in their understanding of how the research and models that were developed could be used to broadly represent the Victorian grid and can be used in subsequent projects and can inform bottom-up modelling.

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

The *Development of illustrative distribution network electrical models for Victoria research* project sought to develop a modelling framework and illustrative network models that can be used to broadly quantify the network impact of electrifying the energy system. Illustrative network models are needed to model the long-term impact of demand and DER changes in a scalable fashion at a system-wide view more efficiently than actual detailed network models. This is illustrated as a key feature of the base case in *Figure 2* below. The illustrative network models developed are not intended, nor suited, to replace actual network models that DNSPs use to quantify local impacts.

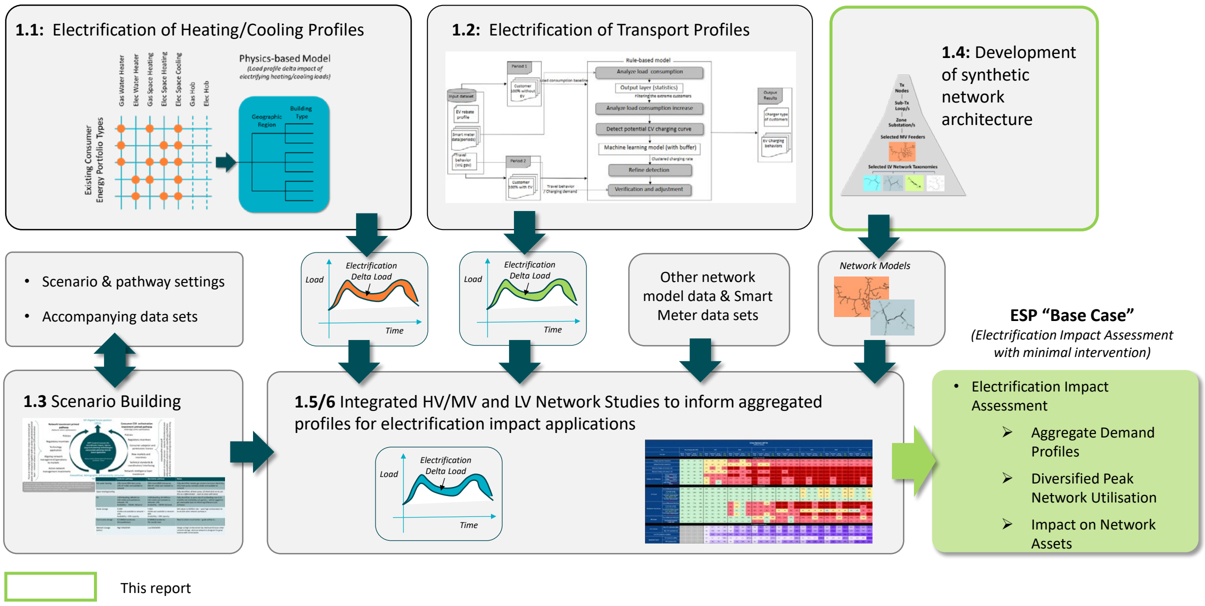

Figure 2 - The base case for electrification impact assessment, highlighting the role of illustrative network models in quantifying network impact.

Increased electrification and installation of CERs are key levers to achieve decarbonisation objectives. The impact of these developments on the distribution networks is material and will require significant investment. To identify the quantum of this impact will require illustrative network models to be developed that can be used for network constraint analyses and techno-economic assessments of various investment options. This is considered material for electricity network infrastructure planning.

The research project developed illustrative network models by adopting a hybrid modelling approach, combining actual medium-voltage (MV) feeders provided by Distribution Network Service Providers (DNSPs) for five distinct network types, along with pseudo-LV network models using typical LV circuit characteristics customised to the specific distribution substation capacity and number of customers. The network models were validated using power flow analysis for a chosen snapshot loading scenario (diversified average individual customer - after diversified maximum demand - representing a peak summer demand) that the voltage and thermal characteristics are within normally accepted industry tolerances.

The network models were used to assess electrification impact through the subsequent projects in work package one: *Integrated HV/MV and LV Network Studies to inform aggregated profiles for electrification impact applications.*

It is noted that at the outset of the Enhanced System Planning project it was envisaged that select network typologies developed by CSIRO under ARENA's National Low-Voltage Feeder Taxonomy Study[3] and the CSIRO's 2013 "National Feeder Taxonomy" for MV networks would be used as the basis for this study. However, there was considerable debate among researchers and DNSP representatives about how relevant they were to the Victorian context and shortcomings for use in subsequent part of the study. Instead, it was decided to use actual Victorian MV feeder models from Victorian DNSPs as a basis for the synthetic MV model development, and pseudo-LV network model development that simplified the connection arrangements for ease of automation and efficiency. The research approach and subsequent limitations is further detailed in Section 3.

When considering how best to extrapolate such an approach NEM-wide, a perennial challenge will be to find a manageable group of network models that sufficiently represent the variety and diversity across, and within, network types across multiple DNSP areas. Each approach has its limitations and the development; data matching and validation of such models is resource intensive. This poses the challenge of both how many models can reasonably be developed and which network models to use to best inform the NEM-wide approach. The development of good models requires deep distribution network asset expertise and data capture, and such resources are in high demand across a range of issues.

A further issue is how to combine illustrative LV models with MV feeders and to what extent this is necessary to sufficiently inform bottom-up modelling anticipated in latter work packages. DNSPs raised that they currently did not perform power flow analysis on an integrated network model from sub-transmission to LV customers due to computational complexity. When power flow analysis is conducted on a portion of the integrated network, the accuracy of the analysis is affected by the assumptions made about the voltage and power flows at the interface point between the local network and the rest of the integrated network. When a MV feeder model is combined with a LV network model, the enduring questions are what assumptions should be made for the voltage (and power flows) at the head of the MV feeder, and at the interface point between the MV feeder and the LV network.

[3] https://arena.gov.au/projects/national-low-voltage-feeder-taxonomy-study/

3. Research methodology and approach

A top-down approach can rapidly inform the annualised and seasonal energy impact of electrification at an aggregated level, but it is hypothesised that a bottom-up approach is needed to inform the impact on network infrastructure deeply integrating Distributed Energy Resources (DER) and Consumer Energy Resources (CER)[4] at each level of distribution network asset from transmission connection through to customer meter.

A bottom-up approach requires modelling of individual customer electricity usage overlaid on existing network infrastructure to inform the need for investment: to provide network capacity for the increased electricity demand while ensuring the electricity supply maintains the quality suitable for operating customer appliances. Distribution network infrastructure consisting of HV, MV and LV networks delivers electricity from the transmission network to the end users and connects DER within the distribution network. The infrastructure is extensive, and significant effort is required to capture the electrical data required to inform the network models. Victorian DNSPs generally have good data on its HV and MV networks but LV network data collection (physical data such as conductor details, phase connection, conductor route) is still in progress. In addition, unlike near-term system planning aimed to identify locations of targeted investment, long-term planning studies require consideration of many scenarios which is computationally intensive when carried out on detailed, actual network models. There is therefore a need for network models that can be used to broadly represent a broad grid in a way that enables simplified "bottom-up" analysis by researchers and industry.

3.1 Approach

It was hypothesised that illustrative network models are sufficient to inform the quantum of network investment, in 5-year blocks, up to 2050. The approach taken to develop the representative network models was based on the following approach:

- HV and MV network data provided by Vic DNSPs for five MV feeders, representing five distinct network types of CBD, urban, suburban, rural-short and rural-long. The HV and MV network data consists of network topology, transformer specifications, impedance profiles, load characteristics, and customer classifications (residential, commercial, and industrial) for both the MV and LV networks.
- due to the lack of complete LV network electrical data and the extensive diversity of LV network topologies, a different approach – pseudo-LV network - was used to represent spatial characteristics and typical network topology of LV network in Victoria. The LV network model was built using “rules-of-thumb” and informed by the five chosen MV feeder network data such as distribution substation size, customer load and classification.

[4] For the purpose of clarification, in this context, DER refers to distributed energy resources in front of the meter, CER refers to distributed energy resources behind the meter.

- the pseudo-LV Network approach does not match the real networks; in that it has greatly simplified the connection arrangements for the ease of automation and efficiency (i.e. this approach has adopted a simplified linear approach to the LV connection topology however in practice it's typically non-linear).
- the pseudo-LV network developed is then connected to the respective MV feeder to form an integrated HV-MV-LV network. An illustrated example of MV-LV network model is shown in Figure 3.
- automatic scripting is used to convert the network data into suitable form for power flow simulations in software package OpenDSS.
- the validity of the network models is checked using power flow analysis for a chosen loading scenario (diversified average individual customer - after diversified maximum demand - representing a peak summer demand) to confirm that the voltage and thermal characteristics are within normally accepted industry tolerances and electricity supply regulations.
- the power flow analysis also enables fine tuning of the network asset parameters such as voltage regulator settings and tap positions of the distribution transformers.

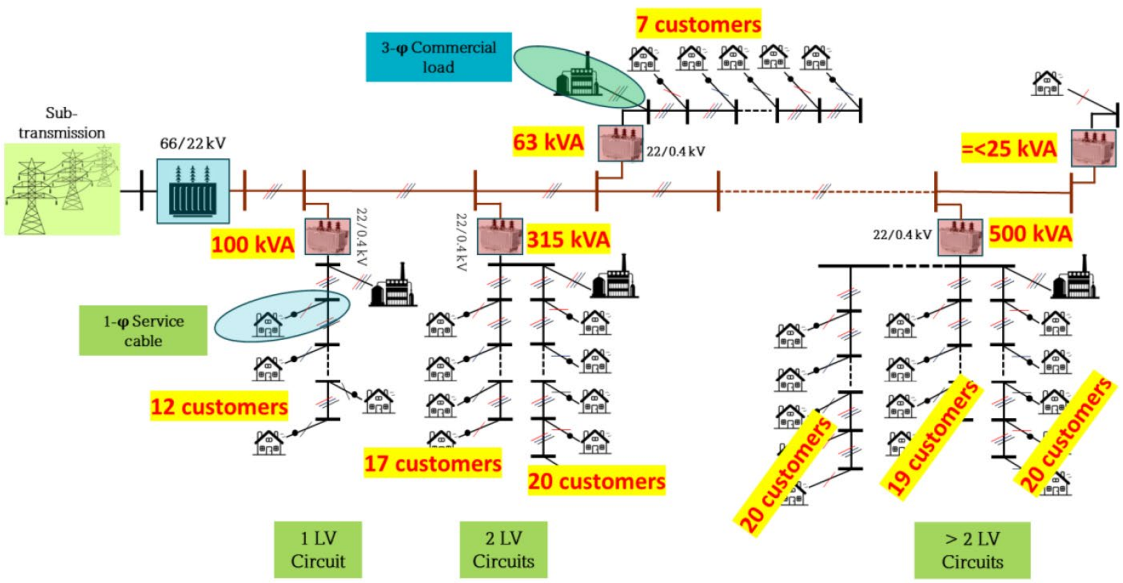

Figure 3. Illustrative example of a MV-LV network model developed by the project

3.2 Inclusions, exemptions and limitations

The researcher's approach considered:

- actual detailed HV and MV network data provided by Vic DNSPs for five MV feeders, representing five distinct network types of CBD, urban, suburban, rural-short and rural-long. These MV feeders are considered "illustrative" of the network types they represent.
- a synthetic approach to the development of pseudo-LV networks for each distribution substation connected to the five MV feeders;

- operational parameters associated with the network models (tap positions of distribution transformers, voltage regulator settings) obtained from snapshot power flow analysis.

To simplify the modelling approach, some design characteristics were incorporated that have inherent limitations. These are:

the MV feeder was left unaltered, including line impedances, line lengths, DSS transformer details, and the overall topology. It is, however, noteworthy that while the rural-long MV feeder consists of both multi-phase MV networks and Single-Wire-Earth-Return (SWER) networks, the SWER networks are modelled as connection points at the MV side of the isolation transformers only. The downstream 12.7kV and LV networks are not specifically modelled.

The following assumptions and considerations have been made while developing the pseudo-LV model for connecting them to each DSS to develop a comprehensive MV-LV detailed model:

- LV line impedances are based on typical overhead line conductors and underground cable installations
- C&I customers were modelled as directly connected to the secondary of the DSS, without further LV circuit modelling
- residential ADMD was fixed for each MV feeder type
- aggregated C&I customer ADMD is assumed to be a % loading of the DSS, with a fixed power factor relative to the MV feeder type
- distribution substations are underground when the substation rating exceeds a set threshold, otherwise a combination of underground and overhead reticulation is applied relative to the MV feeder type and size of distribution substation
- maximum customer numbers per LV circuit are limited relative to the MV feeder type. The design criterion assumes a full complement of customer connections on a circuit before another circuit is added.
- the distance between LV customers is fixed depending on the MV feeder type.
- service wires from the pole/pit to the customer premises are not modelled
- one customer per connection pole/pit

3.3 Base assumptions

To arrive at a reasonable number of illustrative network models for bottom-up modelling, a number of simplifying assumptions were made. Firstly, the five MV feeders were assumed to be “illustrative” of the network types they represent. Furthermore, it can be seen that the pseudo-LV Network approach does not match the real networks in that it has greatly simplified the connection arrangements for the ease of automation and efficiency, and in the absence of detailed LV network data. An assessment of the impact of the above limitations, using ten different types of actual LV network models (provided by a Victorian DNSP) and equivalent pseudo-LV network models (developed by the project methodology), will be informed by a subsequent ESP work package to assess the degree of correlation between corresponding “actual” and “pseudo” LV networks for given DER penetration and loading conditions.

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

From a long-term planning perspective, the availability of illustrative network models that can be used to inform emerging constraints and the quantum of network investment required under different future scenarios of CER uptake and orchestration may be a useful tool for DNSPs. This may be particularly so where there is a desire to have a common and consistent approach across different network patches to inform integrated planning across broader areas such as state-wide or NEM-wide.

The illustrative network models are not suited to pinpoint the locations where investment is required as they are not spatially or topologically accurate and are not able to represent the inherent network diversity (within network types) that exists in practice.

The research has proposed a hybrid modelling approach, combining actual medium-voltage (MV) feeders for five distinct network types, along with pseudo-LV network models using typical LV circuit characteristics customised to the specific distribution substation capacity and number of customers. The choice of the five MV feeders was guided by the DNSPs in consideration of the limited resource availability and project timeline. It may be that more than five MV feeders are required to be more representative. One particular limitation worth noting is the SWER 12.7kV and LV networks, prominent in rural distribution networks, have not been represented in the models. This implies that the network models will not directly inform the limitation as well as investment required to upgrade the SWER networks.

A number of assumptions are used to develop the pseudo-LV network models. While these are reasonable assumptions in the absence of real network data (some of which is still being captured by DNSPs) and the need to simplify from a modelling efficiency perspective, the validity of the models will need to be verified. Validation using ten different types of actual LV network models (provided by a Victorian DNSP) and equivalent pseudo-LV network models (developed by the project methodology), will be informed by a subsequent ESP work package to assess the degree of correlation between corresponding “actual” and “pseudo” LV networks for given DER penetration and loading conditions.

Overall, the integrated HV-MV-LV network models represent “a line in the sand” for assessing the impact of CER uptake. They can be refined/retuned over time to produce more accurate modelling outcomes.

The challenge for whoever does the distribution modelling considerations into an integrated system plan is to have a feasibly small number of representative or illustrative models while covering the breadth of variety and diversity of and within the networks represented and ensuring they are fit-for-purpose to what they are intended to inform over the longer-term. DNSPs may contemplate how they could work together to both assist AEMO have the data and models needed and provide the relevant expertise to build them.

4.2 AEMO

The optimal development path advocated by AEMO in its ISP includes the deployment of low-cost renewable energy to take advantage of the abundant wind, solar and hydro resources in Australia, and firming technology like pumped hydro, batteries, and gas-powered generation to smooth out the peaks and fill in the gaps from that variable renewable energy.

The optimal path forecasts that significant amount of CER storage, coordinated and dispatchable, will be required. Distribution networks are expected to host CER and some utility-scale renewable and storage projects and facilitate coordinated two-way flow of electricity between grids. The mechanisms to encourage CER uptake, distribution network upgrades and investments to enable CER hosting and coordination are still being defined.

The illustrative network models developed by this research project will be used in subsequent work packages (notably WP1.5 & WP1.6) to inform emerging network constraints from electrification at the MV feeder level and when aggregated, at the zone substation and sub-transmission levels. The modelling results can inform future ISPs.

More broadly, an omni-present challenge of representing diverse and complex distribution network systems across the NEM within an integrated system plan is how to develop a scalable and representative approach that can be efficiently modelled and suitably iterated for various scenarios. The use of illustrative models has shown significant promise to address this but need further development than was able under this project to overcome some of the limitations identified. A balance will need to be struck between being informative enough to identify broad addressable issues within an integrated plan while being efficient enough to be feasibly conducted within the ISP timeframes.

It was thought plausible that CBD, urban and sub-urban network types across major cities within the NEM could be reduced to a small number of illustrative model types. However, how manageable it would be to sufficiently represent the variety and diversity within the short-rural and long-rural networks would require further investigation. For all, validation against real networks would help inform this better, and as smart meter data becomes more prevalent this should become increasingly plausible across the NEM.

4.3 Policy makers

The process taken by the research project in developing illustrative network models to assess the impact of electrification illustrates the complexity of the conceptual approach. A lot of effort could be further expanded to improve the "representativeness" of the network models but one should be mindful that there is a trade-off between modelling effort and outcome. From a policy perspective, an agreed modelling approach between policy makers and DNSPs will provide "a line in the sand" for scenario assessment and estimate of future investment quantum from a long-term planning perspective. The limitations of the modelling approach (e.g. SWERs are not explicitly modelled) can be noted and refined over time.

It should be noted that while the intent of the illustrative network models is to allow the impact of electrification be assessed across Victoria for long-term planning horizon, the models cannot be used to pinpoint the locations where short or medium-term investment is required (e.g. EDPR capex submission) as they are not spatially or topologically accurate and are not able to represent the inherent network diversity (within network types) that exists in practice.

4.4 Consumers

While the research project outcome has no direct relevance to consumers, the network models developed will be used by subsequent research projects to inform indicative longer-term network investments required to manage emerging constraints from domestic electrification and the impact of various network interventions on such investments. Network investments will ultimately be passed to consumers in electricity bills while network interventions can potentially be used to moderate bill increases.

4.5 Research

There is opportunity for the research communities to refine the modelling approach to come up with better representative network models. Any approach is recommended to have deep engagement and input from those with deep distribution network knowledge to ensure any modelled approach is as close to real-world as possible and is sufficiently developed to include the impact of using modern network management tools. As networks become increasingly dynamically managed it will be important to update modelling approaches to reflect this. Any model development requires timely and complete data to develop. Researchers can facilitate this through the use of consistent nomenclature and well-considered complete data specifications upfront that are co-developed with the respective network champion who can facilitate the delivery of such data.

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Appendix One

Researcher profile

Conducted by: RMIT University

Lead Researcher: Dr. Kazi Hasan (lead), Prof. Mahdi Jalili (co-lead)

Research Team: Dr. Mir Toufikur Rahman, Dr. Usman Bashir Tayab
Electrical and Biomedical Engineering, School of Engineering

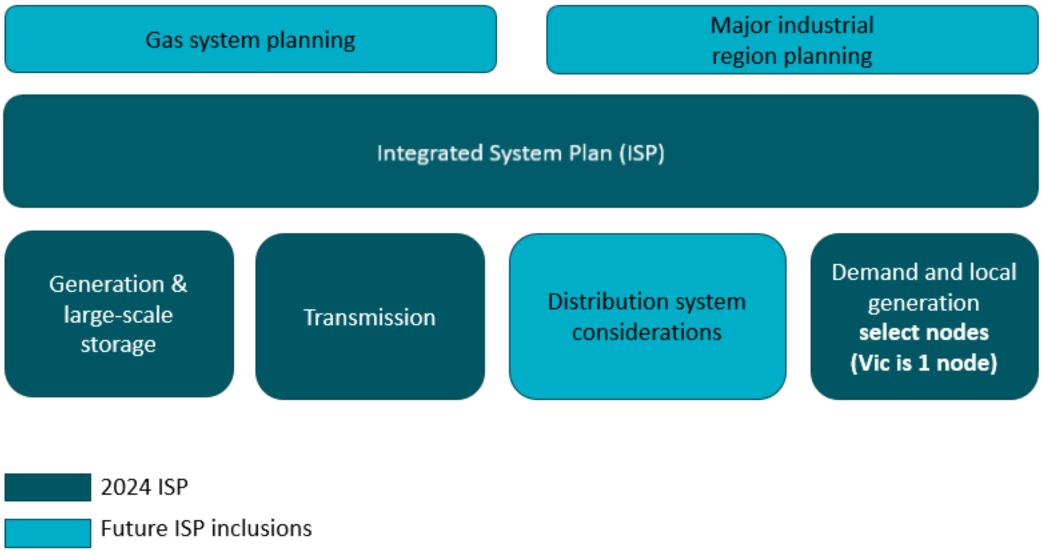
About C4NET

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.

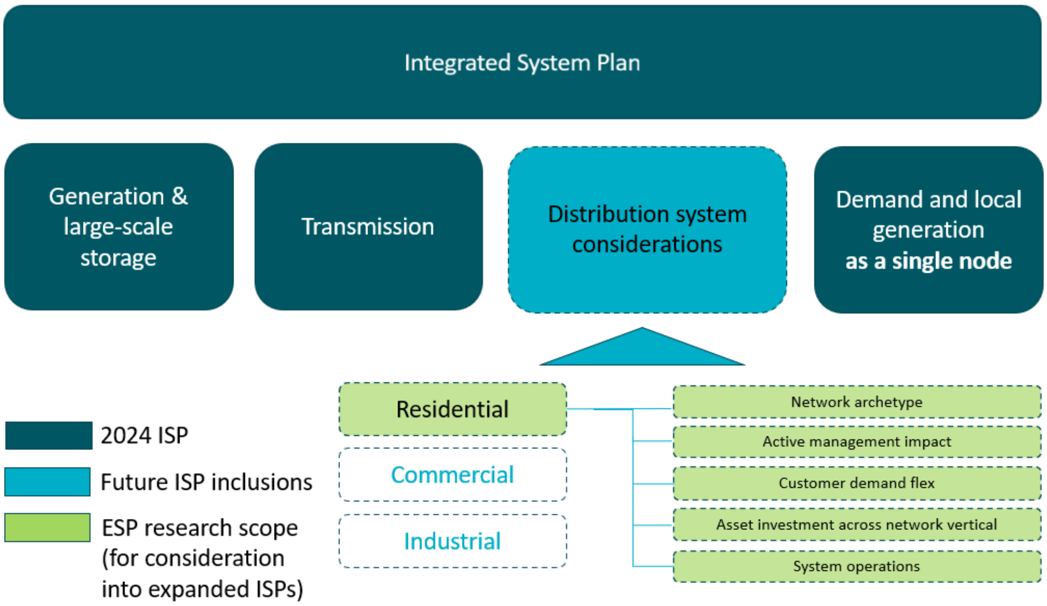
Appendix Two – Bigger picture integration with the ISP

Shift towards whole of system planning



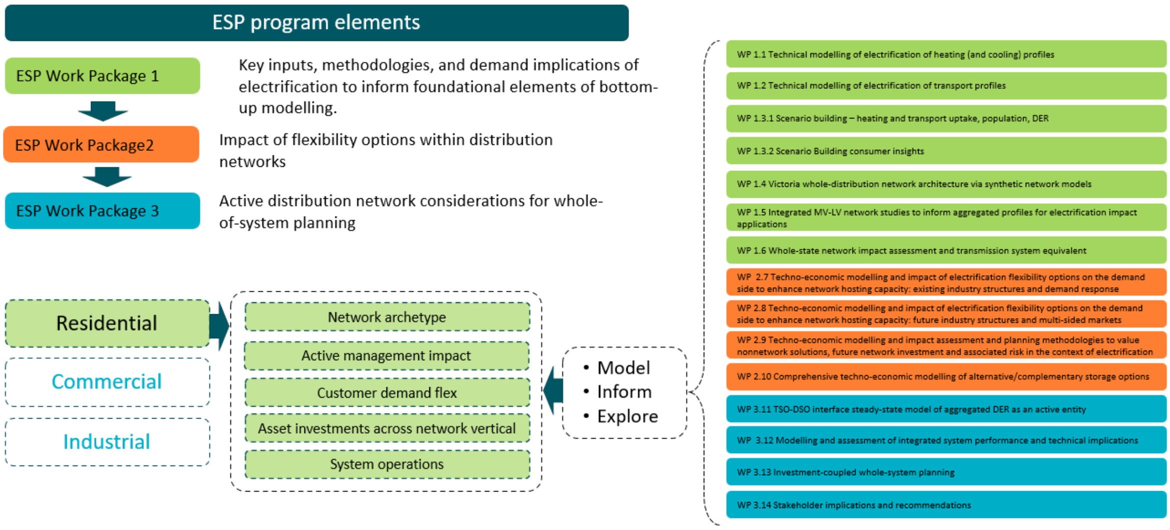
The Energy and Climate Change Ministerial Council (ECMC) accepted the recommendations of the review of the ISP which target transformation of the energy system as a whole, with particular reference to gas system planning, major industrial region planning and distribution systems.

Distribution system components of whole of system planning

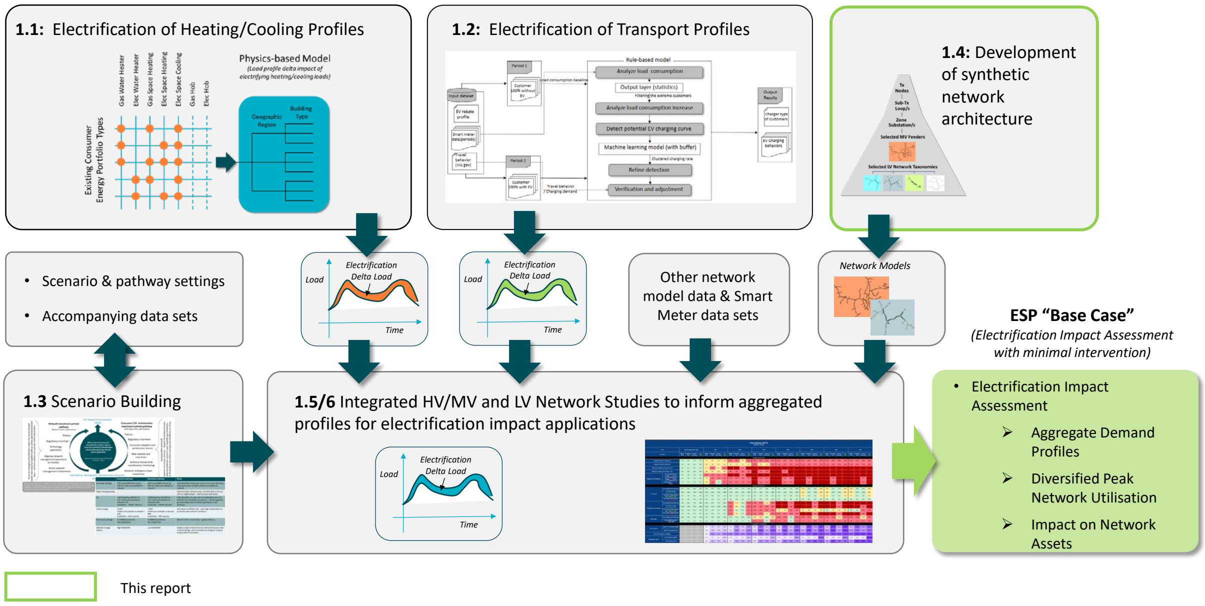


The ESP was scoped to be deliverable with the resources and time at hand to inform feasibility of broader application. It focussed on the more complex areas around residential and low voltage assets of the distribution system, with an application across Victorian networks with methodologies applicable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

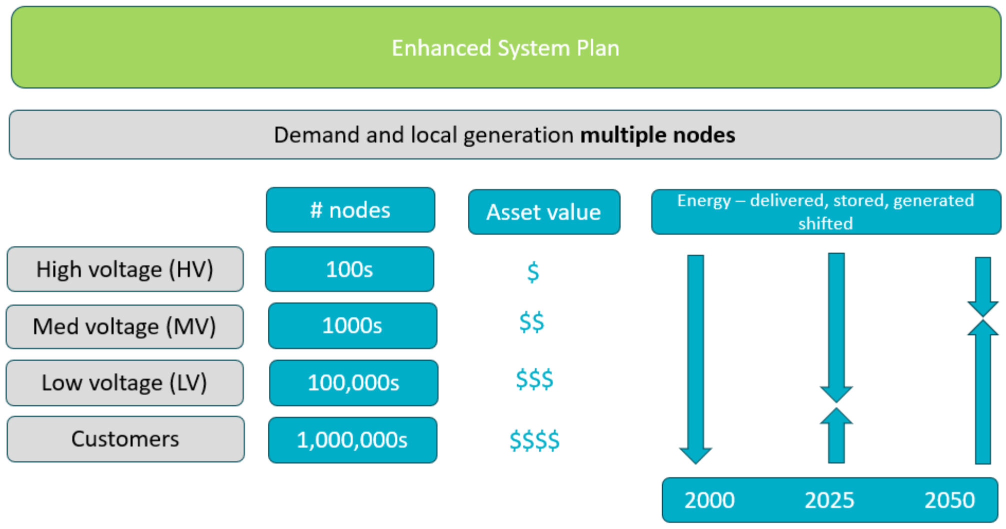
ESP alignment with distribution system components of whole of system planning



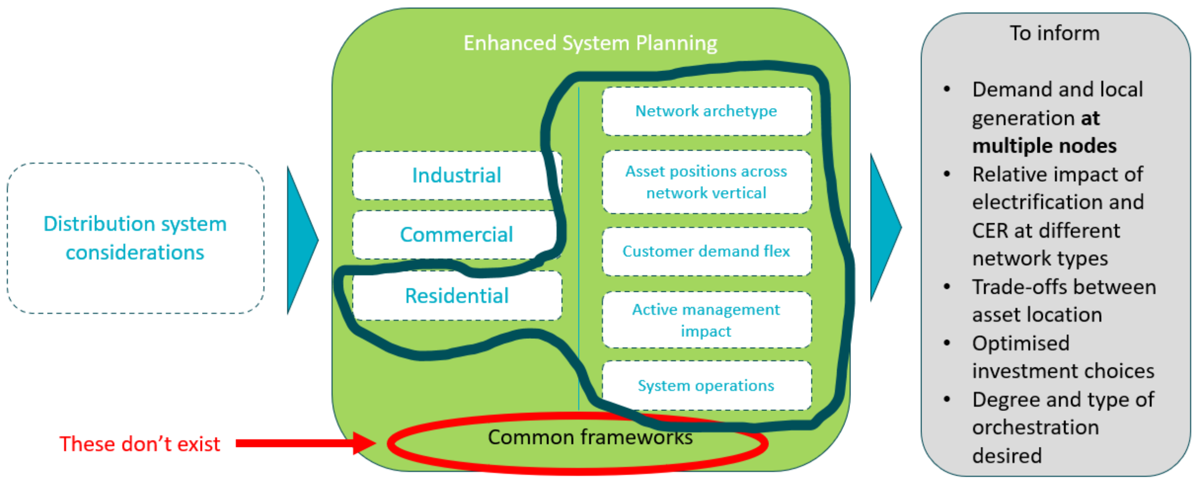
The base case for electrification impact assessment, highlighting the role of illustrative network models in quantifying network impact



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